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GEOPHYSICS IN THE AMERICAS

A SYMPOSIUM OF THE GEOPHYSICS COMMISSION OF THE PAN AMERICAN INSTITUTE OF GEOGRAPHY AND HISTORY, OTTAWA, CANADA, SEPTEMBER 1976

EDITED BY J. G. TANNER AND M. R. DENCE

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INTRODUCTION

This symposium is part of a continuing effort by Canada through its National Section of the Pan American Institute of Geography and History to provide the opportunity for members of the principal disciplines of the institute to meet and discuss concerns and issues. Although this is the first in geophysics, several seminars in other fields have been held in the years between general assemblies of the institute.

This symposium was carried out under the sponsorship of the Department of Energy, Mines and Resources, the Department of External Affairs, the Canadian Society of Exploration Geophysicists, Noranda Mines and Brascan Ltd. Financial support for the travel and subsistence of the delegates from Latin America was provided by the Department of External Affairs and the Pan American Institute of Geography and History. The sessions of the symposium were held in the Government Conference Centre on Colonel By Drive with simultaneous interpretation in English and Spanish available for each session through personnel provided by the Secretary of State for Canada. The local organizing committee for the symposium consisted of Dr. J. G. Tanner, Mr. M. R. Dence, Mr. R. K. McConnell and Mrs. P. F. Van Dusen.

Initially it was intended to hold a purely scientific symposium covering a wide range of topics in the field of solid earth geophysics. However several major earthquakes and increasing interest in the preservation of the environment made it increasingly apparent that a discussion was needed of the role PAIGH could play in the development of socially as well as economically oriented geophysical programs for Latin America. Consequently, the symposium program went through a number of iterations, the last being the incorporation of an education-related session on the afternoon of September 27, 1976 at the request of Ing. J. A. Sáenz, the Secretary-General of the institute.

The sessions themselves were held in an informal atmosphere which encouraged open and frank discussion and led to several interesting exchanges of views. In this respect Tuesday afternoon's session in which the relative roles of government and industry in exploration for oil and gas were debated is worth noting. Public dialogues of this kind among scientists in the field are needed and it is hoped that future symposia of this kind will provide an opportunity for further exchanges of views on this or other issues of the day.

Not all the time during the symposium was devoted to technical sessions. On the afternoon of September 30 a number of the delegates toured the facilities of the Earth Physics Branch. That evening the SILAG working group met to discuss its program for the next four years and the mechanism for transferring the chairmanship of the working group and the SILAG data base to Latin America. A bus tour of Ottawa was arranged for Friday afternoon prior to the vin d'honneur which closed the symposium.

A number of social events were held during the symposium, one of which was informal. For this latter I would like to thank my wife, Louise Tanner, for her efforts in getting the social side of the symposium off to an excellent start by hosting an informal gathering of a number of delegates at our home. The other social events were more formal in character. The dinner hosted by Dr. K. Whitham on the evening of September 29 at the Royal Ottawa Golf and Country Club was a particularly successful event. I thank Mr. M. Sutherland-Brown who arranged the use of the excellent facilities of the ROGCC.

The preparation of the proceedings for publication has been a long and complex process. Fortunately, most participants cooperated by providing edited manuscripts within the time specified by the organizing committee. In cases where it was not possible to send a manuscript all participants but one agreed to have an edited version of the transcript of their contributions prepared for publication. The sole exception was that of Dr. B. D. Loncarevic of the Atlantic Geoscience Centre in Dartmouth, Nova Scotia, Canada who wished to make extensive revisions to his oral presentation, but was unable to do so because of other commitments.

As it was decided to publish the presentations in the language of the originator, special arrangements for editing the Spanish language presentations were necessary. Accordingly Ing. L. Rodrigues the assistant to the secretary-general of the institute visited Ottawa for a week to do the initial editing of the Spanish language portion of the proceedings and to make a summary of the edited transcript for translation into English and French (see Appendix 1). Subsequently, the Spanish language transcript was given a thorough review by Mr. M. R. Dence and Mrs. D. Parkinson to ensure that it was consistent in style and approach with the English language version. The editing of the English language version was carried out principally by Dr. J. G. Tanner with the assistance of Mr. M. R. Dence and Mrs. P. F. Van Dusen. Summaries of all English language proceedings were prepared and translated into French and Spanish (Appendix 1).

None of the manuscripts provided by the authors was sent for outside review, but technical revisions of the manuscripts were made as appropriate. These were not numerous and were nearly always done after seeking the advice of an independent expert in the field. In addition, the editors revised the manuscripts where necessary to attain consistency of style, etc., throughout the volume. The editing of the transcripts of the oral presentations was more difficult because of the need to present off-the-cuff remarks in an easily readable and grammatical format which preserved the essential character of the participant's comments.

A symposium of this kind could not proceed without the help of a large number of people. Mrs. P. F. Van Dusen of the Earth Physics Branch and Mr. G. Blanchet of the Department of External Affairs carried the administrative load for the symposium. Both were particularly effective in keeping the delegates informed of progress and plans for the symposium, managing the finances of the symposium, assisting the delegates during the course of the meeting and in following up on administrative details with the delegates after the meeting. Mrs. G. Lemieux assisted the delegates with travel arrangements during the course of the meeting. Mr. E. Gelinas of the Earth Physics Branch ran the projection system very effectively throughout the symposium. The quality of interpretation during the symposium was excellent by any standard. The interpretors quickly mastered the technical jargon with the result that presentations in either of the two languages were easily followed in the other. For this I thank Miss J. Dykstra, Mrs. C. Massieu, Mr. G. Massieu and Mr. J. Rives of the Secretary of State. The staff of the Government Conference Centre was cooperative and helpful before and during the symposium. I was particularly impressed with the efficiency and accuracy with which they fulfilled our requests.

Subsequent to the symposium the work of Mrs. P. F. Van Dusen, Mrs. M. Herzog, Mrs. D. Parkinson and Mrs. G. Lemieux in typing the manuscript and transcripts and of Mr. L.

Warren in drafting additional figures is recognized with thanks. Mrs. Van Dusen undertook the additional responsibility for organizing the manuscripts into sessions, obtaining photographs and arranging for the necessary copying, etc. The effective work of these individuals is perhaps the principal reason for our being able to meet the deadline of publishing the proceedings within about a year of the time of the symposium.

I would like to thank the senior officials of the Department of Energy, Mines and Resources, the Department of External Affairs and the Pan American Institute of Geography and History for their support of this symposium. Dr. K. Whitham, Ing. J. A. Sáenz, Dr. A. E. Blanchette and Dr. E. Kausel gave their full support to the symposium and contributed substantially to the proceedings by making suggestions for program content and participating directly in the sessions. I would also like to thank the delegates themselves for their contribution to the symposium. Any success the symposium enjoyed was in no small way due to their wholehearted contributions to all the sessions. Finally I would like to thank Ing. L. Rodrigues for his assistance in editing the Spanish language proceedings and for preparing summaries of these.

The printing of the proceedings was arranged through Mr. Claude Lafleur an editor with the Department of Energy, Mines and Resources. I thank him very much for his work in getting the manuscripts ready for the printers. The maps in the pocket were printed by the Defence Mapping Agency in the United States. I thank them very much for producing them to a tight schedule.

J. G. Tanner
Ottawa, Canada
June 1977

INTRODUCTION

Ce symposium entre dans le cadre de l'effort continu que fait le Canada, par l'entremise de la section canadienne de l'Institut panaméricain de géographie et d'histoire, afin de permettre aux membres des principales disciplines de l'Institut de se réunir pour étudier différentes questions et problèmes. Bien que ce symposium soit le premier dans le domaine de la géophysique, plusieurs colloques, dans d'autres disciplines, ont eu lieu au cours des années, entre les assemblées générales de l'Institut.

Les ministères de l'Énergie, des Mines et des Ressources et des Affaires extérieures, la Société canadienne des géophysiciens (Canadian Society of Exploration Geophysicists), les mines Noranda et Brascan Ltd. ont parrainé le symposium. Le ministère des Affaires extérieures et l'Institut panaméricain de géographie et d'histoire ont fourni l'aide financière pour la participation des délégués d'Amérique latine. Les séances ont eu lieu au Centre des conférences du gouvernement, situé sur la promenade Colonel By; des services d'interprétation, en anglais et en espagnol, fournis par le Secrétariat d'état du Canada, étaient disponibles pour chaque séance; M. J. G. Tanner, M. R. M. Dence, M. R. K. McConnell et Mme P. F. Van Dusen constituaient le comité local organisateur du colloque.

On visait, à l'origine, à la tenue d'un colloque purement scientifique qui porterait sur une vaste gamme de sujets dans le domaine de la géophysique de la terre solide. Toutefois, plusieurs séismes et l'intérêt croissant que suscite la préservation de l'environnement ont fait clairement apparaître, peu à peu, la nécessité d'étudier le rôle que l'IPGH pouvait jouer dans l'élaboration de programmes géophysiques, d'orientation sociale aussi bien qu'économique, en Amérique Latine. En conséquence, le programme du colloque a subi un certain nombre de modifications, dont la dernière a été d'ajouter une séance relative à l'éducation, qui a eu lieu le 27 septembre 1976 dans la matinée, à la demande de M. J. A. Sáenz (Ing.), secrétaire-général de l'Institut.

Les séances en elles-mêmes ont eu lieu dans une atmosphère détendue, qui a encouragé une discussion libre et franche et a amené plusieurs échanges d'opinion fort intéressants. Dans cette optique, il est bon de signaler la séance du mardi après-midi au cours de laquelle les rôles relatifs du gouvernement et de l'industrie dans la prospection de pétrole et de gaz ont été étudiés. La nécessité d'un dialogue public de cette nature entre les scientifiques, dans ce domaine, se fait sentir et l'on espère que des réunions analogues futures permettront d'autres échanges d'opinions sur cette question ou d'autres sujets d'actualité.

Toutes les heures du colloque n'ont pas été consacrées seulement aux séances techniques. Le 30 septembre, dans l'après-midi, un certain nombre de délégués ont visité les installations de la Direction de la physique du globe. Le même soir, un groupe de travail du SILAG s'est réuni pour étudier en détail le mécanisme pour le transfert de la présidence du groupe de travail et de la base des données de SILAG en Amérique latine. Des dispositions avaient été prises pour une visite d'Ottawa, en autobus, dans l'après-midi de vendredi avant le vin d'honneur qui a marqué la clôture du colloque.

Un certain nombre d'événements mondains ont eu lieu au cours du colloque, dont un qui n'était pas officiel. Dans le cas de ce dernier, j'aimerais remercier mon épouse, Louise Tanner, des efforts qu'elle a consacrés au côté social du symposium en recevant chez nous, lors d'une réunion amicale, un certain nombre de délégués. Les autres événements mondains avaient un caractère plus officiel. Le souper présidé par M. K. Whitham, dans la soirée du 29 septembre, au Royal Ottawa Golf and Country Club, était particulièrement réussi. Je remercie M. M. Sutherland-Brown qui a pris les dispositions nécessaires pour que nous puissions utiliser les excellentes installations du Royal Club.

La préparation des comptes rendus aux fins de publication s'est révélée longue et complexe. Heureusement, la majorité des participants ont apporté leur aide en fournissant des manuscrits dactylographiés dans le délai précisé par le comité organisateur. Lorsqu'il n'était pas possible d'envoyer un manuscrit, tous les participants, sauf un, ont consenti à préparer une version rédigée de la transcription de leur document pour publication. La seule exception a été celle de M. B. D. Loncarevic, du Centre géoscientifique de l'Atlantique, situé à Dartmouth (Nouvelle-Écosse, Canada) qui désirait apporter d'importantes révisions à sa communication orale, mais a été dans l'impossibilité de le faire à cause d'autres engagements.

Comme il avait été décidé de publier les communications dans la langue de l'auteur, des dispositions spéciales ont été nécessaires pour la préparation des présentations en langue espagnole. En conséquence, M. L. Rodriguez (Ing.), adjoint du secrétaire général de l'Institut, a séjourné pendant une semaine à Ottawa pour la rédaction initiale des procès-verbaux en espagnol et pour préparer un résumé de la transcription publiée en vue de sa traduction en anglais et en français (annexe 1). Subséquemment, la transcription en langue espagnole a été examinée en détail par M. M. R. Dence et par Mme D. Parkinson pour s'assurer qu'elle correspondait tant du point de vue style

et allure à la version de langue anglaise. La préparation de la version en langue anglaise a été effectuée principalement par M. J. G. Tanner avec l'aide de M. M. R. Dence et de Mme P. F. Van Dusen. Des résumés des délibérations en langue anglaise ont été préparés et traduits en français et en espagnol (annexe 1).

Aucun des manuscrits fournis par les auteurs n'a été envoyé à l'extérieur pour étude, mais des révisions techniques ont été apportées le cas échéant. Peu nombreuses étaient ces révisions et elles ont presque toujours été apportées après consultation avec un expert indépendant dans le domaine pertinent. En outre, les rédacteurs ont revu les manuscrits lorsque nécessaire afin d'uniformiser le style, etc. La révision des transcriptions des communications orales a posé plus de difficultés parce qu'il était nécessaire de présenter des remarques impromptues dans un format aisément lisible et correct du point de vue grammatical, tout en préservant le caractère essentiel des commentaires des participants.

Un colloque de ce genre ne peut avoir lieu sans l'appui d'un grand nombre de personnes. Mme P. F. Van Dusen, de la Direction de la physique du globe, et M. G. Blanchet, du ministère des Affaires extérieures, se sont occupés de l'aspect administratif de l'assemblée. Ils se sont révélés particulièrement efficaces pour tenir les délégués au courant de la progression et des projets du colloque, pour la gestion des finances et l'appui qu'ils ont apporté aux délégués au cours de cette rencontre et pour avoir revu les détails administratifs avec les délégués après la rencontre. Mme G. Lemieux a aidé les délégués à prendre les dispositions de voyage pendant la rencontre. Le système de projection a très bien fonctionné au cours du colloque grâce à M. E. Gélinas de la Direction de la physique du globe. La qualité de l'interprétation était excellente. Les interprètes ont rapidement maîtrisé le jargon technique, et de ce fait, les communications dans l'une ou l'autre des deux langues ont été parfaitement suivies. Je tiens à remercier Mlle J. Dykstra, Mme C. Massieu, M. G. Massieu et M. J. Rives du Secrétariat d'état, pour leurs services d'interprétation. Le personnel du Centre de conférences du gouvernement s'est montré très coopératif avant et au cours du colloque. L'efficacité et la précision qu'ils ont apportées à remplir nos demandes m'ont particulièrement impressionné.

À la suite du colloque, je tiens à remercier Mme P. F. Van Dusen, Mme M. Herzog, Mme D. Parkinson et Mme G. Lemieux qui ont dactylographié le manuscrit et les transcriptions et M. L. Warren, qui a rédigé des graphiques supplémentaires. Mme Van Dusen était également chargée d'organiser en sections les manuscrits, d'obtenir des photographies et de prendre des dispositions pour la reproduction, etc. L'efficacité qu'ont démontrée ces personnes au cours de leurs travaux constituent peut-être la principale raison qui nous a permis de publier, dans les délais prévus, les délibérations en moins d'un an du colloque.

J'aimerais remercier de leur appui les hauts fonctionnaires du ministère de l'Énergie, des Mines et des Ressources, du ministère des Affaires extérieures et de l'Institut panaméricain de géographie et d'histoire. MM. K. Whitham, J. A. Sáenz, A. E. Blanchette et E. Kausel ont apporté leur appui total au colloque et aux délibérations tant par leurs suggestions en ce qui concerne la teneur du programme que par leur participation directe aux séances. J'aimerais également remercier les délégués eux-mêmes pour leur contribution au colloque; le succès qui a couronné ce dernier était largement dû à leurs contributions généreuses à toutes les séances. En dernier lieu, je tiens à remercier M. L. Rodriguez pour l'aide qu'il a apportée à la préparation des délibérations en langue espagnole et la préparation de leur résumé.

Les dispositions pour la publication des comptes rendus ont été prises par l'entremise de M. Claude Lafleur, rédacteur au ministère de l'Énergie, des Mines et des Ressources. Je le remercie grandement d'avoir préparé les manuscrits en vue de leur publication. Les cartes qui se trouvent dans la pochette ont été imprimées par la Defence Mapping Agency des États-Unis, que je remercie de les avoir produites dans un délai si court.

J. G. Tanner
Ottawa (Canada)
juin 1977

INTRODUCCION

Este simposio forma parte de los continuos esfuerzos realizados por Canadá, por intermedio de su sector nacional en el seno del Instituto Panamericano de Geografía e Historia, de brindar a los miembros de las principales disciplinas del Instituto la oportunidad de reunirse y debatir temas y problemas de su interés. Durante los años que las asambleas generales del instituto han venido celebrando sus reuniones, se organizaron ya diversos seminarios en otros campos, pero ésta es la primera vez que se realiza uno sobre geofísica.

El presente simposio se ha llevado a cabo bajo los patrocinios del Ministerio de Energía, Minas y Recursos, Ministerio de Relaciones Exteriores, Sociedad Canadiense de Geofísicos de Exploración, la "Noranda Mines" y la firma "Brascan Ltd." Los gastos de viaje y estadía de los delegados latinoamericanos fueron sufragados por el Ministerio de Relaciones Exteriores y el Instituto Panamericano de Geografía e Historia. Las sesiones del simposio tuvieron lugar en el Centro de Conferencias del Gobierno del paseo Colonel By, contando cada sesión con servicios de interpretación simultánea en inglés y español facilitados por la Secretaría de Estado Canadiense. El comité organizador local del simposio estaba integrado por el Dr. J. G. Tanner, los Sres. M. R. Dence, R. K. McConnell y la Sra. P. F. Van Dusen.

Al principio, se trataba simplemente de celebrar un simposio de carácter netamente científico en el que se debatiría una amplia gama de temas relativos al campo de la geofísica de la litosfera. Pero diversos terremotos de magnitud y el interés creciente por la conservación del ambiente pusieron cada vez más de manifiesto la necesidad de un debate sobre el papel que podría desempeñar el IPGH en el desarrollo de programas geofísicos de orientación social y económica para América Latina. Por consiguiente, el programa del simposio experimentó diversas modificaciones, la última de las cuales fue la de que, a pedido del Ing. J. A. Sáenz, Secretario General del Instituto, el 27 de septiembre de 1976 por la tarde se dedicase a una sesión educativa.

Las reuniones se desarrollaron en un ambiente informal, lo que tuvo la virtud de estimular el debate franco y abierto y condujo a interesantes intercambios de ideas. A este respecto, merece destacarse la sesión de la tarde del martes, dedicada a debatir las funciones relativas desempeñadas por el gobierno y la industria en la prospección de petróleo y gas. Los diálogos públicos de este género entre los científicos de nuestro campo representan una necesidad y se abriga la esperanza de que futuros simposios de esta naturaleza brindarán una nueva oportunidad para

desarrollar el intercambio de ideas en ésta u otras cuestiones del día.

No todas las sesiones del simposio fueron dedicadas a cuestiones técnicas. El 30 de septiembre por la tarde varios delegados visitaron las instalaciones de la Dirección de Física Terrestre. Esa misma noche el grupo de trabajo de SILAG se reunió para discutir su programa de los próximos cuatro años, así como el mecanismo para transferir la presidencia del grupo de trabajo y del banco de datos de SILAG a América Latina. El viernes por la tarde, antes de servirse el vino de honor con que se clausuraba el simposio, se realizó una gira en autobús por la ciudad de Ottawa.

Durante el simposio se realizó una serie de reuniones sociales, una de ellas de carácter informal. Por esta última debo dar gracias a mi esposa Louise Tanner por todos sus esfuerzos en hacer que el aspecto social de este simposio tuviese un comienzo auspicioso al oficiar de anfitriona en la reunión que celebramos en nuestro hogar recibiendo a diversos delegados. Los demás acontecimientos sociales tuvieron un carácter más formal. La cena ofrecida por el Dr. K. Whitham el 29 de septiembre en el Club Real de Golf y Country Club de Ottawa fue particularmente exitosa, y quiero expresar mi agradecimiento al Sr. M. Sutherland-Brown por poner a nuestra disposición las excelentes instalaciones del Club.

La preparación de la publicación de las actas de sesiones ha sido un proceso largo y complejo. Afortunadamente, se ha contado con la cooperación de la mayoría de los participantes quienes suministraron los manuscritos dentro del plazo determinado por el comité organizador. En los casos en que fue imposible enviarlo, todos los participantes, con la excepción de uno, convinieron en preparar una versión revisada de sus contribuciones lista para publicación. La única excepción fue el Dr. D. B. Loncarevic del Centro de Geociencias del Atlántico, Dartmouth, Nueva Escocia, Canadá, quien quiso hacer una revisión a fondo de su exposición oral, pero no pudo hacerlo así por haber contraído otros compromisos.

Dado que se decidió publicar las presentaciones en el idioma de los contribuyentes, surgió la necesidad de efectuar arreglos especiales para una publicación de las presentaciones en idioma castellano. A este efecto, el Ing. L. Rodríguez, que asistió al Secretario General del Instituto, pasó una semana en Ottawa, encargándose de la redacción inicial de la sección española de las actas y del resumen de la transcripción revisada para su traducción a los idiomas inglés y francés (véase Anexo 1). Posteriormente, el Sr. M. R. Dence y la Sra. D. Parkinson realizaron una revisión completa de la copia en español para asegurarse de que concordaba en estilo y enfoque con la versión inglesa. La publicación de la versión inglesa estuvo a cargo principalmente del Dr. J. G. Tanner, asistido por el Sr. M. R. Dence y la Sra. P. F. Van Dusen. Se prepararon resúmenes de todas las actas redactadas en inglés, los que se tradujeron a los idiomas francés y español (Anexo 1).

Ninguno de los manuscritos proporcionados por los contribuyentes fueron enviados al exterior para su revisión, sino que las revisiones técnicas apropiadas se hicieron internamente, aunque no hubo muchos cambios y casi siempre se realizaron con el asesoramiento de otro experto en el campo. Los editores, por su parte, revisaron los manuscritos haciendo las correcciones necesarias para lograr la uniformidad de estilo y demás aspectos a lo largo del volumen. La redacción de las transcripciones de las presentaciones orales era una cuestión más difícil ya que había que presentar observaciones improvisadas del orador en estilo accesible y gramaticalmente correcto y que conservase la esencia de los comentarios del participante.

Un simposio de esta naturaleza no podía realizarse sin el concurso de gran cantidad de personas. Las tareas administrativas del simposio estuvieron a cargo de la Sra. P. F. Van Dusen de la Dirección de Física Terrestre y el Sr. G. Blanchet del Ministerio de Asuntos Exteriores, los que se desempeñaron con particular eficacia y mantuvieron a los delegados al corriente de la marcha y programa del simposio, administrando el aspecto financiero, asistiendo a los delegados durante las reuniones y, finalizadas las mismas, prosiguiendo con los delegados la discusión de los detalles administrativos. La Sra. G. Lemieux asistió a los delegados durante el transcurso de la reunión en todo lo que se refiere a viajes. El Sr. E. Gelinas de la Dirección de Física Terrestre manejó con gran eficacia el sistema de proyecciones durante todo el transcurso del simposio. La calidad de la interpretación durante el simposio fue excelente también en todos los sentidos. Los intérpretes dominaron rápidamente el vocabulario técnico pudiéndose seguir las presentaciones en cualquiera de los idiomas con gran facilidad. Por todo ello, agradezco a la Srta. J. Dykstra, Sra. C. Massieu, Sr. G. Massieu y Sr. J. Rives de la Secretaría de Estado. El personal del Centro de Conferencias del Gobierno mostró antes y durante el simposio un gran espíritu de cooperación y ayuda. La eficiencia y exactitud con que satisfacieron nuestras peticiones me causaron, en particular, viva impresión.

Las señoras P. F. Van Dusen, M. Herzog, D. Parkinson y G. Lemieux que dactilografiaron el manuscrito y las copias después del simposio, así como el Sr. L. Warren, que proporcionó las cifras adicionales, se hacen igualmente acreedores a nuestro agradecimiento. La Sra. Van Dusen tuvo, además, otra responsabilidad: la de organizar los manuscritos en sesiones, obtener fotografías y disponer lo necesario para el fotocopiado, etc. Fue la obra eficaz de todas estas personas la principal razón de que podamos cumplir con la fecha límite para la publicación de las actas desde hace aproximadamente un año de tiempo del simposio.

Quiero, asimismo, expresar mi agradecimiento a los altos funcionarios del Ministerio de Energía, Minas y Recursos, Ministerio de Asuntos Exteriores y el Instituto Panamericano de Geografía e Historia por el apoyo que nos brindaron. El Dr. K. Whitham, Ing. J. A. Sáenz, Dr. A. E. Blanchette y Dr. Kausal brindaron igualmente su apoyo al simposio y contribuyeron substancialmente a las actas con varias sugerencias respecto al contenido del programa y con su participación directa en las sesiones. También me gustaría agradecer a los delegados mismos su propia contribución al simposio, ya que lo exitoso que haya podido ser se debió en no pequeña medida a sus entusiastas contribuciones en todas las reuniones. Finalmente, desearía expresar mi reconocimiento al Ing. L. Rodríguez por toda su ayuda en la preparación de la edición española de las actas y su resumen.

La impresión de las actas fue realizada por el Sr. Claude Lafleur, editor del Ministerio de Energía, Minas y Recursos, a quien quedo sumamente reconocido por haber logrado que los manuscritos estuviesen listos para la imprenta. Los mapas del bolsillo del volumen fueron impresos por el Instituto Cartográfico del Ministerio de Defensa de los Estados Unidos al que doy mis gracias por haberlos preparado en tan breve plazo.

J. G. Tanner,
Ottawa, Canada
Junio de 1977

FIRST SESSION
Monday, September 27

PREMIÈRE SÉANCE
Le lundi 27 septembre

PRIMERA SESIÓN
Lunes, 27 de Septiembre

OPENING CEREMONIES

SÉANCE D'OUVERTURE

CEREMONIA DE APERTURA

Chairman/Président/Presidente
DR. J. G. TANNER

Speakers/Conférenciers/Expositores

DR. A. E. BLANCHETTE
DR. K. WHITHAM
ING. J. A. SÁENZ
DR. E. KAUSEL
PROF. G. D. GARLAND

Dr. A. E. Blanchette:

On behalf of the Government of Canada and on behalf of our National Section we welcome you to Ottawa and also thank you for coming. Some of you have undertaken very long and very tiring journeys to come here and we are very pleased to have you.

Over the last ten years it has been the policy of the National Section of Canada, of which I am the president, to organize each year a seminar in one of the disciplines of our institute. We have now held two in the field of archives, two in cartography, one in history, one in geography and now this one in geophysics. When there are no general assemblies of the institute we endeavour to hold a seminar each year and during the years when there is a general assembly we send a delegation of university people, public servants, scientists, and specialists to the general assemblies of the institute; the next one of which will be taking place in Quito not quite a year from now. We also try to publish each year a report on the proceedings of each seminar and copies are sent to the National Sections for distribution to interested people in each country and to each participant of the seminar. We are taping the proceedings and in due course, probably about a year or fifteen months from now, you will be receiving a copy in book form.

I understand that there are a few delegates in the hall here who are not too familiar with the Pan American Institute of Geography and History and I thought I might explain in a few words what the institute is and what the institute does.

The Pan American Institute of Geography and History is a specialized agency of the Organization of American States. It is actually the oldest one I believe. I think it was founded in 1928 by virtue of a decision taken by the foreign ministers of the Americas at their great Inter-American Conference in Havana in 1928. The first work of the institute goes back to 1929 after it settled into its headquarters in Mexico City. The institute works on the basis of four commissions: cartography, history, geophysics and geography and each one has a president. For instance the president of geophysics is with us this morning, Dr. Kausel from Chile. The institute also has a secretariat located in Mexico City and our Secretary General, Sr. Sáenz, is with us this morning and will be saying a few words about what the institute expects out of this seminar.

The institute is dedicated to the proposition of spreading scientific knowledge thoughout the Americas in its four disciplines and this takes the form of publications, meetings, consulting services, scholarships, teaching fellowships and programs of that nature. It has been very active over the last 50 years in this particular field and maintains close relations with the cultural and similar services of the Organization of American States, and in a more distant sort of way the United Nations. It also maintains very close relationships with the Inter-American Geodetic Society of which we have a representative this morning at our meeting. So that I think will be background to help those of you who are not too familiar with the institute in understanding a part of the nature of its work and the type of activity that it undertakes.

Now at this point I would like to revert to this seminar. This one is in field of geophysics and you are all very much specialists in this area. It has been organized mainly by the Department of Energy, Mines and Resources and Dr. Tanner and his staff have worked very hard in preparing the program. My department, the Department of External Affairs, not being a scientific department, has been involved in the preparation of this seminar but rather less so than in certain other disciplines like history or archives where we have a bit more experience so I would like publicly to thank Dr. Tanner, Mr. Dence, Mrs. Van Dusen and others for the many, many hours of hard work they have put into this seminar in preparing the program, in organizing the activities and in setting, what I might call, the scientific tone of the gathering.

At this point I should also like to mention that this is most likely the last seminar of our section which I will be officially opening. I was recently posted by the Canadian government to be Canadian Ambassador to the Organization of American States in Washington and the composition of our National Section is changing as a result. Mr. Sebert, a senior cartographer in the Department of Energy, Mines and Resources, will become our chairman as of this week. I will, in a way, be demoted to vice-chairman but I am quite sure that Mr. Sebert, who has been interested in the institute for many years, will conduct our business very competently and amiably. So after what is my "Swan Song" I should like to, on behalf of our National Section, declare this meeting officially open and wish you well in the conduct of your proceedings. At this point I would like to invite Dr. Whitham of the Department of Energy, Mines and Resources, who is Director-General of the Earth Physics Branch, to say a few words and welcome you on behalf of his department.

Dr. K. Whitham:

On behalf of the Department of Energy, Mines and Resources I would like to welcome you to Ottawa and to extend to you our best wishes for a successful symposium. This department, especially through its Earth Physics Branch, has had a substantial history of involvement with geophysics in Latin America, and more specifically with the Geophysics Commission of PAIGH. Our present ties to the commission began some 15 years ago. At that time Prof. Angus Hamilton of the University of New Brunswick who was then with the Dominion Observatory, the predecessor to the Earth Physics Branch, carried out observations on the gravity calibration lines down the west side of South America, in cooperation with the University of Buenos Aires of Argentina. Subsequently Dr. Morris Innes and later Dr. C. H. Smith, now the Senior Assistant Deputy Minister of EMR, attended reunions of the Commission as delegates for Canada. The stage was set for our recent deeper involvement in the work of the commission by my predecessor, Dr. John Hodgson, who visited a number of Latin American geophysical facilities in 1973. At that time the groundwork was laid for an undertaking which we now know as the definition and adjustment of the Latin American Gravity Net, now being carried out under the aegis of SILAG, an acronym which I am sure is very familiar to many of you who have been associated with PAIGH.

This project, which has been carried out in cooperation with the Inter-American Geodetic Survey, has produced a network which is expected to serve as a prime reference for gravity surveys throughout Central and South America. The results, the culmination of three years effort, will be reported at this meeting. I consider it a most satisfying example of a project of modest cost being carried to success by the tremendous dedication and effort of the few responsible scientists and technical officers in Canada and elsewhere in the Americas.

Your symposium is occurring at a time when geophysicists are becoming more involved with the social as well as the more traditional scientific and economic implications of their disciplines. Undoubtedly PAIGH, through its Geophysics Com-

mission, is aware of this trend and I am sure much of your discussion during the latter part of this week will centre on the role that the institute can play in assisting member countries with the optimum development of their national geophysical programs. As the symposium progresses you will be hearing from prominent members of your scientific community expressing their thoughts on where geophysics stands today and the present and future contributions it can make to Latin American society. In this respect I would particularly like to draw your attention to the second day of discussion where a selection of North American and particularly Canadian programs has been chosen to provide a background to your later discussions. We have asked the authors of these papers to concentrate on the reasons for the programs rather than on details, thereby providing some insight into the rationale behind many of the activities in solid earth geophysics in Canada and North America. We in the Earth Physics Branch have put a particularly strong effort into this part of the program and as a result you will be hearing about our major lines of activity. We can expect that this part of the program will stress the mission-oriented approaches of government agencies to their research activities. I hope that we will all gain new insights into the problems to whose solution geophysics can contribute, and into the opportunities for geophysics in the Americas. I say this although well aware of the serious financial problems plaguing our society and the serious impact these are having on all science programs.

In order to give you a balanced perspective on North American geophysical programs we have asked a number of our colleagues from universities to speak to you. We have done this because we do not feel you should ignore entirely the basic research aspect of geophysical activities in the Americas. In asking scientists from universities to speak we have attempted to place the emphasis on those individuals who have had extensive contacts and experience in Central and South America. I believe you will find the talks of great interest because of the concentration on such topical matters as the dynamics of the earth's crust and volcanic activity.

The final aspect of geophysical activities that will be discussed is the exploration programs being carried out in Canada very largely by geophysical companies and agencies. In North America these programs are large and expensive and consume the talents of a very large number of geophysicists. There is no way we can do the volume of exploration geophysics full justice in a symposium of this nature, but we have attempted to highlight some of the major trends in the petroleum and mining exploration programs.

The latter part of the week, I am told, will see you concentrating on the program of PAIGH for the four-year period commencing in 1977. I suspect you will have no shortage of proposals for activities and your problem will be one which is increasingly familiar to me at a time of government restraint, namely one of choosing a few from many. I understand the executive of PAIGH has made certain policy decisions regarding the emphasis they would like to see given to the geophysical program of your commission, and that within this context, all delegates from Latin America will be asked to give a brief talk presenting their views on the program. This, I expect, will be one of the more important parts of your symposium as it will set the stage for the development on Friday of recommendations to be presented to PAIGH at its general assembly next year.

Recently there has been much public interest in such natural events as the recent Tangshan earthquake and the Soufriere volcano. These typify some of the concerns facing the geophysicist in the hazard field alone. When we consider the problem of the rapidly exhausting conventional hydrocarbon energy resources, and indeed all the limitations associated with a finite earth and resources and yet expanding populations and growing expectations, it is clear that earth scientists of all kinds, including geophysicists, must be prepared to make major contributions for the sake of mankind generally. In this effort international and regional cooperation will be essential for the sake of everyone.

Obviously you have a full program before you and I wish you every success with it.

Siento no hablar español, no obstante deseo decirles unas palabras en su idioma para darles la bienvenida a Ottawa y ofrecerles nuestros votos por el éxito de este simposio.

Confío tener tiempo para asistir a algunas de sus sesiones y debates. Por su parte, espero les quede tiempo libre para visitar nuestra Capital.

Si alguien tuviera interés en visitar la Dirección de Fisica Terrestre, puede ponerse en contacto con el Dr. Tanner o conmigo, para que hagamos los arreglos pertinentes. Muchas gracias.

Dr. J. G. Tanner:

Thank you very much Dr. Blanchette and Dr. Whitham. I've known our Director-General to be bilingual but never trilingual.

The next event involves the establishment of the Resolutions Steering Committee which will report on Friday. As an introduction to this we have asked the Secretary General of PAIGH, Sr. Sáenz, to set the scene by saying a few words about what the commission expects from this symposium. After that, Dr. E. Kausel will establish the Resolutions Committee.

Ing. J. A. Sáenz:

Señores, es para mí un honor poder dirigirme a ustedes, a una concurrencia tan selecta y tan distinguida, para tratar de ampliar el conocimiento que puedan ustedes tener sobre el Instituto Panamericano de Geografía e Historia, algunos de los programas, proyectos y actividades que lleva a cabo el Instituto y también expresar algunas ideas de la Secretaria General en cuanto a la Comisión de Geofísicas y sus futuros programas.

Tal como lo había ya mencionado el Dr. Blanchette, el IPGH es un organismo especializado de la OEA establecido en 1928, uno de los más antiguos, con cierta autonomía de fondo y programas dentro de la OEA, pero que siempre tienden a cumplir los mandatos de los Estados Miembros que son los que lo componen.

El IPGH está dividido en cuatro comisiones: Geografía, Historia, Cartografía y Geofísica, que es la más nueva de todas, ya que fué establecida hará aproximadamente 7 años, y el primer Presidente de esta Comisión está presente, el Ing. Salgueiro, de Bolivia.

Actualmente la Comisión de Geofísica está presidida por el Ing. Kausel de Chile y tiene tres comités: Física Solar Terrestre, Océanos y Atmósfera, y de Tierra Sólida, dirigidas por el Prof. Sandro Radicella de Argentina, por el Capitán de la Marina Pedro Cabezas de Ecuador y por el Padre Ramírez de Colombia, todos muy bien conocidos por ustedes.

Es misión principalísima del instituto, tal como se lee en sus Estatutos fomentar, coordinar y difundir los estudios en las

cuatro disciplinas y promover la cooperación entre los Institutos de América.

El IPGH no cuenta con fondos como para poder llevar a efecto, por sí solo, investigaciones, programas costosos, pero sí cuenta con el acerbo de un grupo vasto de especialistas, científicos y educadores en cada país, a través de los cuales nos ponemos en contacto con las autoridades de los países, y no solamente de los gobiernos, sino con instituciones y organismos internacionales o fundaciones para que respalden económicamente aquellos programas que entran en las políticas de cada uno de ellos. En esa forma, hay una relación con las Naciones Unidas, con la misma OEA dentro de sus otros programas y organismos.

Los programas regulares del Instituto son presentados, discutidos y aprobados a través de las reuniones de consulta de cada una de las comisiones y ratificados a través de la Asamblea General. La última Asamblea General y Reuniones de Consultas se efectuaron en 1973 en la ciudad de Panamá, la próxima en 1977, tendrá lugar en Quito, Ecuador. Podemos ya dar las fechas del 15 al 30 de agosto.

Hemos procurado acortar el tiempo de manera que haya la mayor cantidad de especialistas de cada país.

Cada cuatro años se presentan los programas regulares, que se traducen en actividades a través de los 4 años. Pueden ser actividades que tomen aun más de los cuatro años. Estos programas se espera que sean presentados a través de los representantes de cada país, de acuerdo con sus necesidades y deseos.

Los programas están constituidos por proyectos y estos obedecen a necesidades que se presentan en los países y que consideramos que deben de tomarse en consideración. Naturalmente que tienen que llenar ciertas condiciones o requisitos para lo cual ya la secretaría ha distribuido en todos los países un manual de proyectos, para ayudar a su formulación.

Creemos necesario pensar en los programas a desarrollarse en el próximo período que comienza en el 77 y termina en el 81.

En el último Consejo Directivo que se efectuó en Lima, en junio de este año, se les solicitó a las comisiones que hicieran las relaciones necesarias con los científicos de cada país, para saber qué era lo que pensaban los países o qué deseaban los países que el IPGH desarrollase, qué programas, qué actividades, en que lineas, y estas líneas deben encuadrarse dentro de lo que haya sido aceptado en el instituto como su politica científica y cultural.

Esta reunión que se está iniciando hoy, que debe terminar el viernes, forma parte de este deseo de ir pensando y programando nuestros próximos cuatro anos, tal como el Dr. Whitham y el Dr. Blanchette lo han expresado. Se presentarán en los primeros tres días una serie de trabajos relacionados con todas las ramas de la Geofísica, por lo menos con aquellas en las que el instituto está actuando, que pueden servir como fundamento para definir los programas que nosotros podríamos desarrollar con los recursos del instituto.

Qué es entonces lo que esperamos de este simposio? En los dos últimos días que habrá de discusiones, se espera se presente una linea o un plan maestro de la Comisión de Geofísica, presentes están los tres miembros o Presidentes de los Comités que forman la Comisión de Geofísica, presente está el Presidente de la Comisión de Geofísica y presentes están distinguidos científicos de todas las ramas de la Geofísica, para ayudar entonces a presentar a la próxima reunión de consultas de Geofísica en Quito, un programa comprensivo que trate, dentro de nuestro alcance, de dar impulso a las actividades de Gravimetría, de Geomagnetismo, etc., y sobre todo, y este es nuestro exhorto, un programa que contemple la preparación de los países que están menos desarrollados en Geofísica, programa de adiestramiento que poco a poco permita a nuestros países en América Latina, ir escalando etapa por etapa e ir formándose y dentro de un tiempo poder estar en condiciones de llevar a efecto por si solos los programas de Geofísica.

Esa es la idea de la Secretaría General que espero esté dentro de las ideas que todos ustedes probablemente han traído a este simposio.

Señores, en nombre del Instituto Panamericano de Geografía e Historia, deseo darle las gracias al Gobierno de Canadá a través de la Secretaría de Relaciones de Asuntos Externos del Departamento de Energía, Minas y Recursos, a la Sociedad Canadiense de Exploraciones Geofísicas, a las firmas privadas que han contribuido para que este simposio pueda efectuarse, a la Sección Nacional y sobre todo a ustedes, que han cedido parte de su valioso tiempo para poder asistir y darle el brillo y el éxito que nosotros esperamos de él. Muchas gracias.

Dr. E. Kausel:

El Comité de Resoluciones queda integrado por los doctores Tanner, Lomnitz, Svendsen, Giesecke, Radicella. Lo preside el Dr. Woollard.

Dr. J. G. Tanner:

Next on our program is a talk by Prof. G. D. Garland on **"The Role of Geophysics in Society".**

Prof. G. D. Garland:

The increased awareness in the importance to man of the global environment has brought geophysicists from all branches of the subject into contact with a wide variety of sociological and economic problems and opportunities. Perhaps the involvement of meteorologists and oceanographers in aspects of pollution has been the most visible example, but the solid-earth geophysicist is deeply involved also. While there is a long historical basis for this, the range of opportunities has been greatly expanded by new developments in global tectonics.

Historical

The fact that even "pure" geophysics has a social and economic relationship is not new; in fact, the original research in geomagnetism, geodesy and seismology was closely related to practical problems. On the other hand, recent years have seen a change in emphasis, with the result that many aspects of geophysics have become interwoven with complex sociological and economic questions. Early work in the three fields mentioned above has rather obvious applications. Since the discovery of the declination in geomagnetism about 1450 (Chapman and Bartels, 1940), the usefulness to mariners of charts of the declination has been recognized. In Britain, Edmund Halley was able to obtain the sloop "Paramour Pink" for the two years 1698-1700 in order to make two voyages for the observation of this quantity. His chart represents one of the earliest global maps of geophysical measurements. Even Gauss, to whom the purely scientific value of any investigation ranked very high, recommended that the union of magnetic observatories, organized by him in 1834, observe primarily the declination because of its value to mariners.

In geodesy, the early interest was in the correction of horizontal position for mapping control. With the realization of

the importance of the deflection of the vertical and its influence on astronomically-determined positions, the need for triangulation and for the adoption of reference surfaces becomes apparent. We sometimes forget the unsatisfactory situation that existed in horizontal control well into the nineteenth century. Writing in 1857, Sir William Logan noted the difficulty of constructing the geological map of Canada because of uncertainties in longitude. He pointed out that on maps produced up to 1854, there were discrepancies in the longitude of Chicago of 55′ or 47 miles! These, of course, were not due to deflections of the vertical, but simply to inadequate astronomical observations and poor time control. These errors were gradually eliminated, first by a network of precise astronomical positions and later by the progress of triangulation.

Seismology began with the observation of the effects of great earthquakes, so that the human relationship has always been very apparent. Stories are told in China of the observations made in Peking with the ancient seismoscopes and of the reception of refugees following the indications of shocks. Writing for the British Admiralty Manual of Scientific Enquiry (1849), Robert Mallet described, in surprisingly modern terms, the phenomena to be observed:

"... observations of the forced sea-wave, whether produced by the earth-wave going out to sea or coming in from it... any changes of permanent level of sea and land... the effects of earthquakes on the lives of men and animals; statistics of mortality... burying of objects of human art..."

All of these early objectives remain, but the developments in the science of geophysics have led us to expect more than simple passive observation of terrestrial phenomena and a more vital interaction with human affairs.

Current involvement

The human problems in which solid-earth geophysics can assist could be grouped as follows:

Relatively slow movements of the crust (geodesy)
Seismological phenomena:
- Zoning (seismology)
- Tsunami warning (seismology)
- Induced seismicity (seismology)
- Prediction (seismology, geodesy, magnetism)

Volcanic phenomena:
- (volcanology, seismology, geodesy, magnetism)

Energy sources: Geothermal
- (volcanology, seismology, geodesy, magnetism)

Mineral deposits, oil and water:
- Metallogenesis (plate tectonics)
- Exploration (applied geophysics)

Terrain and permafrost studies (engineering geophysics)

We shall give a few examples of recent work in each of these, especially in the case of the first five, where the methods employed are those of "pure" geophysics. The economic significance of applied and engineering geophysics has been well discussed elsewhere.

It is unlikely that significant further improvement in maps and charts can be expected from improved precision in horizontal geodetic control. Better definition of the geoid has important consequences, but chiefly for those nations capable of launching space vehicles. Nevertheless, it has been convincingly argued by Krakiwsky and Vaníček (1974) that Canada, over which essential geodetic coverage is reasonably complete, requires still better control. Blackie (1974) has indicated the very special geodetic needs for the increasingly important problem of defining the boundaries of oil and mineral properties on the continental shelves.

On the other hand, the study of recent movements of the crust forms one of the exciting newer areas of geodesy with broad implications. Recent and current horizontal motions are of importance in seismic zoning and prediction, while slow vertical motions have their own repercussions on human affairs. Slow vertical movements of millimetres to centimetres per year are observed in many of the tectonically active areas of the world (Pavoni, 1971), while post-glacial rebound produces similar movements in non-active areas. The tilting observed across the Great Lakes (Clark and Persoage, 1970), if it continues, could obviously lead to problems of flooding on one side and shallowing of harbours on the other. The secondary effects of vertical changes in the crust may be felt some distance from the centre of activity. For example, rapid uplift of the Alps appears almost certainly related to vertical movement as far away as Venice. Changes in the latter city, so critical to the preservation of its art treasurers, may well be influenced more by broad-scale tectonic tilting of the crust than by the classical explanation of local deltaic loading.

The basic information for these studies is provided by the geodesist through relevelling at regular intervals, precise level nets well connected to permanent tide gauges. A most interesting development is the ability of the geophysicist to estimate in advance the vertical displacement to be expected from artificial loads as Walcott (1974) has done for the James Bay project.

Earth movements on a shorter time scale fall into the class of seismological phenomena. We could summarize the progress by noting that seismological zoning and tsunami warning systems are well advanced scientifically; the sociological and economic problems are understood if not solved. Induced seismicity is somewhat less advanced while earthquake prediction remains a most difficult scientific problem whose sociological interrelations are just beginning to be appreciated. The raw material for seismic zoning is the historical record of earthquake epicentres and earthquake magnitude. Seismic risk in any area is indicated by some probability index. For example, Fernandez *et al.* (1972) plot the "specific seismicity" in units of 100×10^7 ergs per day for South America. An alternate index is related to the degree of risk as mapped for the United States. The boundaries between seismic zones must be indicated in some detail if the zoning map is to be useful, but this detail is often beyond the resolution possible with the seismic network alone. Boundaries are often drawn on the basis of geological information, a shield area, for example, being entirely contained within a low risk zone. The implication of seismic zoning for the population at large is through codes for building construction and in extreme cases the prohibition of buildings in areas of great hazard. Social and economic problems arise in the case of non-conforming, existing buildings and in the movement of people. On the other hand, there are some striking examples of the clearing of large urban areas from high-risk zones as in the case of Tashkent. Scientifically the actual technique of seismological zoning is probably more advanced than the engineering required for the code as the case of the San Fernando earthquake showed. For some applications, such as nuclear power stations, waste disposal sites and pipelines, seismic zoning becomes doubly important in avoiding dangerous situations because of potential secondary hazards.

Seismological warning systems began with the warning for tropical hurricanes based upon increased microseism activity (Ramírez, 1940). Tripartite arrays of seismometers could trace the movement of the source area of microseisms which Ramírez showed to be closely related to the hurricane. Other methods of surveillance of storms have taken the place of seismological hurricane warnings, but the tsunami warning system remains very effective. Its success depends upon two factors: first, that tsunamis are generated by a very special class of earthquake with foci below the ocean and with a substantial vertical component of motion at the source, and second, that the tsunami wave itself requires several hours to cross an ocean. Earthquakes prone to generate tsunamis can then be recognized and there is adequate time to broadcast a warning. The sociological problem which exists in some countries is that, on receipt of a warning, people go down to the beach to see the tsunami come in.

Induced seismic activity includes all of those shocks which owe their origin to man's activities. The best known examples are the loading of the earth's crust by the impounding of water in reservoirs and the lubrication of previously inactive faults by fluid disposal. Geophysics can assist in averting tragic consequences through providing a better understanding of source mechanisms. Lomnitz (1974) has reviewed the present state of research in the case of impounding. He concludes that there can be a real increase in shallow, low magnitude seismicity beneath reservoirs, probably caused by a decrease in crustal strength brought about by increased hydrostatic pressure. He recommends a pre-construction test of reservoir sites whereby water is pumped into a well drilled into the centre of the proposed site and the threshold pressure for seismicity determined. A perplexing factor is the phase relationship between loading and activity; the relationship is neither simple nor constant. Nevertheless it is clear that the geophysicist will become increasingly involved in the preliminary discussions on the siting of large reservoirs.

The fluid disposal problem is best known through the Denver earthquakes (Healy *et al.*, 1968). Observed correlation between earthquake occurrence and pumping pressure leaves little doubt that the fluid injection was the trigger for the seismicity. Healy *et al.* argue that failure (right-lateral strike-slip) took place on an existing quiescent fault because the frictional resistance at the fault was reduced due to increased pore pressure which reduced the effective normal stress across the fault plane.

The prediction of natural earthquakes remains one of the most challenging of geophysical problems (Scholz *et al.*, 1973; Kisslinger, 1974). Many geophysical measurements may be pertinent to this problem including geodetic measurement of fault motion and tilt, seismicity and electrical conductivity. Work in the United States has tended to emphasize the dilatancy model which supposes an increase in crack volume in the early stages of failure. The rock in the source region tends to become undersaturated with fluid and an observable result would be the decrease in P-wave velocity relative to S-wave velocity. Earthquakes are said to occur shortly after the Vp/Vs ratio has returned to its normal value. The explanation given is that fluid flowing into the dilatant region from the surroundings both restores Vp, and triggers the earthquake. These changes may be followed either by monitoring the velocities using artificial sources or by measuring the electrical conductivity of the region. Other methods of prediction are not necessarily tied to this model. These include geodetic measurement of strain accumulation, foreshock frequency and radon concentration in well water. The Chinese success in prediction appears to result from dependence on the latter two.

In spite of encouraging advances in the understanding of seismic processes the sociological problems associated with prediction remain very great (National Academy of Sciences, 1975). These are chiefly due to the uncertain time window for which a prediction may be issued. The questions include how warnings should be publicized, how the public will react to a warning, the effect of false warnings, the decision to return to normalcy, etc. One of the great problems is that with the relative infrequency of damaging earthquakes in some areas, it will require decades even after prediction becomes routine to establish the pattern of human response. This, of course, is a sociological rather than a geophysical problem, but the geophysicist will be involved because the response will be conditioned by the frequency of earthquakes in the vicinity and the sociologist should relate his investigations to the seismologists' zoning.

Conscious of the legal and economic impact of predictions, particularly those with a long time-window, and realizing the possibility of public officials wishing to avoid warnings the National Academy of Sciences panel made the very specific recommendation:

"Predictions should be developed, assessed and issued to the public by scientists rather than by political officials. Procedures must be developed to ensure the free and timely flow of information concerning predictions to all segments of the public. Legislation may be required to ensure that information that an earthquake will occur at a given location and time will not be withheld from general knowledge to the advantage of special interests."

The prediction of volcanic eruptions and the consequences of prediction are perhaps more straightforward than in the case of earthquakes. Through compilations such as the Catalogue of Active Volcanoes of the International Association of Volcanology and Chemistry of the Earth's Interior, the region of danger is normally known and defined by historical records. Monitoring of the depth of seismic precursors (Eaton and Murata, 1960) appears to furnish a useful prediction with a satisfactorily precise time window.

We have been discussing the minimizing of natural or man-made hazards. The remaining involvements of geophysics in our society are more positive in that they involve the search for energy and materials. Exploration for and development of geothermal energy is a particularly good example. Basic physics of the earth is involved not only in the general strategy of locating favourable areas but also in direct exploration and evaluation of reservoir potentials. As a map of geothermal fields shows the developed geothermal areas of the world are almost all near plate boundaries. Within a generally favourable area the development of a high quality steam field, such as those of Larderello, Italy or the Geysers, California depends upon a precise balance between the rate of groundwater inflow and the rate of heat flow, presumably from shallow magmatic sources. Too high a rate of water inflow leads to a hot water field, as at Wairakei, New Zealand which, while still valuable, requires a more complex technology for its utilization.

A number of geophysical methods have been used successfully for exploration in areas such as New Zealand, Mexico, the United States and Iceland. Direct measurement of near-surface temperature and heat flux is an obvious approach, but heat flow

anomalies associated with geothermal areas may be only moderate in magnitude (Lachenbruch *et al.*, 1976). Measurements of seismic noise have been used in Mexico, California (Iyer and Hitchcock, 1976) and Iceland (Ward and Bjornsson, 1971). Ward (1972) has pointed out that while microearthquakes provide a useful exploration tool, they may represent a hazard to eventual development of the field. Electrical conductivity measurements have been used (Hoover *et al.*, 1976; Stanley *et al.*, 1976) to locate areas of conductive hot rock, although a steam reservoir itself may show as a region of high resistivity.

The papers cited by Lachenbruch *et al.*, Iyer and Hitchcock, Hoover *et al.* and Stanley *et al.* are from an interdisciplinary study of the Long Valley Caldera, which is perhaps the geothermal area which has been investigated by the greatest variety of geophysical tools.

The general place of geothermal resources in the global energy budget has been the subject of a number of discussions. Certainly, the experience of Italy, Iceland, New Zealand and California show that installations in single fields of the order of 400 megawatts are completely feasible; that installation costs are comparable to those of conventional steam generators while operating costs are lower and that fields have lifetimes of many decades.

The relationship of metallic mineral deposits to plate tectonics represents one of the most exciting possibilities of the new ideas in global structure. While the subject may appear to be a geological one, geophysics is so deeply involved in the definition of subduction zones, island arcs and spreading centres with particular emphasis in the ancient counterparts of these features that it cannot be excluded. Sillitoe (1972) has shown the relationship of metal provinces of western America to the down-going Pacific Plate. The correlation appears to be remarkably well established, when allowance is made for the fact that a single area may contain deposits of different ages. Sillitoe notes that there can be regions along strike where deposits are very few and he attributes these to low-productivity segments of the ocean ridge system. Sawkins (1972) has discussed sulphide ore deposits in relationship to all types of plate boundaries noting their relative rarity at divergent and transform boundaries. Mitchell and Bell (1973) have worked out in detail the relationship of mineral deposits to island arc formation. Obviously, mineral exploration is, and will be, increasingly influenced by these plate tectonic relationships. Geophysical measurements, such as seismic wave velocity, gravity, paleomagnetism and electrical conductivity will be used to identify ancient ocean floor and ancient plate boundaries and will form part of the exploration strategy.

The direct use of applied geophysics in exploration for oil, minerals and water, and in engineering problems, is well known. Recent reviews have reported on new developments in western countries (Espey, 1975) in which $1.25 billion was spent on geophysical exploration in 1974 as is the case in the USSR (Zietz *et al.*, 1976). There appears to be no lessening of the role of geophysics, for many years an integral part of any exploration program for petroleum and an almost universal component of mineral exploration. Perhaps the most appropriate reference for the present group is Brown's (1970) review of its place in the U.N. Development Program. Brown listed projects in 39 countries on prospects ranging in size from 400 to 123,000 km^2. Twelve strictly geophysical methods were employed (including airborne and ground) for activities costing from $700,000 to $3,000,000 per project. Successes recorded by him include copper (Argentina, Uganda, Chile), tin (Bolivia) and magnetite (Chile, Ivory Coast). The variety of methods and the global distribution is testimony to the value of geophysics particularly in the reconnaissance phase.

Finally, I should like to turn to one of the more indirect social advantages of geophysics, that of international cooperation. The very earliest examples of organized cooperation between scientists in different countries were the Magnetische Verein of Gauss and Weber, established in 1834 and the Iternationalische Gradmessung, organized in 1867. From these developed the International Association of Geomagnetism and Aeronomy and the International Association of Geodesy, now constituents of the International Union of Geodesy and Geophysics. In a similar way international seismology developed through a number of regional organizations, including the Jesuit Seismological Association notable for its training of seismologists. The IUGG was organized in 1919, but even before then the world had seen the First Polar Year of 1882. Later programs such as the International Geophysical Year of 1957-58 and the Upper Mantle Project represent the most universal cooperative scientific projects that have been attemped. The objectivity of science offers an important lesson on what can be done in human relations and no field of science has been so involved with international cooperation as has earth science.

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Discussion

Prof. Radicella:

Quisiera hacer un comentario, más que una pregunta. Creo que es muy importante el hecho de la trascendencia de los cambios atmosféricos o los cambios ambientales introducidos por la actividad humana en Latinoamérica, a lo cual usted no se ha referido en su charla y que creo que en algún momento debiéramos nosotros también tener en cuenta en esta reunión. El problema de los cambios ambientales introducidos por la presencia de grandes diques en Latinoamérica, es muy grande y poco estudiado. Esa es otra área completamente distinta a la que usted ha mostrado pero que también interesa a la Geofísica en términos generales.

Prof. G. D. Garland:

As I mentioned, I did not attempt to be exhaustive in problems, I simply picked out some problems which appeared to me to show the interaction of solid earth geophysics, yes.

SECOND SESSION
Monday, September 27

DEUXIÈME SÉANCE
Le lundi 27 septembre

SEGUNDA SESIÓN
Lunes, 27 de septiembre

BACKGROUND PAPERS

TRAVAUX DE RÉFÉRENCES

ANTECEDENTES DE TRABAJOS

Chairman/Président/Presidente
MR. M. R. DENCE

Speakers/Conférenciers/Expositores

DR. E. KAUSEL
PROF. G. P. WOOLLARD
DR. C. LOMNITZ
MR. P. TANGUAY
MR. E. FELLER

Mr. M. R. Dence:

The first of the review papers this afternoon will be by the President of the Geophysics Commission, Dr. E. Kausel, who will talk on the **"State of Geophysics in Latin America"**.

Dr. E. Kausel:

Yo quisiera hacer en este momento una pequeña reseña de lo que es la actividad geofísica en latinoamérica, con el objeto de poder luego promover una discusión con respecto a qué debiera hacerse, ya sea para mejorar el estudio de la geofísica o mantenerlo a un buen nivel donde ya se lo haya logrado. Por lo tanto mientras yo leo estas palabras, me gustaría que ustedes pensaran en una corta discusión que no debería pasar de la media hora que tenemos fijada.

El trabajo esta relacionado con la geofísica en latinoamérica, y el estado presente de la geofísica en latinoamérica es bastante difícil de analizar por una sola persona debido a que abarca una enorme y variada gama de disciplinas, muchas de ellas muy alejadas de la especialidad del que está hablando. Necesariamente se cometerán algunos errores y omisiones, muchos diría yo, que ruego me perdonen primero y los pongan en evidencia a continuación con el objeto de mejorar lo expresado.

El simposium se ha organizado precisamente para planear las actividades de la Comisión de Geofísica del IPGH a la luz de los antecedentes que cada uno de ustedes planteará y que deberá resumir finalmente el Comité de Resoluciones.

Por razones de organización y administración, la Comisión de Geofísica del IPGH está utilizando la clásica subdivisión de la Geofísica, en Geofísica de la Tierra Sólida, Océanos y Atmósfera y Física Solar Terrestre.

A pesar de que globalmente estas tres ramas de la Geofísica tienen un desarrollo similar en latinoamérica, hay algunas disciplinas contenidas en estas tres ramas que se destacan nítidamente por haber alcanzado un mejor nivel. Así, por ejemplo, la Meteorología, la Geología, la Geofísica de Prospección en Yacimientos Minerales y Petróleo, se destacan tanto por la cantidad de trabajos como por el número de especialistas que existen en la actualidad. Quizás la razón para ello resida en la necesidad de los países de contar con antecedentes confiables en la predicción del tiempo para fines de navegación aérea, agricultura, etc., en el caso de la Meteorología; y la necesidad imperiosa de búsqueda de recursos minerales y petróleo en el caso de la Geología y de la Geofísica de Prospección. Coincide también que son justamente estas disciplinas las que cuentan con estudios formales en varias universidades latinoaméricanas desde hace ya por le menos dos décadas.

Las cifras dadas por el profesor Garland hoy en la mañana, en relación a fondos utilizados en exploración geofísica, muestran claramente el interés por esta actividad comparado con los fondos que los gobiernos y las universidades de latinoamérica destinan a otras ramas de la Geofísica.

Disciplinas como la Sismología, Geomagnetismo, Geotermia, Vulcanología, Gravimetría, Geofísica Marina, Oceanografía, fenómenos relacionados con la Ionósfera, etc., han empezado a ser impulsados a nivel de gobierno solo recientemente reconociéndoseles la importancia socioeconómica que tienen. El nivel alcanzado es, sin embargo, insuficiente. Para dar una idea de este nivel tomaré como ejemplo algunas disciplinas:

La Gravimetría. Gracias al interés que han demostrado la mayoría de los países a través de sus institutos geográficos, algunos de ellos en cooperación con el Servicio Geodésico Interamericano, se cuenta ya con redes gravimétricas aceptables. Ultimamente estos valores han sido volcados en forma de mapas de anomalías de aire libre y anomalías de Bouguer. Sin embargo, solo en contados países estos mapas han sido sometidos a interpretación regional. Falta también conectar las anomalías continentales con las observaciones realizadas a lo largo de las costas.

En general, estas mediciones gravimétricas fueron comenzadas por los países con el objeto de hacer estudios relacionados con la desviación de la vertical. Sin embargo, no han sido utilizadas para esos fines. Salvo contadas excepciones, las mediciones han sido utilizadas por las universidades o científicos relacionados con la gravimetría, en estudiar la corteza y el manto superior de la tierra.

Por otro lado, con el advenimiento de la teoría de la tectónica de placas se sabe y se ha podido observar en muchos lugares, que los valores de la gravedad sufren variaciones seculares bastante importantes, que también están relacionados lógicamente con cambios de la altura, y desplazamientos horizontales. Aqui cabría un estudio con respecto a cuál es el número de veces que uno debiera medir la gravedad en algunos puntos, con el objeto de estar seguro de que la precisión con que se está trabajando es la conveniente. En algunos países los trabajos de nivelación se realizan a la décima del milímetro en el caso de nivelaciones de primer orden. Pero una renivelación de toda una red toma un período demasiado largo, y casi nunca se alcanza a volver a medir los valores obtenidos anteriormente. Sin embargo, esos valores tienen que haber cambiado mucho, por ejemplo el caso de Chile en el terremoto del año 1960, en donde unos ochocientos kilómetros de costa se hundieron aproximadamente unos dos a tres metros como término medio. Eso significa en variaciones de la gravedad, valores apreciables que son medibles incluso con gravímetros no demasiado sofisticados. Sin embargo, nosotros seguimos utilizando los mismo datos para seguir avanzando con la red a otros lugares y puede que esos valores ya no tengan un significado a la precisión con la que se siguen midiendo los datos básicos.

Considerando los problemas presupuestarios que generalmente existen para estos trabajos, debiera poder conocerse cuál es la dimensión y densidad de puntos de la red, más conveniente a los fines que con ella se busca, y que sea compatible con la posibilidad de remedirla en un periódo aceptable.

En el caso de la Sismología, gran parte de los trabajos se han centrado hasta el momento en mejorar las redes sismológicas de los países, tanto al nivel nacional como latinoaméricano. Un papel importante en este desarrollo le ha cabido al Centro Regional de Sismología para América Latina (CERESIS), al promover y asistir técnicamente a muchos países en la instalación de estaciones sismológicas. Actualmente México y Venezuela tienen sus propios planes, que una vez terminados constituirán sin duda un avance importante para la Sismología.

Hace falta, sin embargo, preparar personal a nivel medio como Operadores de Estaciones Sismológicas, e Interpretadores Rutinarios de los Datos Sismológicos. Personal que pueda mantener en buenas condiciones las estaciones, en especial en lo que respecta a la calibración, que es un defecto muy importante que se puede notar en las estaciones latinoamericanas. La mayor parte de las estaciones no están calibradas, de manera que los datos obtenidos solo sirven para trabajar de determinación de epicentros con el tiempo de llegadas de las ondas sísmicas y no se pueden utilizar para hacer estudios de, por ejemplo, ondas superficiales o problemas de inelasticidad en el interior de la

tierra. Ya se han realizado cursos de Operadores de Estaciones Sismologicas en varias oportunidades organizados por el CERESIS.

En este momento se lleva a cabo un curso de un mes, en San Juan, Argentina, para capacitar a interpretadores y electrónicos que están a cargo de estaciones sismológicas en diferentes países de Latinoamérica. Estos cursos son de gran importancia, dado que para cualquier sismólogo la necesidad de tener datos buenos está relacionado con la forma en que se están operando las estaciones sismológicas.

Fuera del trabajo básico de mantenimiento de las estaciones sismológicas y de interpretación rutinaria de los datos sísmicos, hay lógicamente algunos países que cuentan con grupos de investigación que van más allá de la simple interpretación rutinaria de los sismogramas.

Se están haciendo en la actualidad estudios de la estructura de la corteza y el manto superior, por ejemplo, el Proyecto Nariño, en que Bolivia, Perú, Ecuador y Colombia, en combinación con la Khan Institution y otras organizaciones están estudiando la corteza y la parte superior del manto a partir de perfiles sísmicos de reflexión.

También se están realizando trabajos de Geofísica Marina, en colaboración con universidades de los EEUU, particularmente en Argentina, Perú, Colombia, Ecuador, Chile, algunos países de Centro América y México.

Estudios de sismicidad y riesgos sísmicos. Es el campo donde más se han interesado los sismólogos latinoamericanos, donde hay más trabajos publicados. No necesariamente publicados en revistas internacionales, pero por lo menos en revistas nacionales o de conocimiento de la región.

Sin embargo, parece necesario en este campo volver a estudiar los sismos históricos. Se han estado utilizando numerosos datos de sismos históricos en latinoamérica, pero tales datos no son completos ni para magnitudes de 7 para arriba. No son suficiente para poder estudiarlos estadísticamente en forma confiable, de manera que habría que volver a las fuentes originales históricas, incluso al tiempo de la Colonia, con el objeto de escudriñar y ver si todavía se pudiese encontrar antecedentes de fenómenos a agregar a la lista de sismos, o se cuente con nuevos datos que permitan volver a estimar la magnitud de los ya estudiados.

En lo que respecta al estudio de la sismicidad y el riesgo sísmico hay en este momento algunos países que han organizado lo que se llama Oficina de Emergencia que a fin de poder cumplir con su misión, requieren de rápida información sobre la situación de los epicentros. Lamentablemente, las instituciones que deberían proporcionarles la información, no están en condiciones de hacerlo. Los equipos que poseen son insuficientes en número y calidad. En más de un caso deben recurrir a datos macrosísmicos para la ubicación de los epicentros.

Esto debe ser mejorado, para lo cual es necesario instalar estaciones telemétricas, a fin de obtener los datos con suficiente rapidez.

Es lo que está haciendo México, que implementa una red de estaciones. Seguramente el Dr. Lomnitz nos hablará luego sobre esa red, en la que los datos van a llegar centralizados y rápidamente, pudiéndose en corto plazo entregar antecedentes sobre el epicentro.

También tiene importancia para los efectos de los sunamis. Nosotros, por ejemplo, o cualquier país que esté en la Costa del Pacífico, no puede esperar que llegue el dato de alarma del sunami desde Hawai, porque después de producido el temblor en el Perú, Chile o Ecuador, normalmente una ola va a demorar solo de diez a quince minutos en llegar a la costa. Tiempo demasiado corto para poder dar una alarma a través del Centro de Alarmas de Sunamis de Hawai. Nos servirían los datos de Hawai cuando se produzca un terremoto en Japón, pues entonces tendremos el tiempo necesario para prevenir cualquier desastre. Pero en el caso de temblores en la Costa de Sudamérica el dato es muy tardío.

Se hace entonces necesario, en último término, contar con estaciones telemétricas con el objeto de que si con los primeros datos sabemos que el temblor tiene una magnitud mayor de siete y medio, que el epicentro está en el mar, y que el foco no está a más de 50 kilómetros de profundidad, existe el peligro de un maremoto y deben darse las instrucciones necesarias para que la población abandone los lugares peligrosos, cosa que sería muy difícil a través del sistema de alarma de Hawai.

El estudio de predicción de sismos está recién comenzando. En realidad hay pocos antecendentes sobre predicción de temblores en Latinoamérica. Nosotros en Chile estamos recién comenzando el desarrollo de un programa, instalando estaciones sismológicas en una zona piloto con el objeto de estudiar cuales serían los métodos más convenientes de predicción de temblores.

En Chile los mecanismos de temblores, la situación con respecto al movimiento de placas es distinto que, por ejemplo, en California, en donde son dos placas que se mueven a lo largo de la Falla de San Andrés; a lo largo de una falla transformada. Nosotros estamos en una zona de subducción y por lo tanto la distribución y la profundidad de los temblores es bastante distinta.

En general los temblores destructores en Sudamérica son temblores que se producen muy cerca de la costa o, incluso, la mayoría en el mar. De manera que es muy difícil colocar una red de estaciones locales para estudiar, por ejemplo, variaciones de la velocidad de las ondas sísmicas con el objeto de hacer una predicción de un temblor. Por otro lado, si otros temblores de magnitudes importantes se producen en el interior, en el Continente, y van siendo cada vez más y más profundos (50 kms), no estamos seguros si con una red local de estaciones sismólogicas vamos a poder obtener anomalías de velocidades de las ondas sísmicas y estaríamos en condiciones desfavorables para hacer una predicción. De manera que el campo de la predicción de sismos en latinoamérica está en pañales y es bastante difícil poder decir si vamos realmente a hacer predicciones en un corto plazo, digamos unos diez o quince años.

Se están haciendo algunos estudios sobre tectónica de placas (siempre en lo que a sismología se refiere). Se trabaja en México, con datos continentales y marinos; Colombia, Ecuador y Perú en conjunto en el proyecto Nariño, que da algún antecedente también relacionado con el movimiento de subducción. Se han hecho también algunos trabajos en Chile sobre las variaciones de la velocidad de las ondas sismicas alejandose de la mesodorsal marina del Pacífico. Se ha encontrado que realmente las velocidades van aumentando a medida que uno se aleja de la mesodorsal.

Esto se ha obtenido con el estudio de ondas superficiales.

En general, el número de investigadores en Sismología es bastante bajo, de manera que basta que uno o dos sismólogos decidan emigrar de un país para que prácticamente la Sismología en ese país quede en cero. Por eso, creo yo que la forma de trabajar en Sismología sería tratar de promover trabajos en conjunto entre los países, de manera de que el pequeño número de sismólogos que hay pueda mantenerse en contacto más per-

manentemente, y entonces, en esa forma, poder desarrollar investigaciones que tengan más valor de las que se están haciendo en este momento. Hay trabajos de mucho valor, indudablemente, pero es un número bastante pequeño con relación a los que se están haciendo en el mismo campo.

En la parte de Geomagnetismo, especialmente en lo relacionado con Física de la Tierra Sólida, es muy poco lo que se está haciendo en Latinoamérica, donde faltan estaciones geomagnéticas.

Quizás Argentina, Perú y México sean los países en los cuales las estaciones geomagnéticas se han mantenido en mejor forma, ofreciendo datos por un período de tiempo lo suficientemente largo como para ser analizados. En los demás países las estaciones funcionan por poco tiempo y se paralizan; luego se vuelven a poner en funcionamiento sin ser calibradas y así sucesivamente.

El IPGH ha tratado de ayudar en ese sentido con el objeto de que las estaciones geomagnéticas latinoamericanas tengan una base de calibración común.

Un estudio interesante que esta haciendo un grupo de investigadores en el Perú en colaboración con la Khan Institution, y que está relacionado con geomagnetismo, es el correspondiente a la zona anómala de conductividad eléctrica bajo los Andes.

Actualmente se intenta prolongarlo a Chile y Argentina para poder definir como es realmente esa zona de conductividad eléctrica anómala debajo de los Andes.

En Geofísica Marina solamente se están haciendo trabajos en conjunto. En realidad es muy difícil que un país latinoamericano pueda mantener un barco oceanográfico, por ejemplo, para hacer geofísica marina por su cuenta. En general los trabajos que se han realizado hasta este momento han sido en colaboración con países Europeos o universidades de Estados Unidos, pero no en forma independiente. A esta lista podría agregar otros antecedentes con respecto a otras líneas de investigación como flujo calórico, meteorología, etc. Pero no quisiera abrir juicios sobre campos que realmente no domino.

Al final podríamos tener una pequeña discusión en ese sentido y ver cuáles son en estos campos las líneas que debieran ser ayudadas; qué problemas hay en general para el estudio de la geofísica en latinoamérica. Yo diría que en primer lugar hay que mejorar la infraestructura de personal medio, es decir, personal que trabaje como operadores de las estaciones sismológicas, meteorológicas, etc. Es el personal de este tipo el que es necesario aumentar, dado que todos los entecedentes que se usan posteriormente dependen de los datos primarios.

Hay que aumentar también el número y el nivel de los investigadores.

Llegar en varios países a contar con los recursos humanos y materiales que permitan trabajar con tranquilidad en todos estos campos. Yo creo que una de las razones por las cuales hay escasez de investigadores, es el hecho de que no hay estudios formales de geofísica en la mayoria de los países. Tengo entendido, quizá esté equivocado, que en este momento solamente se da el título de Maestría en Geofísica en México y Chile; en Argentina también hay algo de estudios formales en Geofísica pero se llega a un nivel menor, de manera que internamente en los países no hay como formar geofísicos. No me refiero a la Geofísica de prospección sino a geofísicos que esten capacitados para dedicarse a la investigación. La mayoría de los que están trabajando en este momento en latinoamérica, han hecho sus estudios en Europa o los EEUU y han vuelto a sus países posteriormente.

Un índice que me gustaría proponer, aunque no absoluto, pero que da una cierta idea, es el de los trabajos que han sido publicados en revistas internacionales, por ejemplo, en el Journal of Geophysical Research, el Geophysical Journal y el boletín de la Seismologycal Society of America. Yo tengo antecedentes de los últimos dos años que indican que el número de trabajos publicados en el J.G.R. es de 336 artículos escritos por 637 autores.

De ellos, solamente hay cuatro trabajos pertenecientes a autores de latinoamérica, y esos cuatro trabajos han sido escritos por cinco autores, de manera que ustedes pueden comparar: de 336 trabajos presentados, 4 pertenecen a autores latinoamericanos de 637 autores, 5 son latinoamericanos; eso es en el Journal of Geophysical Research. En el Geophysical Journal hay 200 trabajos presentados por 450 autores — estoy dando números redondos para no cansarlos — 4 trabajos latinoamericanos, 4 autores latinoamericanos; y en el Boletín de la Seismologycal Society of America hay 229 trabajos publicados, por 434 autores, de los cuales hay nuevamente 4 trabajos latinoamericanos, por 5 autores.

Indudablemente que este no es un índice de lo que se hace en Sudamérica, porque es mucho más lo que realmente se hace, de los que se publican en revistas internacionales, tanto por el problema del idioma, como por el problema de que hay que pagar las páginas a publicarse.

Hay una serie de problemas que impiden a los científicos latinoamericanos publicar en revistas internacionales, pero indudablemente también está relacionado con el pequeño número de investigadores que hay en latinoamérica, que puedan presentar algo de interés para las revistas internacionales. De allí la importancia de que en este momento haya dos revistas, la revista « Geofísica » del Instituto Panamericano de Geografía e Historia y la Revista « Geofísica Interamericana » que publica la UNAM, porque eso va a permitir que poco a poco los investigadores latinoamericanos tengan la posibilidad de publicar en un órgano de difusión que sea conocido más allá de sus fronteras. Esto les dará la confianza necesaria para poder ponerse en contacto con investigadores de otros países e ir elevando el nivel de las publicaciones de este Continente.

Otro punto que habría que considerar, es el que trata el tema de la búsqueda de una forma de mejorar la ayuda internacional, en especial, que sea más contínua.

Es decir que se cuente con financiamiento a largo plazo, con lo que se lograría un mayor efecto.

Por último, para terminar, me gustaría referirme a la necesidad de mejorar los sistemas de información geofísica. En este momento hay un número muy grande de datos que se han tomado en varios campos de la geofísica de latinoamérica, y que sin embargo, no es posible utilizarlos por el hecho de que están diseminados, nadie sabe exactamente dónde. Al haber pocas publicaciones en latinoamérica, hay poco publicado, pero sin embargo hay bastante hecho que está guardado en alguna parte, que nadie lo ha utilizado y que sería conveniente escarbar y sacar nuevamente a la luz; para eso, la única forma es tener algunos sistemas de información geofísica con el objeto de reunir esos antecedentes y que sirvan entonces, tanto para los científicos latinoamericanos como para científicos de otros países, en las investigaciones relacionadas con latinoamérica. Gracias.

Mr. M. R. Dence:

Thank you very much Dr. Kausel. Are there any questions or comments from the floor?

Discussion

Dr. A. Giesecke:

Solo quería comentar respecto a la poca cantidad de trabajos que son publicados por latinoamericanos en las revistas como J.G.R. y Journal of Geophysics, y esto es nada más que un comentario a la luz de la experiencia en el Perú; viendo el informe nacional que hemos traído, yo creo que realizamos en nuestros países una gran cantidad de trabajos que merecerían ser publicados; pero quién sabe si es correcto que así sea. La búsqueda de nuestros investigadores en nuestros países, va hacia aquellas actividades que están directamente relacionadas con problemas socioeconómicos, por ejemplo, la de determinar el riesgo sísmico en caso de un embalse grande. Este tipo de trabajo no encaja en las publicaciones científicas, y quien sabe sino hace falta un tipo de publicación que dé cabida a estos trabajos, que son muy importantes para nuestros países pero que, sin embargo, son probablemente irrelevantes para « J.G.R. ». Gracias.

Dr. E. Kausel:

Estoy totalmente de acuerdo con eso y en uno de los campos donde más se nota ese carácter local que tienen los trabajos, es en geología; hay muchos trabajos de geología que no pueden ser publicados en revistas internacionales porque están relacionadas con geología local. Ahora, lo que sí yo diría, es que incluso en geología hay trabajos que pueden ser publicados a nivel internacional si se los reúne y se forma un cuadro general de un problema regional, que es la suma de muchos trabajos pequeños. Indudablemente que un trabajo que aparezca en una revista internacional significa una cantidad bastante grande de otros trabajos que han sido hechos y publicados internamente; pero, en todo caso, algún significado tiene.

Ing. A. Brussoni:

Un comentario con respecto a la cantidad de datos que existen y de lo cual, en realidad, no hay conciencia. En relación a Geofísica Marina, tanto Brasil, Argentina como Uruguay y lo mismo ocurre con Venezuela, hay miles, decenas de miles de kilómetros de líneas sísmicas en poder de las compañías estatales de gobierno; en el case de Uruguay, lo conozco directamente, para una superficie relativamente pequeña nosotros tenemos en este momento (desde el 71 hasta ahora), casi diez mil kilómetros de línea sísmica y además complementada con gravimetría y magnetismo; la Argentina entiendo que debe tener 60 o 70 mil kilómetros de línea sísmica.

Todo este tipo de datos en este momento está necesitando de una reorientación, porque ha habido una serie de dificultades en los programas de exploración o sea que sería importante exhortar a las compañias estatales, a una política de reunificacion de esos datos y estudios regionales. Muchas gracias.

Dr. E. Kausel:

Y quizás aqui habría que agregar que un sistema de información es conveniente en esos casos. Hay numerosos datos de gravimetría marina, por ejemplo, que no han sido ligados al continente y que son tomados, ya sea por empresas estatales o por barcos oceanográficos internacionales.

Tales datos no han sido todavía utilizados por los propios países para hacer su mapa de gravedad, incluso alejándose un poco de la costa. Se llega simplemente hasta el borde y ya no se cuenta con más datos.

Mr. M. R. Dence:

Thank you. I am sure our next speaker will address similar problems and this will be a discussion that can carry on during the week.

Prof. Woollard, from the United States, who I am sure needs no introduction to the people in the audience, will speak on **"The Status of Geophysical Research in Latin America"**.

Prof. G. P. Woollard:

This discussion will present a synthesis of what the writer feels are significant advances in knowledge or program in each geophysical discipline as it relates to obtaining a better understanding of the complex geological-geophysical setting which characterizes Latin America. There will be special emphasis on areas of recent and on-going geodynamic change. With this background particular sets of data are then considered as parts of an integrated interdisciplinary study of a specific problem, namely, the pattern of mineral zonation found in the Andes and its possible relation to plate tectonic dynamics.

The geophysical program in Latin America reflects the application of geophysics to the resolution of: (a) economic problems related to the development of natural resources, (b) sociological-economic problems related to naturally occurring hazards affecting life and property, (c) practical problems related to national development and land utilization, particularly mapping and (d) scientific problems of a geologic, geodetic or geophysical nature. These diverse objectives require an examination of the program in the context of the overall geographical, geological and geophysical setting. This is obvious since areas for oil, gas and mineral exploration and development, as well as groundwater and geothermal exploration and development, are related to geological setting. Similarly, not only determination of where earthquakes, tsunamis and volcanism are apt to occur, but also their prediction, is related to geological-geophysical setting and the ongoing dynamic processes in the earth which in large measure have their origin outside of the geographic boundaries of Latin America. An additional factor that has been of importance in affecting the program is accessibility, since much of Latin America is characterized by dense jungle and high rugged mountains with a resulting paucity of roads and areas where even small aircraft or helicopters can land. The foregoing plus economic considerations, such as the cost of conducting different types of geophysical investigations, the economic "pay-off" that might be expected from a given type of investigation and the state of the national economy, requires geophysical programs to vary significantly from country to country. The geological and geophysical setting, however, is the primary consideration and, as this cannot be divorced from the concept of crustal plate tectonics, this aspect of geological-geophysical relations will be considered as part of the total setting defining the geophysical program.

The geological and geophysical setting of Latin America

As seen from Fig. 1, whether considered from a geographic or a geological viewpoint, Latin America can be regarded as having three basic divisions: Mexico, the Central America-Caribbean area and South America. As the origin of these divisions have their roots in plate tectonics, a brief review of plate tectonic history affecting Latin America is in order.

On the basis of reconstructions of geological and magnetic lineation data (see Dietz and Holden (1973) for example), it appears that about 200 m.y. BP there existed a megacontinent, PANGEA, which had Mexico and Nicaragua as the southern end of the North American block in juxtaposition with South America. At that time it is probable that the ancestral Rocky Mountain system formed a continuous cordillera with an ancestral Andean Mountain system. Although conjectural, the presence of Paleozoic metamorphic rocks and miogeosynclinal sediments in Mexico, Nicaragua and Colombia, but an absence of such rocks in Costa Rica and Panama would tend to support this hypothesis. During late Triassic-early Jurassic time (~180 m.y. BP) PANGEA started breaking up and one of the first events appears to be the development of a rift between what is now Nicaragua and Colombia. As the North and South American continental blocks drifted apart the Central America-Caribbean area opened up as a seaway. At that time the Atlantic area was still closed and South America was in juxtaposition with Africa. It was not until about 135 m.y. BP that the Atlantic started to open along the line of the present Mid-Atlantic Ridge. Although the exact history of the Central America-Caribbean area is difficult to reconstruct, it does appear that the initial spreading centre between North and South America became inactive with time as a more complex regional stress pattern developed. This was a consequence of the further breakup of PANGEA and the rotation of continental blocks to adjust to newly formed crustal spreading centres.

In the area between Mexico and Colombia the changes were far from simple, as evidenced by the Nicaragua Rise which extends through Jamaica and now separates the Yucatan Basin from the Caribbean basin and the apparent continuation of both geologic and gravity anomaly trends from Cuba into the Yucatan-Belize area, suggesting an old, now inactive, island arc system. The development of near east-west trending strike slip boundary faults resulted in a reorientation of former north-south structural trends in Guatemala, Honduras and Nicaragua. These and similar trends along the coast of Venezuela are related to the later development of the present active island arc system in the Caribbean gap between Nicaragua and Colombia and eastward movement of the Caribbean plate whose eastern boundary is now marked by the Lesser Antilles island arc. The present isthmus area of Costa Rica and Panama appears to have formed as a result of diapiric obduction of initially subducted oceanic plate material followed by volcanism. In other words, the isthmus area appears to have had the same origin as the Cordillera Occidental in Colombia with which it is continuous. Both were a product of Pacific rather than Caribbean plate movement even though they were a part of the latter plate (Dewey, 1972).

Therefore the plate tectonic history of the Central America-Caribbean area is complex, as is the development of the present plate boundaries and rise crests portrayed in Fig. 1. To understand these and their development one has to consider the regional aspects of plate motion between the Atlantic and the Pacific.

On the basis of crustal age values defined by magnetic lineations it is clear that, despite the opening of the Atlantic along the mid-Atlantic Ridge, Africa has remained essentially stationary and the Atlantic (including the mid-Atlantic Ridge and North and South America) has moved westward for at least 135 m.y. over the Pacific plate. This conclusion is based on the fact that crust of this age is found off the coasts of Europe, Africa, North America and South America and, although similar old age crust is found in the western Pacific, it is not found off the Pacific coast of either North America or South America. The oldest crust found in the eastern Pacific area is in the Nazca bight (Arica elbow) area off the coast of South America where the crust has an age of only about 55 m.y. The Atlantic coasts of both North and South America have thus been "passive" continental margins over the past 135 m.y. whereas the Pacific coasts have been "active" margins. The latter have been zones of convergence between plates moving in opposite directions with the Pacific oceanic plate being subducted and assimilated beneath the thicker continental plate border. It is this process that has resulted in the formation of the Middle America and the Peru-Chile Trenches and the Pacific continental border zones characterized by earthquakes and volcanism, folding and uplift, intrusions and ore deposits.

As seen from Fig. 1, the subduction pattern has not only been irregular, as is seen from the pattern of oceanic crust having an age older than magnetic anomaly 7, but also changed with time (see also Herron, 1972). A key factor affecting the formation of the present East Pacific Rise which took place about 26 m.y. ago, was the impingement of the North American continental block on the old East Pacific Rise. As South America impinged on the Chile Rise spreading centre at about the same time as California on the old East Pacific Rise (Handschumacher, 1976; Dott, 1976), the two collisions of spreading centres with continental blocks resulted in significant tectonic changes. The principal ones were (a) a westward jump of the East Pacific Rise to its present location off South America, (b) the reformulation of the Nazca plate off South America to include the old (now fossil) East Pacific Rise, (c) the opening of the East-West trending Galapagos Rise crustal spreading centre off the coast of Ecuador to form the Cocos Plate and (d) the disruption of the Andes-Antarctic Mountain chain leading to the formation of the Scotia Sea and arc and the eastern displacement of Andean segments into the Atlantic (2,000 km in the case of South Georgia).

As seen from Fig. 1 the fossil East Pacific Rise appears on the basis of the magnetic data to have been continuous with the Chile Rise and crossed the present East Pacific Rise at about the equator to continue up the axis of the Mathematician Seamounts off Mexico and thence northward off the coast of California. That there was crustal reorientation is evident in the difference in strike of the ancient Grijalva, Mendana, Nazca, Challenger and Mancha fracture zones offsetting crust of 27 m.y. (magnetic anomaly 7) and older age from that of fracture zones such as the Easter Island fracture zone along the Sala y Gomez Ridge which strike normal to the present East Pacific Rise. It also is to be noted that subduction of oceanic crust older than magnetic anomaly 7 beneath the continent was most pronounced north of 10° south latitude and south of 40° south latitude.

The most recent tectonic change related to plate tectonics is the rifting apart of the continental crust in Mexico to form the Gulf of California, an event that appears to have started about 5 m.y. ago coincident with the shift in the location of East Pacific Rise spreading centre (Handschumacher, 1967).

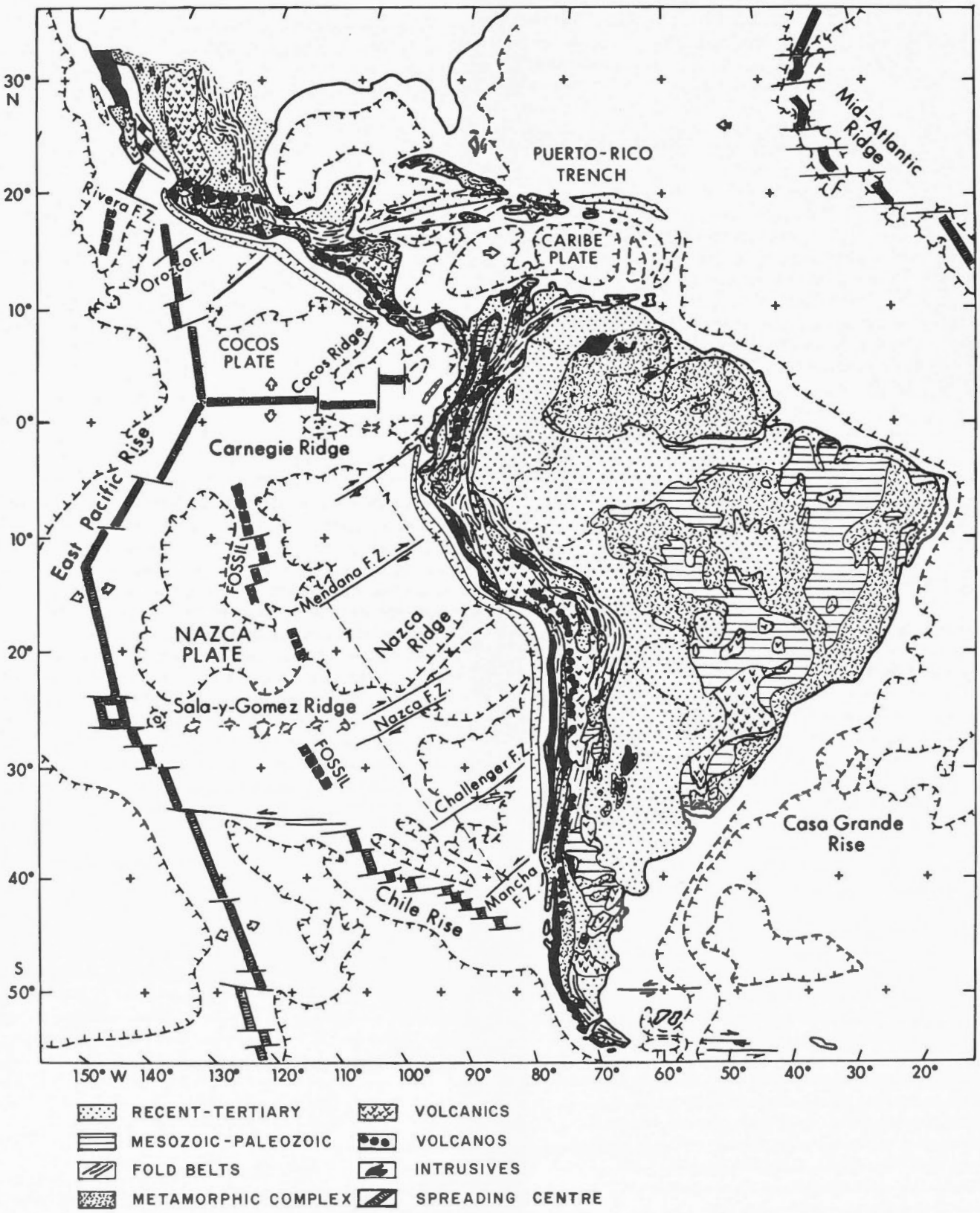

Figure 1. Geological map of Latin America and its plate tectonic setting.

As the above brief review of plate tectonic history affecting Latin America only reflects what can be reconstructed for the past 180 m.y., it clearly has no bearing on much of the geology represented in Latin America, particularly South America. However, it does help clarify the geological and tectonic patterns along the west coast area and in the Caribbean area and, although the Scotian Sea area was only alluded to briefly, it is seen from Fig. 1 that the relations that have developed there are very similar to those found in the Caribbean area. The Falkland (Malvinas) ridge is clearly a counterpart to the Nicaragua Ridge and, as noted earlier, the east-west trending boundary faults on the Scotian plate, along which there has been strike-slip motion, are similar to those bounding the Caribbean plate. The eastward migration of both the Scotian arc and the Lesser Antilles arc presumably is a consequence of a lack of continental block obstruction and a higher crustal spreading rate in the Pacific than in the Atlantic.

The shield areas exposed both north and south of the Amazon River in Brazil and the evidence for past oceanic plate subduction found along the Atlantic coast of South America are related to events that occurred at a much earlier stage in earth history than that considered here. However, during the period considered there was widespread andesitic volcanism in Cretaceous time in the Andean region and the intrusion of batholiths in Jurassic, Cretaceous and Tertiary time. This was followed in early Cenozoic time by folding, faulting and uplift that both geologic evidence and recent studies of secular changes in gravity (Mazzini, this volume), indicate is still in progress.

Areas of present tectonic activity indicated by earthquakes

The areas of current tectonic activity in Latin America are defined primarily by earthquakes and volcanism, and it is to be noted in the case of earthquakes that their tectonic significance depends upon knowing not only their epicentre spatial distribution and magnitude but also their depth of occurrence, their first motion and the distribution of aftershocks. Figs. 2 and 3 show, for example, the distribution of shallow focus (0-70 km depth) and intermediate depth (71-300 km) earthquakes that occurred in the Middle America-Caribbean area during the period 1961-69 as compiled by the now U.S. National Oceanographic and Atmospheric Agency. Inspection of Fig. 2 in conjunction with Fig. 1 indicates shallow depth earthquakes are associated with (a) the present East Pacific Rise extending up into the Gulf of California and the Galapagos Rise spreading centre off Ecuador, (b) transform faults related to and normal to these active crustal spreading centres, (c) transcurrent faults such as those bounding the Caribbean Plate and extending into Central America from Cuba, (d) the Lesser Antilles island arc, (e) areas of continental border oceanic plate subduction marked by the Middle America and Peru-Chile Trenches, (f) former areas of crustal subduction having vertical uplift as in Colombia, (g) areas of present day volcanism, (h) the continental border areas paralleling the zones of oceanic plate subduction, (i) zones of continental transcurrent fault movement as along the San Andreas fault system which originates at the head of the Gulf of California and (j) a few isolated areas of occasional activity that could be related to a number of causes.

Fig. 3 shows that intermediate depth earthquakes generally only occur where there is (a) current oceanic plate subduction as

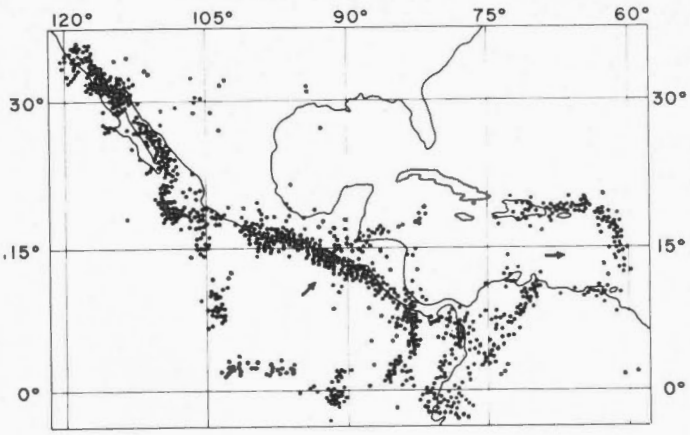

Figure 2. Distribution of shallow focal depth (<70 km) earthquakes in Middle America-Caribbean area.

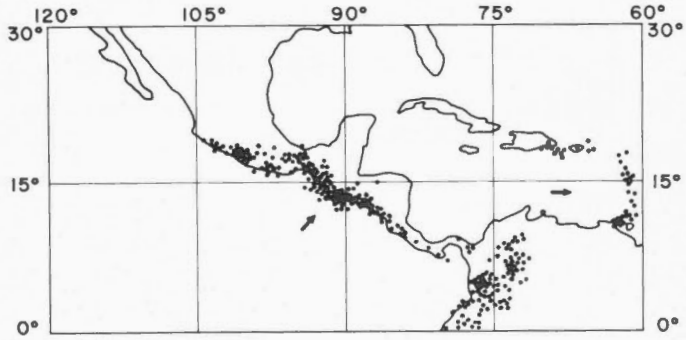

Figure 3. Distribution of intermediate focal depth (71-300 km) earthquakes in Middle America-Caribbean area.

on the back arc side of the Lesser Antilles island arc and inland from the Middle America continental border trench and (b) where there is evidence for recent past crustal subduction and continuing uplift and crustal adjustment as in Colombia. It should also be noted that crustal subduction can lead to diapiric obduction or actual plate overthrusting of oceanic material to produce ophiolite sequences and that shallow and intermediate depth earthquakes now occur in such areas even though diapiric obduction has ceased.

Also note that such areas, as in the Cordillera Occidental in Colombia and the Nicoya geologic complex of western Panama and Costa Rica, appear invariably to be characterized by abnormally high gravity values. As a result, the Bouguer gravity anomalies may be positive rather than negative in sign even at elevations in excess of 1,500 metres.

That the earthquake pattern in South America conforms in general to that for crustal subduction is shown in Figs. 4 and 5 respectively illustrating the distribution of shallow and intermediate depth earthquakes. Very deep focus earthquakes (about 600 km depth) also occur in South America, although not in Middle America. These very deep foci earthquakes only occur as two distinct belts east of the area of intermediate depth earthquakes (Fig. 5). In Fig. 4 the pattern of offshore shallow depth earthquakes shown off the coast of Chile at 45° south latitude is related to crustal spreading on the Chile Rise. Along the coast it will be noted that two distinct groupings of epicentres are defined. On the basis of first motion studies by Stauder (1973, 1975) the inland belt of shallow focus earthquakes, best developed

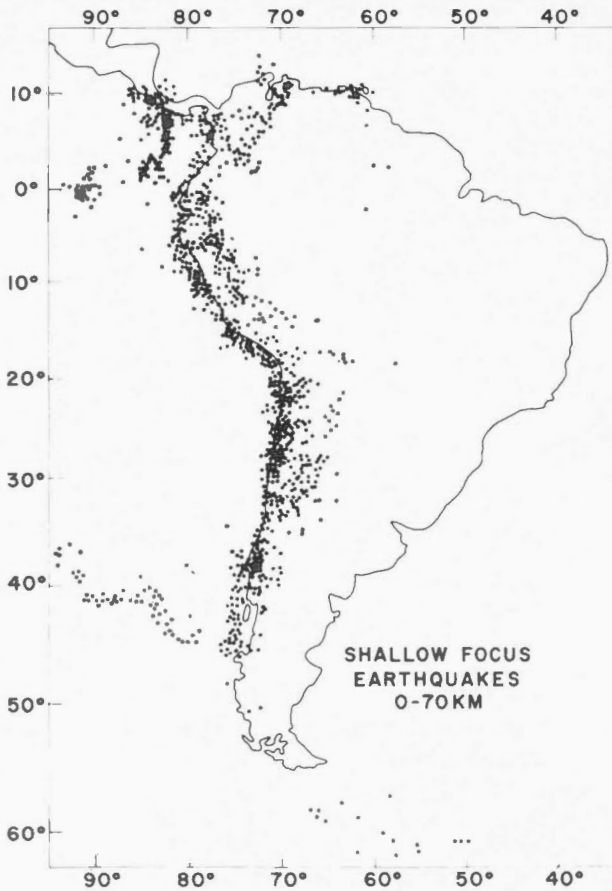

Figure 4. Distribution of shallow focal depth (<70 km) earthquakes in South America.

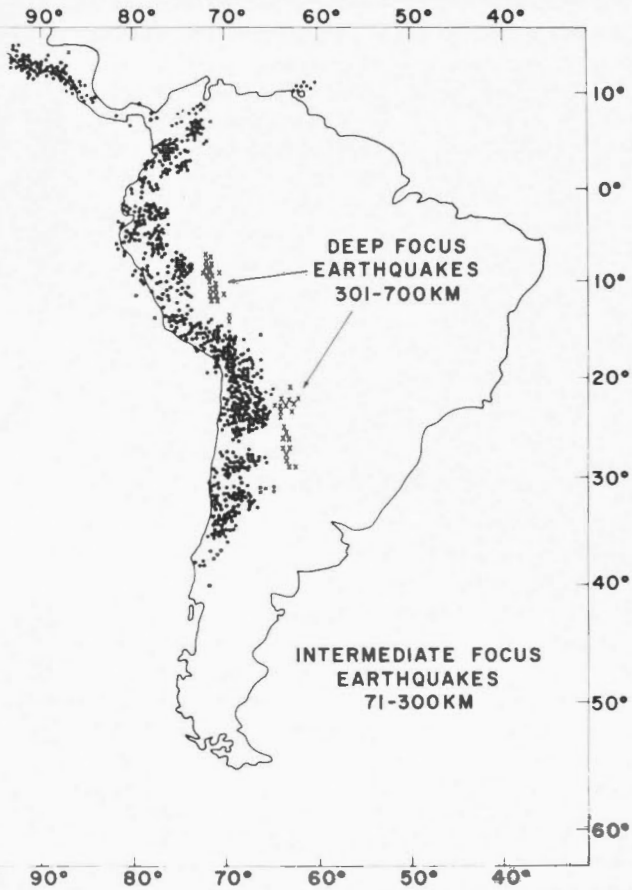

Figure 5. Distribution of intermediate focal depth (71-300 km) and deep focal depth (300-750 km) earthquakes in South America.

south of the equator, differ from those in the coastal trench area in that they represent compressional movement in the upper crust whereas the offshore-coastal belt of shallow depth earthquakes result from tensional movement in the downgoing subducted slab of oceanic material. In contrast to the intermediate depth earthquakes, which also appear to result from tensional stress, the very deep earthquakes appear to be a result of compressional stress.

As it is important to know which types of earthquakes pose the greatest potential hazard to life and property, as well as where they occur, what time sequence (periodicity) is associated with their occurrence and geological or other associations, the earthquakes research program in Latin America has been an active one of long standing. Such studies gained considerable momentum, especially in the countries subject to earthquakes, during the International Geophysical Year and since then through the establishment of the world system of standardized short and long period seismograph stations, the organization of CERESIS and international research programs such as the International Upper Mantle Project and the present Geodynamics Project. Special programs such as that for the geological and geophysical study of the Andes and the IDOE study of the Nazca plate have also contributed significantly to the study of interrelations in seismicity.

Some of the results of these studies that have shown promise for the prediction of earthquakes as well as an increased understanding of seismicity are brought out in the following figures. In Fig. 6 a plot of the areas in which there is progressive longitudinal crustal rupture in association with large magnitude ($M > 7.7$) shallow focus earthquakes is shown. Three distinct groupings are indicated: one along the coast of Colombia from 4° north latitude to the equator, one along the coast of Peru between 10° and 16° south latitude and one along the coast of Chile between 25° and 46° south latitude. Kelleher *et al.* (1973) feel that the intervening "quiet" zones are areas of high probability for future large earthquakes. Also shown in Fig. 6 are (a) the locations of recent volcanism which also comprise three groupings but which have no consistent relationship to the zones of shallow depth, high magnitude earthquake rupture zones, (b) the zones of high and low seismic energy propagation (Q values) as now defined on limited data, (c) the location of the marked electrical conductivity anomaly affecting the magnetic field in the Andes as defined by Schumucher *et al.* (1966) that is associated with the above zone of low Q values and (d) the location of the two groupings of very deep focus earthquakes.

Fig. 7 shows a plot of seismic energy release pattern as determined by Ocola (1966) and Castano, *et al.* (1972) and the relation of this pattern to the electrical conductivity anomaly and low Q zone with which it appears to be associated. As the conductivity anomaly is centred in the area between the bands of high energy release, it appears that there is a real difference in the rheological properties of the crust in the zone of low Q values.

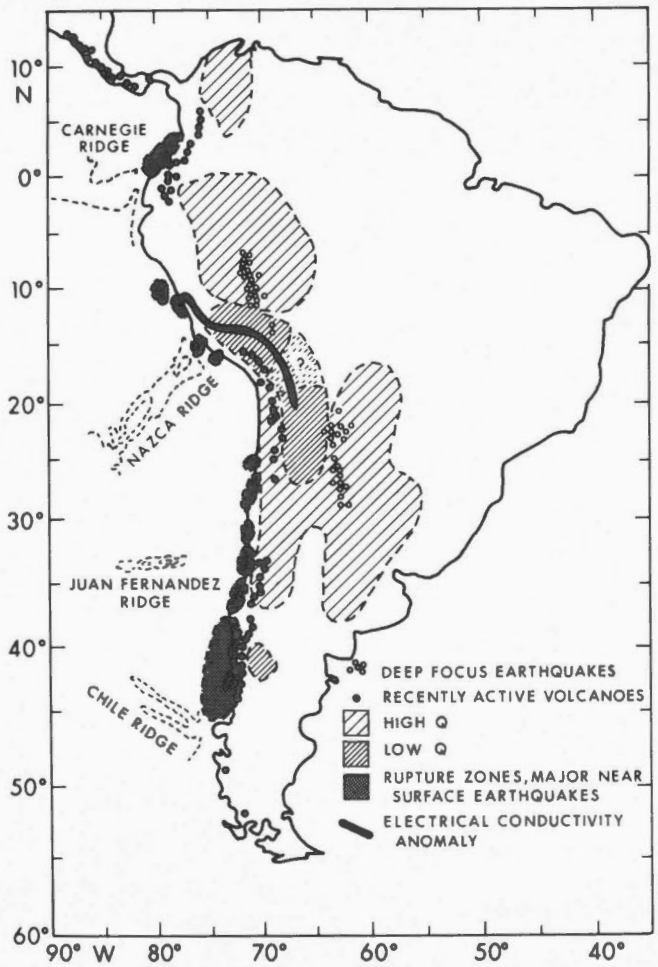

Figure 6. Distribution of associations noted in South America having significance for seismological studies and the prediction of earthquakes.

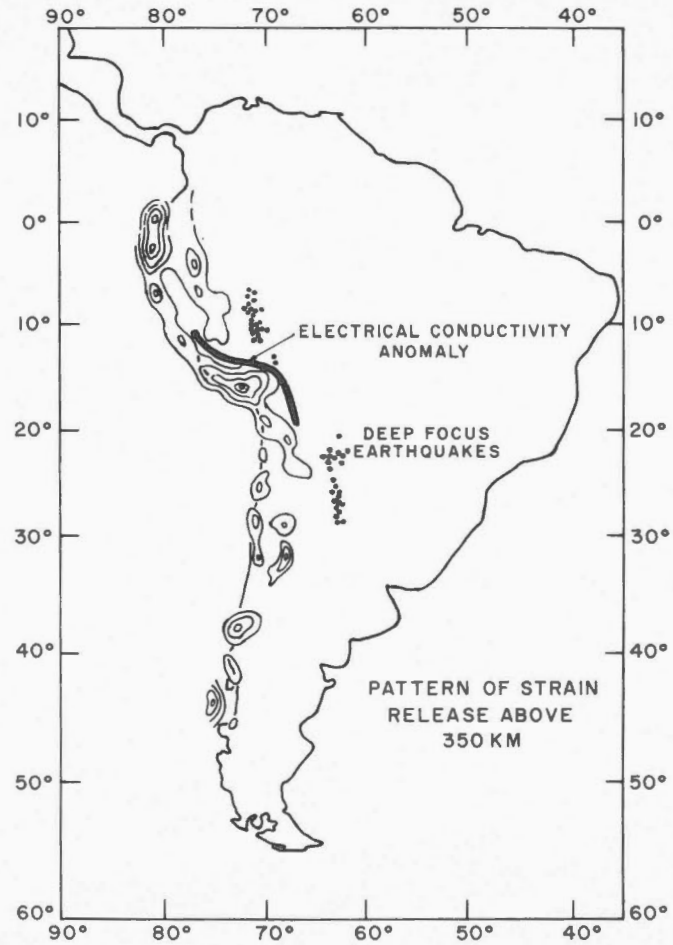

Figure 7. Relation of seismic energy release pattern to zone of low Q values and Andean electrical conductivity anomaly.

Fig. 8 shows an examination of the earthquake data in terms of the dip of the Benioff zone and depth of seismicity to define changes in subduction pattern along the coast of South America from Colombia to southern Chile. Each of the plots (Section A through L) represents in general, a projection of data over a band 4° wide to a central position, the mean location and orientation of which is given on the map insert. All of the plots are aligned with respect to each other on the axis of the Peru-Chile trench identified by the letter "T". The location of the coast line is marked by C and the principal Andean mountain ranges by A, or A with a W, C or E subscript where there is more than a single cordillera as in Colombia. As seen from Fig. 8, the dip of the Benioff zone varies significantly with location. It is also seen that the plane of intermediate depth earthquake activity associated with the downgoing slab changes direction and appears to be near horizontal in some regions. Also note that there is always a gap in seismicity between the deepest intermediate focus earthquakes and those with a deep focus.

As indicated earlier, the first motion studies by Stauder (1973 and 1975) indicate that earthquakes in the downgoing slab are a result of tensional stress in contrast to overlying shallow focus as well as very deep focus earthquakes which are found to result from compressive forces. Stauder (1973) also showed that the pattern of depth of seismicity along strike varies significantly with area. In Fig. 9 Stauder's plot has been extended to give a continuous section along strike south of 12° south latitude in order to show better the rather sharp changes in seismicity pattern. As these changes could be related to breaks in the subducted plate and correlate with geologic features, the changes in Benioff zone dip angle, location of volcanoes, height of the Andes and depth of normal ocean floor as well as that of the Peru-Chile Trench are also shown.

The deepest sector of the Peru-Chile trench and the centre of highest uplift in the Andean Altiplano appear to correlate with the steepest dips for the Benioff zone (sections F, G and H) and maximum depth of intermediate depth earthquake seismicity. This zone is flanked by areas where the subducted plate either changes dip to progress essentially horizontally or else there are no intermediate depth earthquakes below about 200 km (sections E, I and J). As these boundaries appear to correlate with the location of the offshore Nazca Ridge and the Sala y Gomez Ridge, it would appear that old fracture systems in the oceanic crustal plate have been maintained as zones of weakness in the subduction zone and have governed the pattern of uplift in the Andes and defined the longitudinal boundaries of the altiplano. An additional factor appears to have been a higher resistance to crustal subduction in the Nazca bight (Arica elbow) area where the oldest oceanic crust occurs off the west coast of South America and

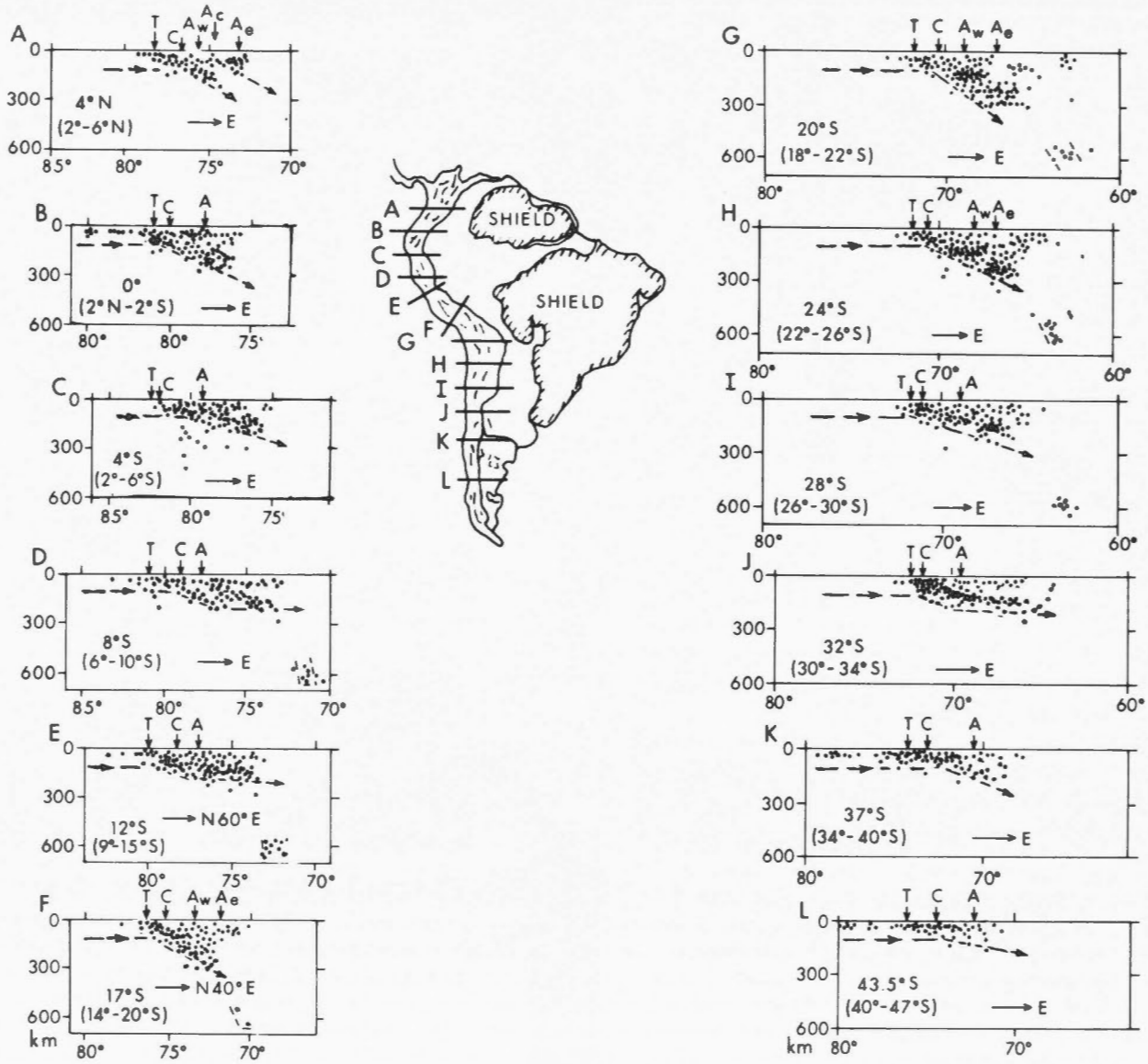

Figure 8. Changes in dip of the Benioff zone and depth of seismicity along the West Coast of South America.

whose location in general coincides with that for the deepest portions of the Peru-Chile Trench. Another factor indicating stress relations is the tight folding of Paleozoic sediments on the east side of the Andes which only occurs east of the altiplano area. It is also in this sector of apparent maximum resistance to oceanic plate subduction that there is the highest level of seismicity. The data shown in Fig. 9 suggest that the Juan Fernandez Ridge marks another probable fracture zone influencing the seismic pattern.

As there is an apparent correlation between the maximum depth of intermediate foci depth earthquakes and the dip of the Benioff zone below the 100 km level which, as seen in Fig. 8, appears to define the location of the base of the subducted oceanic crustal plate and its path, a plot was made of maximum depth of seismicity as a function of the angle of dip of the Benioff zone. The plot of point values for each of the sections of Fig. 8 is shown in Fig. 10-A. A companion plot using average values for depth ranges of 190-210 km, 230-250 km and 290-300 km is shown in Fig. 10-B. Fig. 10-A indicates two groupings of the data both of which suggest that a 10° change in dip on the Benioff plane is related to about a 100 km change in depth of seismicity. However, the data for sections A, G and J appear to have a negative offset of about 50 km from that of the other sections. The plot of average values (Fig. 10-B) indicates a systematic change of about 80 km in the depth of seismicity for a 10° change in the dip of the Benioff plane with a zero angle intercept corresponding to a depth of about 75 km for seismicity. This agrees closely with the value of about 50 km indicated by the data of Fig. 10-A and with observation south of 42° south latitude as shown in Fig. 9. As the correlation appears to be real, the implication is that there are significant changes in the rheological properties of the crust in progressing along the strike of the Andes. Whether these are related to variations in the thickness of the continental crustal block or changes in heat regime and the effective depth of the asthenosphere or some other factor is not known. Although in part there is a correlation with the low Q values associated with the altiplano region of deepest seismicity and also the present pattern of crustal spreading rate on the East Pacific rise, there is no apparent consistency in these relations. In other words, these

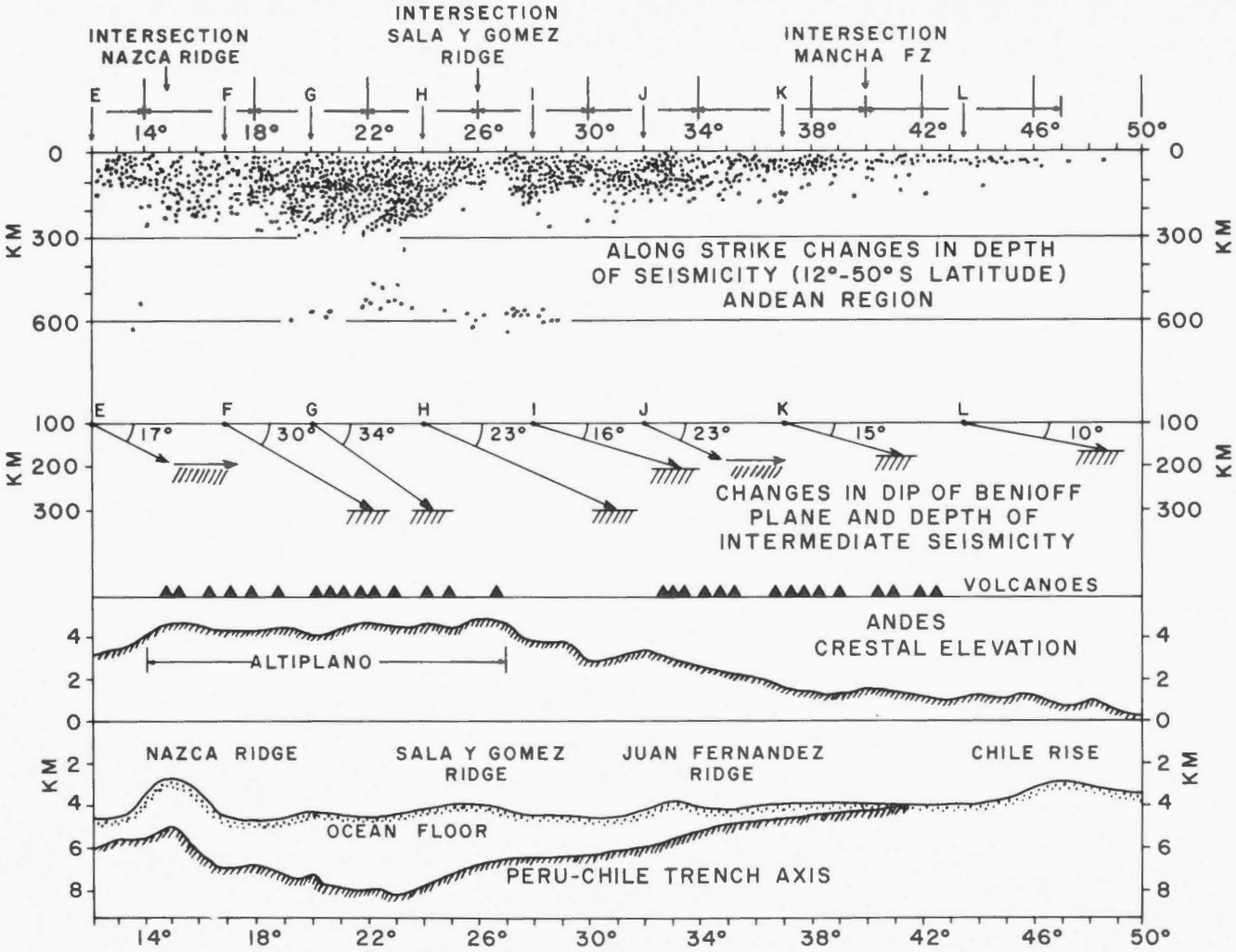

Figure 9. Along strike changes in depth of seismicity, dip of Benioff zone, Andean elevation, and depth of Peru-Chile trench.

relations are similar to those noted for the location of volcanoes which bear no consistent relation to either the dip of the Benioff plane or the depth of seismicity.

The most logical explanation as to why the sections A, J and G appear displaced from the other data in Fig. 10-A, is that there is some local factor that is perturbing the dip of the Benioff plane. That the dip of the Benioff zone is probably anomalous rather than the depth of seismicity is suggested by the fact that the depth of seismicity values change more systematically regionally than do the angles of dip on the Benioff plane. The latter in general relates consistently to the depth of seismicity (Fig. 10B). This would not be expected if the dip of the Benioff zone was influenced mainly by localized changes in the geologic environment while the depth of seismicity was governed by geological factors at depth integrated regionally across strike between breaks as in Fig. 9.

That the geological environment changes significantly along strike in the Andes is evident from the geological pattern (Fig. 1). Seismic crustal measurements in both Colombia and in the central altiplano area of Peru, Bolivia and northern Chile have demonstrated that some of these changes are more than a skin effect and have their origin at depth. The crustal section in Colombia based on offshore shooting and onshore recording up to the crest of the Cordillera Central is of special interest since it is found to cross an area of diapiric obducted, initially subducted, oceanic crust. At the surface this area is marked by elongated belts of "greenstones" and abnormally high gravity values centred between the Cordillera Occidental and Cordillera Central. In Fig. 11 two models of crustal structure are shown that appear to satisfy equally well both the seismic and gravity data. Model I is that of Meyer *et al.* (1976), and II is that of Meissner *et al.* (1976). While differing in detail, both show that basal crustal material, and possibly mantle material, has been brought up essentially to the surface. This structural derangement is not evident in the earthquake data shown in section A of Fig. 8 which includes the area, although it will be noted that two distinct separate subducted plates are suggested.

In the altiplano area of the Andes (area of section G) there has been a continuing program of seismic crustal investigation since the International Geophysical Year (1957-1958). The first measurements using fan recording from large mine blasts in northern Peru and northern Chile were initially reported (Tatel and Tuve, 1958) as defining a normal continental crust. A reinterpretation of these data (Woollard, 1960) indicated a crustal thickness of about 65 km in the western altiplano area of Peru and 70 km in northern Chile. The most recent work (Ocola *et al.*, 1971; James, 1971) using in-line seismic recording for shots fired in lakes, indicates that in the central altiplano area of Bolivia the

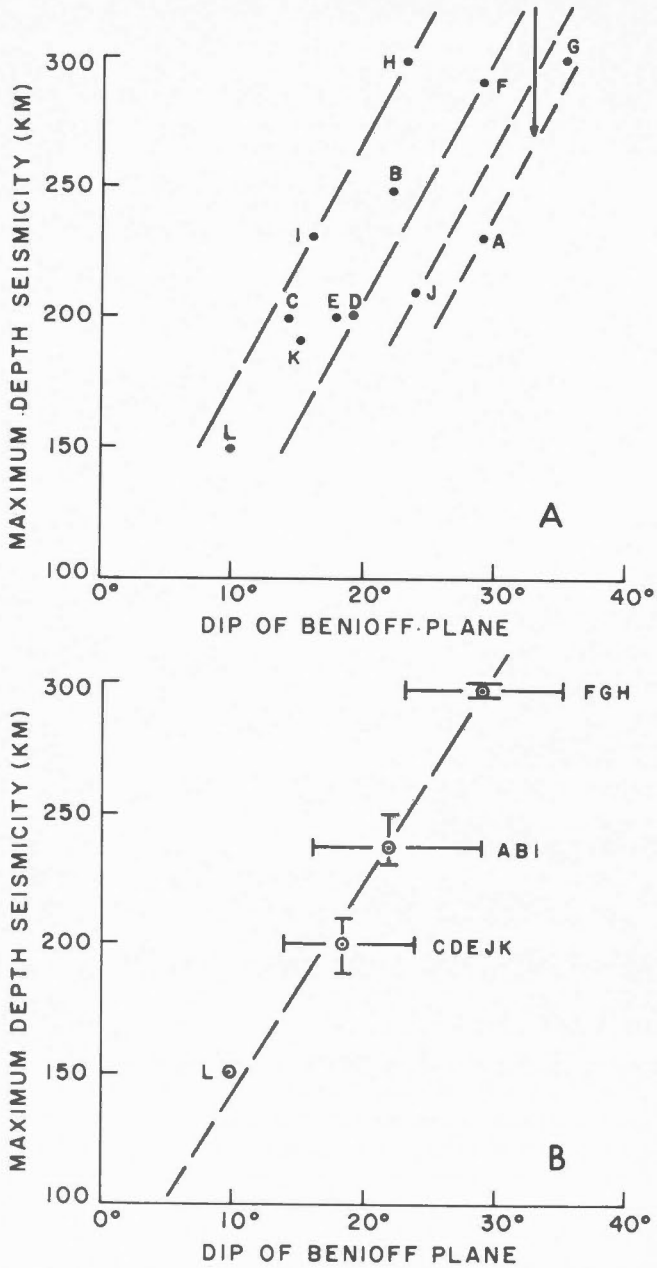

Figure 10. Plot of depth of seismicity as a function of dip on Benioff zone.
A — Point values (4° latitude intervals)
B — Average values

crust has a thickness of about 76 km and in Peru about 73 km. These determinations in each case were handicapped by not being able to get good Moho first arrivals so that a velocity of 8 km/sec had to be assumed in each area. The explanation for this appears to lie in the low Q zone, noted earlier, apparently extending up to Moho level. This conclusion is based on the rule of thumb that the depth of penetration of seismic signals from a surface source is about one fourth to one third of the distance between the shot point and receiving site and the fact that no energy in general could be recorded beyond a distance of 240 km regardless of shot size used.

The crustal structure reported by Ocola *et al.* (1971) for the central altiplano area in Peru for two profiles extending north and south from Lake Langui-y-Layo is shown below.

	South profile			North profile		
Layer	Vel km/sec	Thickness km	Depth km	Vel km/sec	Thickness km	Depth km
1	4.5	6.4		4.5	3.7	
2	6.04	25.4	6.4	5.7	17.1	3.7
3	6.75	41.1	31.8	6.8	50.0	20.8
4	8.0*		72.9	8.0*		70.8

* Assumed value

The crustal structure reported by Ocola *et al.* (1971) for the Bolivian sector of the central altiplano is:

Layer	Vel. km/sec	Thickness km	Depth km
1	4.7*	9.1	
2	6.0	16.8	9.1
3	6.8	50.1	25.9
4	8.0*		76.0

* Assumed

For comparison the crustal section determined by Woollard (1960) for the northern Chile sector of the western altiplano border area based on the data of Tatel and Tuve (1958) is:

Layer	Vel. km/sec	Thickness km	Depth km
1	5.5	6.0	
2	6.35	28.4	6.0
3	7.0	35.9	34.4
4	8.0*		70.3

* Defined by second arrivals.

James (1971) using earthquake travel-time data as recorded with portable arrays of seismographs deduced a somewhat different picture of crustal structure beneath the altiplano of Peru. His sections are shown below.

Layer	V_p	V_s	W. Cordillera Depth below Sea Level (km)	Central Altiplano Depth below Sea Level (km)	E. Cordillera Depth below Sea Level (km)
	km/sec				
1	5.0	2.88			
2	6.0	3.46	2	7	6
3	6.6	3.58	21	22	26
4	7.9	4.45*	62	67	58
5	8.0	4.40	103	108	?

* V_s beneath East Cordillera boundary is 4.3 km/sec.

If allowance is made for the surface elevation and if layer 4 with a compressional velocity of 7.9 km/sec is regarded as marking the M discontinuity and base of the crust, the above sections are in good agreement with the explosion seismic refraction results obtained in the same general area. However, as is evident from the explosion data, there are significant variations in the compositional structure of the crust in the altiplano. It also is to be noted that the gross structural pattern beneath the altiplano area defined by James (1971) using earthquake data (shown in Fig. 12) does not conform in plan to that of the altiplano central plain. However, it does conform in pattern to that of the zone of low Q values and the conductivity anomaly (Fig. 7), and can be related to the higher dip of the Benioff zone and depth of seismici-

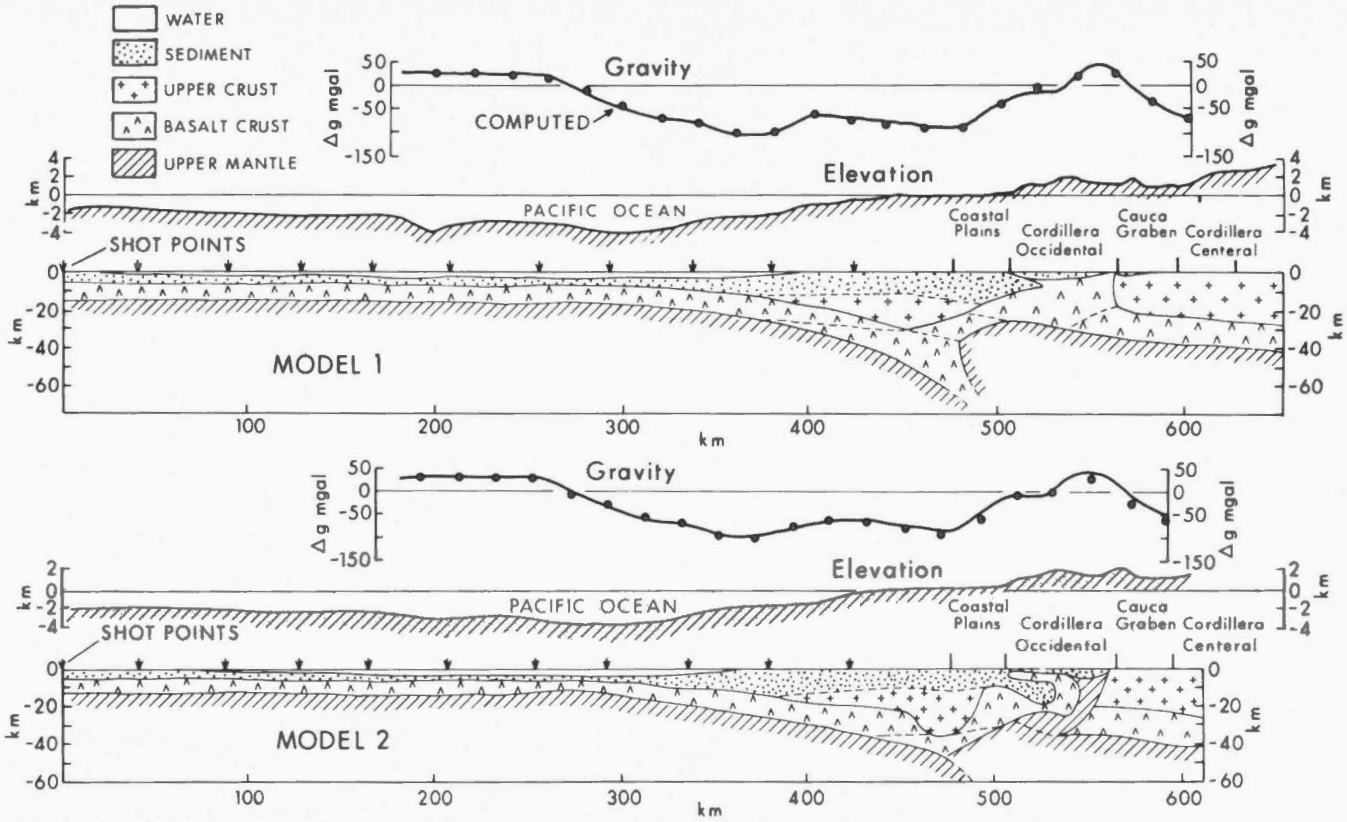

Figure 11. Crustal models beneath the Andean region of Central Colombia.
Model 1 — Interpretation by Meyer *et al.* (1976)
Model 2 — Interpretation by Meissner *et al.* (1976)

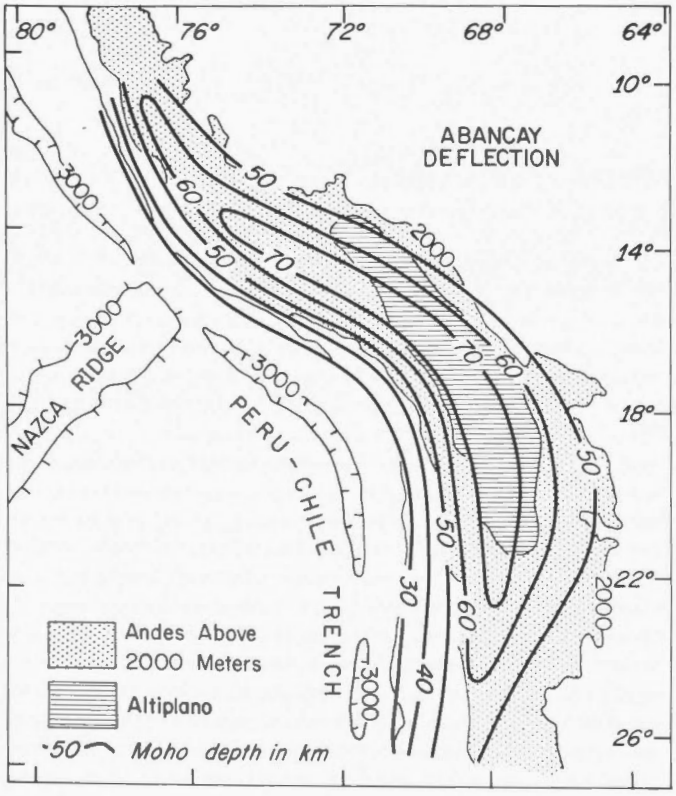

Figure 12. Moho configuration under Andean Altiplano. After James (1971).

ty on sections F, G and H of Fig. 8 in this area. Attention is also called to the detailed analysis by Rodriguez *et al.* (1967) of earthquake data in this and the two adjacent areas indicating the subducted oceanic plate is fragmented beneath the altiplano area.

Studies related to the prediction of earthquakes

That earthquakes do not occur on a random basis, either spatially or with regard to time, is generally recognized. As noted earlier, Kelleher (1972) has shown that very large magnitude ($M \geq 7.7$) shallow focus earthquakes tend to reoccur in restricted areas (see Fig. 6) along the coast of South America. Although the intervening "quiet" areas could be related to aseismic creep adjustment to strain, Kelleher *et al.* (1973) believe that such large earthquakes characterized by along strike rupture patterns only occur where there have been long periods (100 years or more) of stress accumulation. Under this concept the present "quiet" areas are potential areas for similar large earthquakes after the long term strain pattern has been accommodated in the present "active" areas. One peculiarity of these large earthquakes is their spatial pattern of occurrence as a function of time (Fig. 13).

In Fig. 13 the large shallow focus earthquakes used by Kelleher (1972) plus others of similar magnitude ($M \geq 7.7$) and shallow focal depth along the coast of South America as listed by Duda (1965), are plotted with respect to their spatial and time distribution for the period 1900-1970. Three periods of activity are indicated in each of four areas: Colombia, Peru, central Chile and southern Chile. Note there is an indication that if a cycle of large

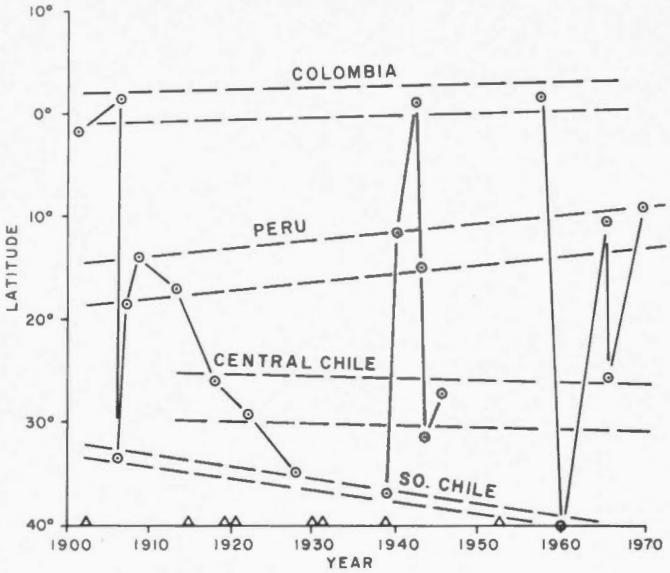

Figure 13. Time-space relations for large (M ≥ 7.7) shallow depth earthquakes along the coast of South America.

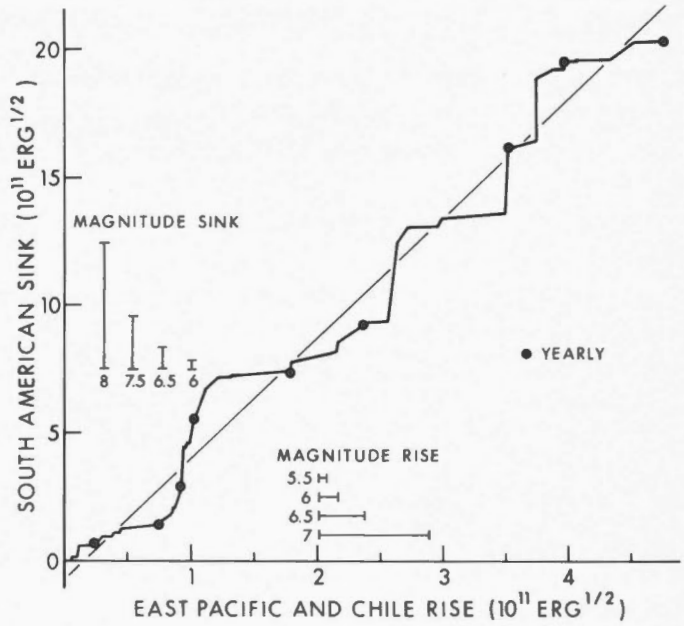

Figure 14. Relation of energy release on the East Pacific Rise to energy release at the continental border of South America. After Berg *et al.* (1977).

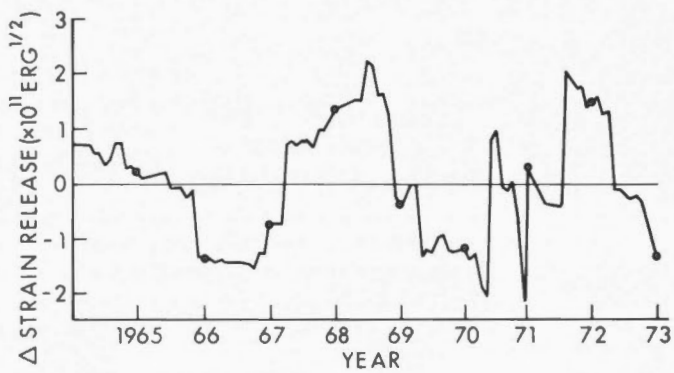

Figure 15. Periodicity of energy release along coast of South America. After Berg *et al.* (1977).

coastal earthquakes starts in Colombia it triggers a big earthquake in southern Chile which is followed by similar earthquakes in Peru and later in central Chile. If the cycle starts in southern Chile it triggers big earthquakes in Peru, then Colombia, Peru again and then central Chile. Events thus appear to oscillate spatially over periods of from 7 to 26 years with intervening periods of from 11 to 12 years in which there are no major coastal earthquakes. Whether the initiation of an epoch alternates between Colombia and southern Chile is not known although this is suggested by the data shown. It will be noted that most of these large earthquakes occur in Peru and central Chile with those in Peru in general preceding those in Chile. In both areas the reoccurrence rate is much the same and varies from 22 to 28 years. In Columbia and southern Chile the reoccurrence rate is more variable; in Colombia it is 16 to 34 years and in southern Chile 11 to 22 years. It also is to be noted that although there does not appear to be any significant shift in the area of occurrence of these large earthquakes in Colombia and central Chile with time, there does appear to be a change in both Peru and southern Chile. In Peru the shift is to the north and in southern Chile it is to the south.

A study by Berg *et al.* (1977) showed that this seismic periodicity is related to crustal spreading on the East Pacific Rise. In this study the energy released by earthquakes along the East Pacific and Chile Rises between the equator and 45° south latitude over the period January 1, 1967-December 31, 1972 was equated to that released by shallow focus earthquakes along the sinking edge of the Nazca plate. As shown in Fig. 14 in which energy released on the sinking plate edge is plotted accumulatively on a monthly basis as a function of that released on the rise, there is an alternation of values about a least squares best fitted line. This indicates that when the rise is active the sinking edge is quiet and vice versa. When the deviations from the least squares line are plotted as a function of time (Fig. 15), it is seen that for the period considered there is a periodicity of about three and a half years. Although this period does not correspond to that noted for very large shallow focus earthquakes shown in Fig. 13 it does indicate that the stress buildup is incremental and related to crustal spreading from the rise areas. It also suggested that very large earthquakes might well occur with a periodicity that is some multiple of 3.5 years.

If the data on the occurrence in Latin America of all earthquakes of magnitude 7 or more are examined, it is found that they are associated with earthquakes with deep and intermediate depth foci as well as those of shallow depth. The distribution of these large earthquakes which can result in the destruction of property and loss of life is shown for the period 1900-1965 in Figs. 16 and 17. Fig. 18 shows a plot of these earthquakes as a function of latitude and time to bring out local trends of occurrence. In this plot the earthquakes having shallow (0 — 70 km), intermediate (71 — 300 km), and deep depths (301 — 700 km) are differentiated except for those associated with the Lesser Antilles and the fault system extending from Cuba to Central America which are indicated by a separate symbol. This was done to avoid confusion with earthquakes occurring at the same latitudes in Mexico, Central America and the Caribbean.

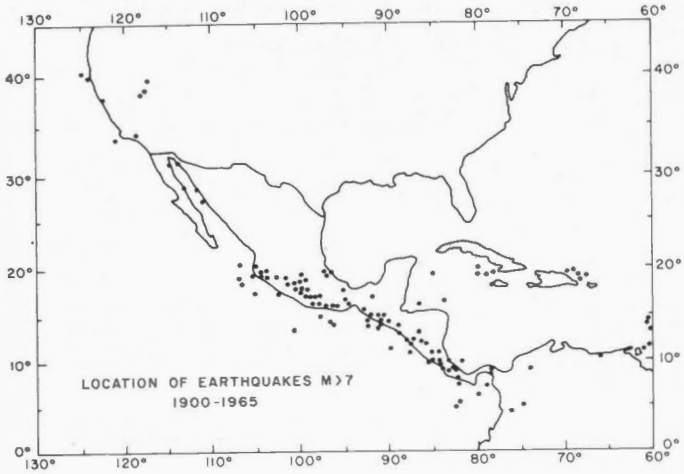

Figure 16. Distribution of all large (M>7) earthquakes in Middle America-Caribbean Area.

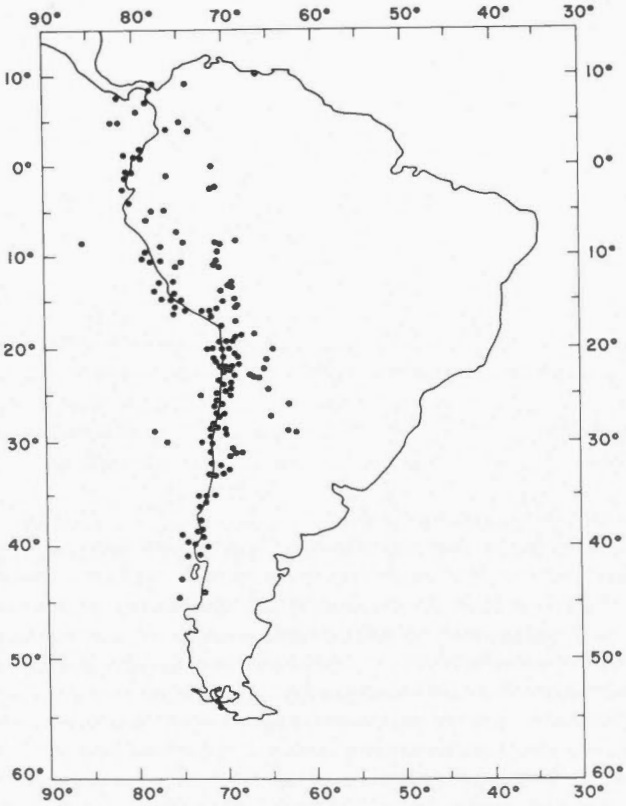

Figure 17. Distribution of all large (M>7) earthquakes in South America.

As seen in Fig. 18 the large earthquakes associated with the opening of the Gulf of California and strike-slip motion on the fault system extending up into California from the head of the Gulf of California are infrequent. There is, though, a pattern of northward migration lasting about 6 years followed by a gradual migration southward over a period of about 36 years.

In the Caribbean area there is an indication that large earthquakes occur in a pattern of south to north migration with time culmination in a higher occurrence of large earthquakes at about a 28-year interval.

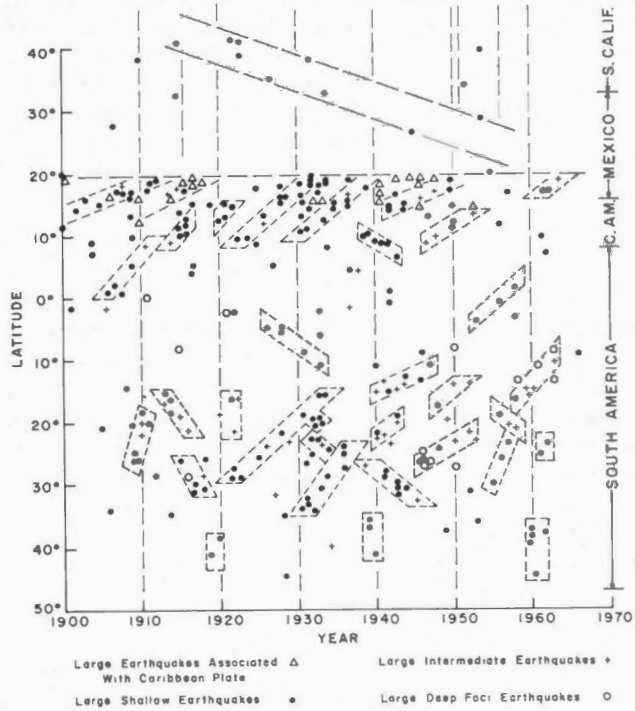

Figure 18. Spatial distribution of large earthquakes in Latin America as a function of time for the period 1900-1965.

In Mexico there is a similar pattern of south to north migration with time that, in part, starts in Central America, or frequently about 14° north latitude, the location of the Cayman fault extending into Guatemala. The resulting saw tooth pattern of occurrence peaks at 20° north latitude about every 20 years.

Central America, except for the period between 1938 and 1944 when there was an apparent migration with time of large earthquakes from north to south, is characterized by the same south to north migration pattern noted in Mexico and in the Caribbean area. Some of the patterns of migration of large earthquakes originating in Panama and Costa Rica terminate at the Cayman fault which seems to give rise to a higher frequency of earthquakes in the Honduras-Guatemala area.

The Colombia-Ecuador area (12°N — 7°S) in general, is one of infrequent large earthquakes, and as seen, only three periods are indicated when there was an apparent migration of large earthquakes with time. Those between 1906 and 1911 and 1953 and 1958 were a south to north migration as in Central America and Mexico, and that between 1926 and 1933 a north to south migration. These periods of apparent migration of large earthquakes correspond to the time of greatest occurrence of earthquakes and the periodicity indicated is about 22 to 24 years.

The Peru-central Chile area (10°S to 35°S) appears to be an area of converging and diverging migration patterns of large earthquakes with time. As a result most of the central area is subject to a major earthquake about every 5 to 6 years. It will be noted that few large earthquakes were reported prior to 1910 and that the southward trend in the pattern of occurrence from 1910 to 1940 has reversed and has been northward since 1940. Another apparent change since 1940 is the predominance of large intermediate and deep focus earthquakes.

Southern Chile (36°S — 47°S) in contrast to the other areas of Latin America appears to be characterized by a fairly regular

pattern of two or more major earthquakes occurring within a very short time period about every 20 years.

Although some of the relations brought out in Fig. 18 are undoubtedly fortuitous, such a presentation does provide a starting point for any investigation related to the prediction of large earthquakes.

Prediction of volcanism in Latin America

Michel (1973) in investigating the occurrence of volcanism in Latin America and its relation to time and earthquake activity concluded that there was a north to south progression in volcanism that, in general, started with a peak in volcanic activity in Mexico, followed by a much more pronounced period of activity in Central America where two or more formerly dormant volcanoes became active during epochs of volcanism. Despite the gaps between the volcanic ranges of Mexico, Central America, Colombia-Ecuador, Peru-northern Chile and central-southern Chile, Michel found the onset of increased volcanic activity progressed southward at a remarkably constant rate of about 925 km/year. For the period investigated, 1900-1970 there appeared

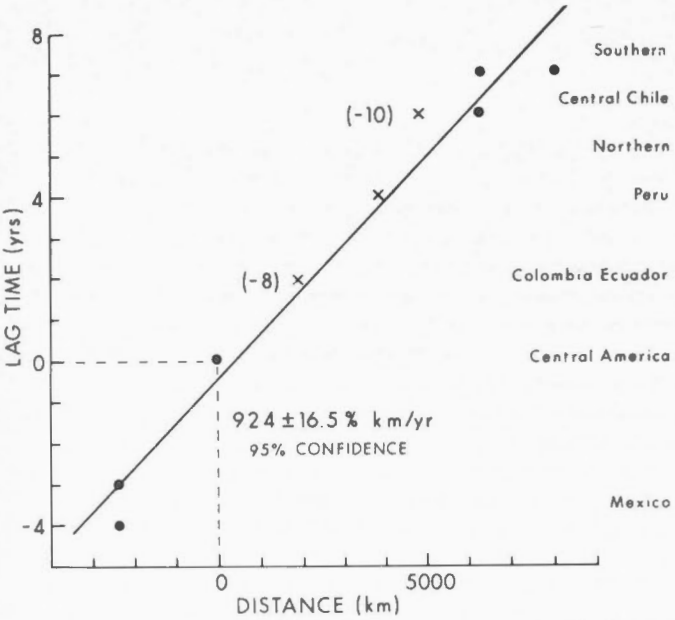

Figure 19. Time-distance plot for progression of epochs of volcanism in Latin America. After Berg and Sutton (1974).

to be three such sequences, and on the basis of these data Berg and Sutton (1974) constructed the time-distance plot shown in Fig. 19. Berg and Sutton (1974) also postulated that there is a probable correlation between the times at which two or more formerly dormant volcanoes in Central America become active and the occurrence of very large (M > 7.5) shallow depth earthquakes about 9.3 years later in southern Chile. As the lag time indicated for the progression of volcanic activity from Central America to southern Chile (see Fig. 19) is about 7 years, the indication is that these large earthquakes follow an increase in volcanism in southern Chile by about 2.3 years. However, this does not appear to be borne out by the data on volcanic activity in southern Chile which according to the table below suggest the events are contemporaneous.

Year of Increase in volcanism in Central America (2 ÷ activated volcanoes)	Year of large (M> 7.5) shallow earthquakes in Cent. & South. Chile	Latitude of EQ. occurrence	Time Lag in years for EQ.	Renewal volcanism S. Chile	EQ Time Lat.
1902	1906 (M 8.6)	34°	4	1906	0
1914	1922 (M 8.4)	28.5°	8	1920	2
1919-20	1928 (M 8.3)	35°	8-9	1929	−1
1930-31	1939 (M 8.3)	30.8°	8-9	1941	−3
1939	1943 (M 8.3)	30.8°	4	1941	2
1952	1960 (M 8.3)	39.5°	8	1960	0
1961	1971 (M 7.5)	33°	10		
			Avg. 9.3		Avg. 0

Although the above would suggest that an increase in volcanic activity coincides with the occurrence of large earthquakes, and it does appear to hold for the volcanic province of central and southern Chile, this is not the general case.

In Fig. 20 five sets of graphs are presented showing, for the period (1900-1965), the number of active volcanoes and the number of large (M > 7) earthquakes for all depths of occurrence associated with each of the volcanic belts in Latin America except the Lesser Antilles region.

The earthquake data are thus restricted to the areas characterized by volcanism. Although most volcanoes occur where the depth of seismicity is from 100 to 150 km, shallow and deep focus earthquakes are also included since large earthquakes (M > 7) might well play a role in triggering volcanism. To check this the large intermediate depth earthquakes are differentiated from the others in Fig. 20.

Several things appear worthy of note in Fig. 20: (a) the pattern of increased volcanism occurs in three distinct epochs in each area except Mexico where only two epochs are indicated, (b) the three epochs of increased volcanic activity in Central America, designated A, B and C, do not all carry through as a systematic time sequence in each area of volcanic activity: — "A" is missing in Mexico, "B" occurs late in the Peru-northern Chile area and "C" occurs early in the Colombia-Ecuador area and (c) the progression rate of epochs of volcanic activity between Central America and southern Chile are not as regular as indicated by Fig. 19: — epoch "A" took about 4 years, epoch "B" took 7 years and epoch "C" took 6 years. The periods between epochs vary from about 18 years to 22 years between "A" and "B" and from about 31 to 33 years between "B" and "C" if the anomalous relations in the Colombia-Ecuador and Peru-northern Chile areas are disregarded.

If the earthquake data are considered in conjunction with the volcanic data, it is seen that in Mexico periods of abnormal occurrence of large earthquakes preceded the epochs of volcanic activity, and that, at the times of maximum volcanic activity, there were no large earthquakes. The data suggests, in fact, an inverse relationship between the occurrence of large earthquakes and volcanic activity. An even more striking inverse relationship appears to exist between the seismic pattern in Mexico and volcanic activity in Central America. This is not evident in the earthquake data for Central America although there appear to be local peaks in the number of large earthquakes preceding the epochs of volcanism. That the Central American earthquake data show a pattern of more or less continuous large earthquakes is

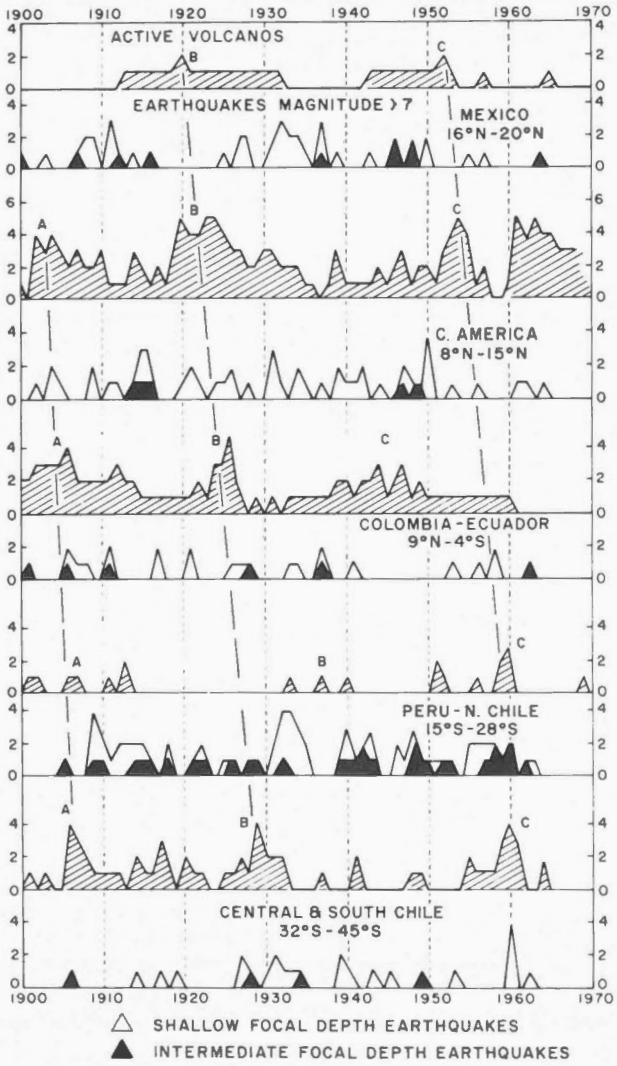

Figure 20. Plots of epochs of volcanism and the occurrence of large (M>7) earthquakes in Latin America.

probably a result of both oceanic plate crustal subduction and strike slip faulting causing earthquakes in this area. As a result, there are no apparent periods of stress build up and release, and although the apparent inverse correlation between volcanism in Central America and stress release pattern in Mexico through large earthquakes could be fortuitous, the duplication in assymetry of pattern for the two phenomena in the two areas having the same locus of subduction (the Middle America Trench), suggests it is real.

In the Colombia-Ecuador area there is a peak in the number of large earthquakes preceding both volcanic epochs "B" and "C" and the suggestion of an inverse relationship between volcanic activity and the occurrence of large earthquakes.

In the Peru-northern Chile area relations are confused with a suggestion of large earthquakes preceding epochs of increased volcanism and a fairly definite indication of contemporaneous occurrence of large earthquakes with increased volcanism.

In the central Chile-southern Chile sector relations are similarly confused with a suggestion of an increase in the number of large earthquakes in association with increase in volcanic activity for both epochs "B" and "C", but not epoch "A".

In summary, the above observations on a changing relationship between periods of volcanism and occurrence of large earthquakes suggest that there are two converging north to south time sequences for large earthquakes and increased volcanic activity. However, this is not too evident in the plots of the data. That large intermediate depth earthquakes are a precursor of increased volcanic activity is evident in both Mexico and Central America, but this does not appear to always hold for the other areas.

Because there are no volcanoes in the areas where the dip of the Benioff plane changes to near zero inclination at a depth of about 200 km (sections D, E, and J of Fig. 8) or seismicity ends at the same shallow depth adjacent to such an area (section C of Fig. 8), volcanism appears to be related to the subduction pattern and depth of the asthenosphere or overlying depth of partial melting. The volcanism in southern Chile where the depth of seismicity does not exceed about 150 km (see sections K and L of Fig. 8) would suggest that the asthenosphere and depth of partial melting in this area is much nearer the surface than further north. This could be a consequence of the Chile Ridge being subducted beneath the continent, an event which apparently resulted in widely scattered basaltic volcanic centres in southern Patagonia and Tierra del Fuego in late Cenozoic time. One final observation is that there are gaps in seismicity at depth either below or almost below points of volcanism. These gaps suggest magma reservoirs or markedly lower values of Q. Seismic studies at and adjacent to major volcanoes, such as are now being conducted in Central America by the University of Texas in collaboration with Latin American colleagues, should soon shed some light on this relationship.

Gravity investigations in Latin America

The study of gravity in Latin America got its start in what is now Ecuador during the French Academy expedition of 1735 to investigate whether the earth is flattened like a tomato or shaped like an egg. It was Pierre Bouguer on this expedition who noted with pendulum period observations that the mass of the Andes is somehow compensated, thus setting the stage for the later development of the concept of isostasy. Because of the importance of gravity in geodetic mapping, most Latin American countries have since developed an active gravity program as part of the national geodetic program. In the last few decades this work has been augmented by the use of gravity in the search for oil and gas. As a result gravity coverage on the whole is on a par with surface mapping and level line control regionally and potential areas of petroleum occurrence, in general, are well covered. Gravity anomaly maps as a result have been made for a number of countries in Latin America, and Draquicevic (1974) has published a regional Bouguer anomaly map covering all of South America. However, as the contour interval used for this map is 50 mgal (a consequence of scarcity of data for some areas and the very large Bouguer anomalies associated with the high Andes), Draquicevic's map only brings out clearly the gross change in Bouguer anomaly pattern, particularly in the Andean region. Under PAIGH sponsorship and support from the National Science Foundation a more detailed Bouguer anomaly map and a free air anomaly map encompassing all of Latin America are now being prepared and should be completed in about two years time. As now planned this map will include the offshore area to the edge of the continental shelf.

The prediction of gravity values

The prediction of gravity is based on the recognition of gravity domains (Woollard, 1969) in which there are consistent relationships of regional free air and Bouguer gravity anomaly values to regional elevation values. As shown by Woollard and Strange (1966) by using this relationship it is possible to extend knowledge of the regional gravity anomaly pattern into unsurveyed areas with a reliability of about 5 to 10 mgal. In the case of South America this has been done for both free air anomalies and Bouguer anomalies over the entire continent (Wilcox, this volume). One thing of particular note in the free air anomaly map presented by Wilcox which was prepared using both observed and predicted values and which has a contour interval of 10 mgals outside the Andean region, is the presence of a near continuous gravity minimum ranging from −20 to −75 mgal along the eastern flank of the Andes. As this is masked in the companion Bouguer anomaly map presented by Wilcox, it illustrates the importance of having free air anomaly maps as an alternative to isostatic anomaly maps for bringing out local and regional changes in geology. While this has been recognized for some time (see for example Woollard 1962, 1976) free air anomaly maps have not been prepared generally because of the large topographic effect incorporated in free air anomalies in areas of high topographic relief. On a regional basis this topographic effect can be effectively removed by working backwards from regional 1° x 1° Bouguer anomaly values and correcting for the regional 1° x 1° elevation values.

In the case of the free air anomaly minimum shown by Wilcox on the east side of the Andes, Baglietto and Cerrato (1970) have found from seismic work in this area that there is a 5 km deep trough in the crystalline "basement" surface. They also found marked negative free air anomalies in the same region on a gravity traverse across Argentina. Introcaso and Huerta (1972) similarly found marked negative free air anomalies on the east side of the Andes on the transcontinental gravity traverse they made somewhat north of that reported by Baglietto and Cerrato.

Free air anomaly values can thus bring out geologic changes much more clearly than do the Bouguer anomaly values where there is a steep Bouguer anomaly gradient, as on the flanks of mountain ranges and the borders of continental shelves. A good example of the latter is the study by Hayes (1966) of the Peru-Chile trench. They used free air anomaly values to show that the Peru-Chile Trench is a geologically continuous sub-surface to the tip of South America even though the trench as a sea floor feature disappears at about the latitude of Valdivia, Chile (40° S).

Although the interpretation of a gravity "high" or "low" will always be ambiguous until there are seismic measurements to define whether the gravity anomaly is a consequence of a density change or a change in rock surface configuration, gravity does pinpoint areas for further investigation. Also through the use of "residual" values determined by filtering out the regional effect or through the use of second derivative values, gravity can frequently bring out small structures that might be missed in seismic work.

Secular changes in gravity

Another application of gravity besides the above geological applications and its use in the study of deflections of the vertical and other applications in geodesy, is in the study of secular changes in mass. During the International Geophysical Year the writer set up a program of periodic gravity connections between McMurdo Station on bedrock at the edge of the Antarctic ice sheet and the South Pole station where the ice sheet is over 3,000 metres thick to determine whether the ice cap was shrinking or accreting. Repeat measurements of gravity connections in Mexico (Woollard and Monges, 1970) have indicated that the plateau of Mexico is rising regionally but that Mexico City itself locally is sinking. As brought out by Mazzini (this volume) it appears the Andean block has risen considerably in the period between 1944 and 1973 as indicated by a change ranging from 2.35 to 2.46 mgal at two stations in the crestal area of the Andes at about 33° south latitude. Transitory secular changes in gravity have also been observed in association with periods of volcanic activity due to crustal dilation preceding volcanism and crustal subsidence following it (Woollard, unpublished).

Gravity, therefore, can contribute to many types of investigation in Latin America and, although no mention was made of its applications in mining, other than as indirectly suggested through the study of geological changes, it has an additional role in down hole measurements. While this role has not been exploited, in Latin America, as far as the writer is aware, it has proved successful in defining mineralized areas at depth in other areas.

Although earth tides have been measured gravitationally in several places in Latin America, they are not discussed here because without considering the included ocean tide effect, which is difficult to evaluate, they can only serve as a correction to observed gravity values. One thing that should be mentioned is that a comparison of computed earth tide values using various methods with observed values in Mexico, Colorado and Alaska for periods of 2 to 6 months (Woollard *et al.* 1973) indicated that only the Longman (1959) equations gave good agreement with observed values at all three locations.

The magnetic program in Latin America

The magnetic program in Latin America, as elsewhere, has three components: (a) the observatory program of secular changes related to ionospheric changes which in general can be tied to sunspot activity (b) the field program of magnetic mapping for defining geological changes and (c) the program of studying paleomagnetic pole changes and reversals in magnetic polarity with time. In most countries there are one or more magnetic observatories which make significant contributions to the study of the world-wide long term secular change in the magnetic field associated with the earth. These observatories are also essential to each country in defining changes in magnetic declination since without this information old survey lines, boundary markers and property lines located magnetically cannot be relocated. The observatories also provide the short term diurnal changes necessary for correcting field measurements and define periods of magnetic storms when field measurements might be of questionable value. A good example of their value in interpreting field data was presented by Handschumacher (1976) in connection with purported magnetic lineations at sea on the Nazca plate off Peru. Handschumacher showed that the magnitude of the mapped lineations for the days involved could be matched almost exactly with the diurnal change recorded at Huancayo Observatory in Peru and therefore could not be interpreted as magnetic lineations related to seafloor spreading. This resolved a major discrepency between shipboard data and Project Magnetic airborne magnetic data taken on a fast flying aeroplane where the diurnal

effect was only obvious as a long wave length regional change in magnetic values.

Airborne magnetic as well as ground-based magnetic surveys have been carried out in most areas having a potential for petroleun occurrence and also on a local basis for some areas of mineral occurrence. However, there has not been the same degree of magnetic coverage in most countries as there has been with gravity observations. This is understandable as a few magnetic observatories, like seismic observatories, can satisfy most national needs. With time, however, it can be expected that the magnetic mapping program will be extended along with airborne electromagnetic mapping on a more systematic basis.

Paleomagnetic studies, while not widespread in Latin America, have been conducted at several universities, particularly at the University of Buenos Aires. These studies (Valencio, 1971) indicate that the South Pole in Ordovician time was located north and east of the present continent of South America at what is now about 12° north latitude 26° west longitude and that by Permian time had moved to about 60° south latitude with little change in longitude. Subsequently the polar path has gone through a couple of tight convolutions in reaching its present position.

One aspect of the observatory magnetic program alluded to in describing the regional geophysical setting found in South America is the determination of the electrical conductivity anomaly in the altiplano reported by Schumacher *et al.* (1966) and also described in more detail by Casaverde and Giesecke (1968). According to the latter authors this anomaly could be related to a high temperature perturbation that rises from a depth of about 240 metres on the east side of the Andes to a depth of the order of 60 km beneath the crestal area of the Andes. As shown in Figs. 6 and 7 the orientation of the axis of this anomaly is similar to the structural trend of the Andes in the vicinity of the Abacany flexure. This structure is centred in a zone of low Q values and located between two zones of high seismic energy release (Ocola, 1966).

Although not a part of the magnetic program, mention should also be made of magneto-telluric studies that are being carried out in Argentina. As far as the writer is aware no results have been reported.

The heat flow program in Latin America

Although heat flow measurements have been made in a number of places in Latin America, the heat flow values reported have not indicated any areas characterized by abnormal values except in volcanic regions. Even in Lake Titicaca, Peru, on the altiplano where both low Q values and the high conductivity anomaly suggest high temperature at relatively shallow depth, Sclater *et al.* (1970) found the average heat flow is only 1.32 μ cal/cm^2 sec which is slightly below the average value for continents. Similarly, Uyeda (personal communication), who measured heat flow in 20 mines in the Andean region and in some 35 widely distributed oil wells, found no indications of abnormal heat flow except in obvious geothermal areas. As the low heat flow values found in the altiplano can only be regarded as anomalous in the light of the other data, there has to be some reasonable explanation. However, in view of the somewhat subnormal seismic velocity for the basal crustal layer (6.6 km/sec) and the anomalous occurrence of 7.9 km/sec upper mantle material underlain by material of only 8.0 km/sec below 110 km as reported by James (1971), the explanation does not appear obvious.

Geochronology program in Latin America

Although geochronology properly comes under the heading of geology (bio-stratigraphic dating) or geochemistry (isotope dating), it is an essential part of understanding geological-geophysical relationships in any area. In Latin America as a result of the complex history of superimposed orogenies in both the exposed shield areas of Brazil and in the mountain systems of Mexico, Central America and the Andean region of South America, reliable dating is essential. It is noteworthy that many rock units originally regarded as being of Precambrian age have been definitely established to be of Paleozoic age and that intrusive bodies once thought to be of the same age are now being shown to have been emplaced at different periods over a long span in time. Although scientists from countries outside Latin America have contributed significantly to resolving geochronological problems in Latin America, much of the work is now being done in Latin America and geochronological laboratories using isotope methods now exist at five institutions in Brazil, four in Argentina, one in Chile, one in Venezuela and three in Mexico. The importance of this work cannot be overemphasized not only from a purely scientific but also from a mineral exploration standpoint.

Relations with reference to ore deposits

One of the first things noted by the early Spanish conquistadores was the great abundance of gold and silver held by the Aztecs in Mexico and the Incas in South America and it was these riches that led to the initial wave of European immigration to Latin America. The subsequent discovery of large copper deposits in the Andes and large iron deposits in the shield areas of Venezuela and Brazil have made Latin America an area of continuing geological interest. With the advent of plate tectonic theory it was only natural that it was soon advocated that plate tectonics could explain the apparent zoned occurrence of mineralization found in the Andes (see Fig. 21). This zonation from magmatic iron deposits at the coast; porphyry copper-molybdendum deposits further inland; zoned copper-zinc-lead-silver deposits and contact metasomatic deposits with iron, copper and zinc as well as hydrothermal deposits with gold and silver in the central Andean area; nickel-cobalt sulphide deposits and tin-tungsten-bismuth-silver deposits in the eastern cordillera area, is generally one of increasing temperature of formation. It strongly suggests there is a relation to the dip of the Benioff plane beneath the Andes and the depth of the subducted oceanic plate. As most of the metallic elements represented, particularly iron, manganese, copper, nickel and cobalt do occur in some abundance on the seafloor either in the sediments or as manganese nodules and the rarer minerals appear as trace elements both in the sediments and seawater, it can be argued that these elements were progressively distilled from the subducted oceanic material as temperatures increased with increasing depth of subduction and carried by rising solutions in association with igneous intrusions to be emplaced as ore deposits in the overlying crust. This concept has led Mitchell (1973), for example, to postulate that metallogenic belts are related to the dip of the Benioff plane. Dickinson and Hatherton (1967) more concretely have shown that there is a relationship between the potassium content of island arc andesites and the depth to the Benioff plane. Sawkins (1972) has shown that the occurrence of sulphide ore bodies can be related to areas of plate convergence. There are, however, a few problems that have to be resolved before the role of plate tec-

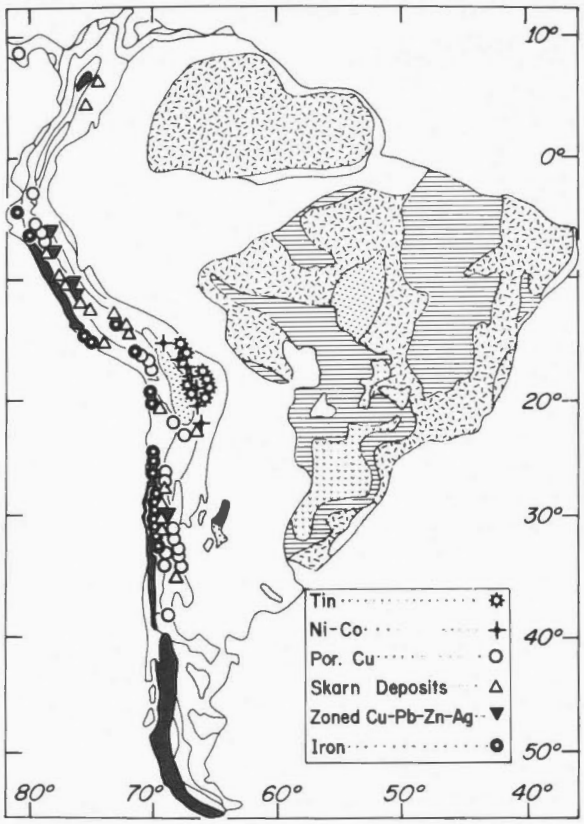

Figure 21. Areal plot of types of mineral deposits found in the Andean region having an igneous association.

tonics in metallogenesis can be regarded as being completely established.

(a) How can one differentiate oceanic sediments now being subducted as a source for mineralization from ancient geosynclinal sediments also of marine origin? (b) How can the subduction concept of thermal distillation be reconciled with the affinity of certain types of host rock lithology identified as having been of eugeosynclinal, miogeosynclinal, continental or volcanic origin? (c) How can the subduction concept be reconciled with the close relationship of many ore bodies to intrusive bodies and volcanic conduits evident in contact metasomatic deposits, zoned mineralization surrounding many intrusive bodies and the effect of erosion and exhumation on the distribution of mineralization apparent at the exposed surface? (d) How can the subduction concept be reconciled with the preferred occurrence of certain minerals in certain areas along strike and of the occurrence of the iron deposits on the eastern side of intrusive bodies in the Andes and the porphyry coppers on the western side?

To elaborate on item b above, Petersen (1970) has noted: (a) the porphyry coppers appear to occur predominantly where there are clastic and volcanic sediments and an absence of limestone, (b) the zoned copper-zinc-lead-silver deposits generally occur in association with evaporites, (c) the contact metasomatic deposits and lead-zinc deposits occur only where the host rock is predominantly limestone, (d) the Bolivian tin-tungsten-bismuth-silver deposits occur only in a limited area characterized by magnetite and graphite in the sediments and where there is an absence of extensive evaporites, (e) there is a general west to east change from eugeosynclinal to miogeosynclinal type sediments across the Andes with consequent change in type of sediment and host rock that is compatible with the observed zonation of mineral deposits.

With regard to the proximity relation to intrusive bodies, the evidence is confused and has several aspects. Two are of a mineralogical nature and the others spatial. Considering the mineralogical ones first, there is no consistent pattern of spatial relationships for plutons of different ages with somewhat differing mineralogical composition. In Colombia, where there are three belts of intrusives of, respectively, Jurassic, Cretaceous and Tertiary age, there is a west to east spatial pattern with the youngest nearest the coast. In Peru and Chile the spatial distribution is the reverse with the youngest intrusives occurring in the eastern cordillera. That the potassium content in the latter area increases from west to east is well established. Vergara (1972) and James (1971) have shown that the relation of potassium to depth of the Benioff plane for both andesitic volcanics and a pluton in Peru fit the empirical relations found by Dickinson and Hatherton (1967) for island arc andesites in general. However, Kausel and Lomnitz (1968) note volcanoes also occur where there is no Benioff zone.

The spatial relationship is compounded by there having been extensive block faulting at the time of Andean uplift with resulting major horsts and grabens. Subsequent erosion of the differentially uplifted horst blocks has resulted in different levels of exhumation of the batholithic bodies with consequent exposure of different types of mineralization.

Another spatial complication is the occurrence of transverse breaks in geological pattern which, as noted earlier, appear to control the distribution of Tertiary to present volcanism and the segregation of the volcanic belts into three distinct segments. There are similar changes in ore deposition along strike. The amount of crustal uplift can also be readily seen as a function of the height of the Andes. Sillitoe (1974) in studying the tectonic segmentation of the Andes and its relation to magmatism and metallogeny, in fact, has identified what he feels are at least twelve such transverse breaks. As several of these also appear in the pattern of seismicity, changes in the dip of the Benioff plane, the depth of seismicity associated with the Benioff plane, location of offshore seafloor ridges and fracture zones, they cannot be regarded as being purely superficial.

Fig. 22 represents an attempt to put most of this diverse information into perspective through a series of plots of the parameters mentioned as a function of latitude. Some slight distortions due to changes in Andean strike are not serious. From southern Chile up to the Arica elbow (50° to 18°S), where both the Peru-Chile Trench and the Andes have essentially a north-south strike, there is no displacement between Andean and trench events. From the Arica elbow to the intersection of the Nazca Ridge with the continental boundary (18° to 15°S) there is about a 3° northward displacement of Andean position from corresponding positions in the Peru-Chile Trench. From the Nazca Ridge to the Huancabama deflection area (15° to 5°S) Andean positions are displaced about 1.5° northward from corresponding trench positions. Across the Huancabama-Amotape zone (5° to 2° S) there is no displacement between trench and Andean positions. North of 2° S there is about a 1° southward displacement of Andean positions from corresponding positions in the Peru-Chile Trench.

The data shown are: (a) the change along strike in depth of seismicity south of 12° S for intermediate foci depth earthquakes, (b) the inclination of the Benioff plane and depth of seismicity

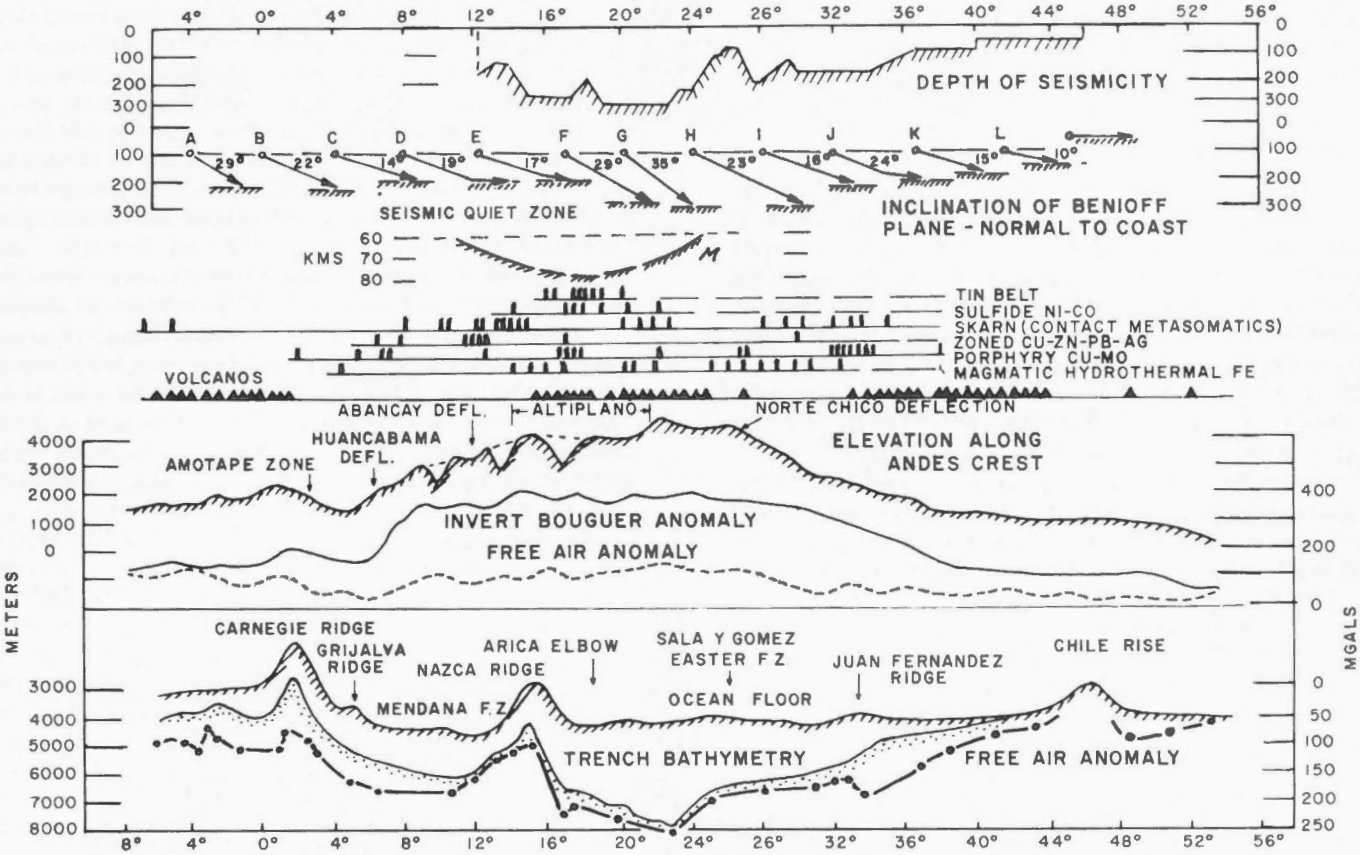

Figure 22. Along strike changes in various parameter values and ore deposition pattern in the Andes.

defined by intermediate foci depth earthquakes as averaged, in general, over 4° wide latitude bands, (c) the configuration of the base of the crust (M discontinuity) beneath the altiplano along its axis as reported by James (1971), (d) the latitudinal occurrence of different types of ore deposits having an apparent intrusive rock association, arranged to conform with the overall zonal pattern of occurrence — the iron deposits are near the coast and the tin deposits are in the eastern cordillera; this pattern also corresponds to the overall west to east change from eugeosynclinal sediments to miogeosynclinal sediments, (e) the location of the Cenozoic volcanic belts, (f) the average crestal elevation of the Andes based on 1° x 1° averaged values, as presented by Wilcox (this volume), (g) an inverted plot of averaged 1° x 1° Bouguer anomalies as presented by Wilcox (this volume), (h) the 1° x 1° free air anomaly values as presented by Wilcox (this volume), (i) the mean depth of the ocean floor adjacent to the Peru trench based on 1° x 1° averaged values, (j) the depth of the Peru-Chile trench along its axis, (k) the free air anomaly values observed over the axis of the Peru-Chile trench by Hayes (1966) and (1) unpublished information from various sources.

As the primary objective of Fig. 22 is to establish whether there are basic relationships between ore deposition in the Andes and geophysical-geological parameters having a relationship to plate tectonics, the first thing to note is that the ore deposits fall into three groups along strike. The first occurs as a diagonal swath extending inland from the coast trending west to east from 4° to 8° S. The second area could be a composite as the northern and southern boundaries of this region have different across strike trends. The northern boundary diverges east and west from a central point at about 10° S. The southern boundary trends more or less directly across strike at about 23° S. The third zone starts at the coast at about 25° S and its boundaries define a parallelogram due to a progressive eastward migration of ore deposition across strike from 26° to 35° S.

That the above along strike pattern of mineralization suggested in Fig. 22 is somewhat misleading due to changes in strike of the Andes and west to east and east to west shifts in mineralization, is brought out in Fig. 21 which shows the areal pattern of occurrence.

In Fig. 21 the Nazca Ridge — Abancay deflection alignment is clearly seen as a significant break in pattern both in terms of the kind of mineralization and the start of an eastern zone of mineralization. Another break appears to be associated with the northern boundary of the altiplano central valley and the appearance of nickel-cobalt deposits in the eastern belt and porphyry copper-molybdenum deposits in the western belt. Another important break appears to be associated with the southern terminus of the eastern belt at about 23° S.

If we now look at Fig. 22 with the data of Fig. 21 in mind, the first striking feature is the absence of major ore deposits in Colombia. The structural break evident in the change in geologic strike from north-northeast to south-southeast in the Amotape zone centred on the Gulf of Guayaquil with all geologic trends locally striking east-west is of more than superficial significance since it also correlates with the southern terminus of the Colombia-Ecuador ophiolite and volcanic belts and a sag in the

crestal elevation profile of the Andes. Furthermore the lack of mineralization cannot be attributed to a lack of intrusions since three epochs of batholithic intrusion are represented in Colombia with significantly different levels of exhumation by erosion. Yet the only significant mineralization is gold-silver skarn (metasomatic) deposits between 5° and 7° N. From a geophysical standpoint there is nothing abnormal in the dip of the Benioff plane or the depth of seismicity in this area other than a suggestion that two active subducted plates are present in Colombia (see section A of Fig. 8). The most marked geophysical anomaly is the gravity high (see free air anomaly profile) which can be related to diapiric obduction leading to the emplacement of the ophiolites, as seen in the seismic crustal sections shown in Fig. 11. Although geologically the northwest corner of Colombia has been postulated to be a part of the Caribbean plate (Dewey, 1972) and gravity data suggest the original Peru-Chile trench now swings inland at about Buenaventura, these relations should not rule out mineralization. There are also extensive evaporite deposits mined for salt which should have been a favourable environment for zoned copper-zinc-lead-silver deposits which are conspicuous by their absence.

If we examine the next area, that from the Amotape Zone (2° S) to the Nazca Ridge-Abancay deflection line (12° S), all of the deposits occur in association with the coastal batholith and, except for the one iron deposit, are located on the east flank of the batholith in association with pre-uplift andesitic volcanic deposits and Jurassic-Cretaceous sediments. In this area the dip of the Benioff plane is low (about 17°) and the depth of seismicity shallow (≲200 km) with indications that at this level the subducted plate is travelling horizontally, presumably at the base of the continental plate. If this is the case, the continental plate cannot be more than about 100 to 130 km thick depending on the thickness assumed for the subducted plate. There is an associated pattern of progressive uplift of the Andes to the south, a significant break in the Bouguer anomaly profile at about 7° S suggesting a marked increase in thickness of the lithospheric plate or significant decrease in mean density, and a gradual, but significant, deepening of the Peru-Chile trench. As the relation of gravity values to trench depth changes dramatically at about 10° S (location of the Mendana fracture zone), indicating an increase in density which is maintained to about 33° S (the Juan Fernandez Ridge), there is an indication that the oceanic crust being subducted is different between these points. If reference is made to Fig. 1 it is seen that between the Mendana and Challenger fracture zones (10° to 32° S in the trench) there is significantly older oceanic crust being subducted as indicated by the displacement pattern for magnetic lineation 7. The indications of the trench data on gravity-depth relations are therefore corroborated by the offshore magnetic lineation data, and as seen, there is a corresponding break at essentially the same boundaries indicated in the relation of Bouguer anomaly values to surface elevation values along the crest of the Andes.

In terms of changes in surface geology and mineralization in the central area, the subduction of the Nazca Ridge appears to have marked significance. Not only is there an associated flexure in the Andean system and the coast line, but a widening of the orogen, an abrupt termination of the coastal batholith, uplift of the coastal area so that Precambrian rocks characterize the coastal zone and either a widening of the mineralized zone now divided by a graben to give two mineralized belts or the formation of two separate belts. This pattern persists for the most part to about 23° S where there is an abrupt change in depth and that of the Peru-Chile trench reaches its maximum. This point corresponds to that for maximum regional uplift of the Andes, the southern termination of the altiplano and the end of the east and west belts of mineralization. It is within these bounds that the nickel-cobalt-sulfide deposits and tin deposits occur in the eastern Andes, the Moho reaches its greatest depth, the dip on the Benioff plane is steepest (35°) and the depth of seismicity for intermediate focal depth earthquakes is greatest (300 km). This area is also a zone of low Q values and an electrical conductivity anomaly occurs at about the same depth as the Moho beneath the altiplano.

It is also seen that the pattern of changes in depth of seismicity along strike is conformable to that for change in Moho depth although displaced slightly from it and that the area of deep Moho values ($H > 60$ km) is centred over the area of greatest mineralization and, in particular, over the area of the tin and nickel-cobalt deposits where the seismic crustal measurements were made.

Of all the geophysical associations noted, the most dramatic is that for the change in depth of seismicity at 26° S which is clearly associated with a change in pattern of mineral occurrence. As seen from Fig. 21 the new pattern that emerges south of 26° S is one of a single belt of mineralization in which iron deposits predominate. It is a zone where the Benioff plane has low angles of dip with an indication of the subducted plate moving essentially horizontally and with the depth of seismicity for intermediate foci depth earthquakes being about 200 km. This zone is also one of rapid decrease in crestal elevation in the Andes with the relationship of elevation to Bouguer anomaly indicating a change in lithospheric density. This change stabilizes at 30° S where the pattern of mineralization changes to give a two-belt pattern of porphyry copper deposits offset significantly from the coastal belt of iron deposits. This last pattern of mineralization ends at about 34° S, where the southern Chile volcanic belt starts, the depth of seismicity for intermediate foci depth earthquakes shallows rapidly and the dip of the Benioff plane progressively decreases from 24° to 10° to ultimately 0°. The southern boundary of mineralization also corresponds to a marked change in depth of the Peru-Chile trench, axial free air anomaly values as noted earlier and the location of the Juan Fernandez ridge. Except for one porphyry copper deposit at 38° S, on the apparent fault boundary terminating the coastal batholith, there is no evidence for mineralization at points further south. This cannot be attributed to a lack of batholithic intrusion as a large batholith extends all the way to Cape Horn. It could be that uplift south of the apparent transverse fault boundary at 38° S, which brings Precambrian rocks to the surface at the coast, resulted in the removal by erosion of former mineralization. However, as this fault boundary also marks another change in the relationship between surface elevation and Bouguer anomaly values suggesting a change in lithospheric density, there could be a change in mineral genesis as appears to occur under similar conditions in Ecuador at the Amotape zone.

All of the above "coincidences", shown in Fig. 22, between changes in mineralization pattern and geophysical parameter values as well as associated changes in geology with apparent counterpart changes, in most cases, with the configuration of the Peru-Chile trench, strongly suggest that plate tectonics does play a real role in defining the occurrence of ore deposits in the Andes. This does not negate in any way the importance of the chemistry of the host rock, the proximity to an intrusive body or the role of

erosion. These geological factors are important, but they only represent one facet of a complex set of relations that, although clearly related to ocean plate subduction, have yet to be investigated in adequate detail. Certainly the cursory study presented here can only be regarded as a first step in laying the foundation for further work and in particular the type of studies recently reported by Rodriguez *et al.* (1976) and March (1976) related to magmatism and ore genesis in the context of plate tectonics.

The main value of the writefs study, which represents only one aspect of the Andean Geophysical Program adopted in Buenos Aires and further amplified under the International Geodynamics Program, is that it does point out the value of having a cooperative multidisciplinary research effort. A hopeful sign for the future is that cooperative research is becoming increasingly common throughout Latin America. This can only result in significant advances in knowledge in earth science since most of the significant problems in earth science are represented in the Latin American area.

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Mr. M. R. Dence:

Thank you Prof. Woollard for your interesting presentation. Our next speaker is Dr. C. Lomnitz who will present a paper entitled **"Education in Geophysics in Latin America".**

Dr. C. Lomnitz:

Me cabe la difícil tarea de hablarles del problema educativo en Geofísica en América Latina, y digo que es difícil no solamente por el tema sino también por el hecho de que el Dr. Kausel ya prácticamente ha dicho gran parte de lo que yo iba a expresar y además el resto es en gran parte conocido, por lo menos de mis colegas latinoamericanos, por lo tanto y especialmente en deferencia a nuestros anfitriones canadienses, me voy a permitir presentar este trabajo en inglés:

I should like to preface these personal remarks by stating that the viewpoint I am going to expose is exclusively my own. It does not represent anything or anybody else.

In order to understand the plight of education in the earth sciences in Latin America today, we should probably go back to the Corbeda movement of 1918 which as you will remember was probably the first large scale student movement in the western hemisphere. The grievances of the Corbeda students were many but here I shall stress only one. Namely, the demand for more national and social relevance of the university curricula. This was a protest against the prevailing tendency of Latin American universities of the time to turn out only lawyers, doctors and engineers and to insist upon professional standards at the expense of academic breadth and depth. When it was the turn of the Corbeda generation to reach positions of power in the universities and in government, they attempted to practice what they had preached earlier. As a result, university instruction was largely wrenched from the control of the educated fringe of the upper classes and was turned into a major instrument of upward social mobility in Latin America.

This was the time of the ascent to power of the middle classes in many countries of Latin America, as typified for example by the Chilean constitution of 1925. In Mexico the revolutionary government asked Vasconcellos to re-open the old university to a new orientation which would be clearly populistic, nationalistic and Latin Americanistic. Thus, Vasconcellos designed a new school emblem which features the map of Latin America flanked by an eagle and a condor with the motto "Through my race shall the spirits speak". Other national universities in Argentina, Columbia, Chile, Brazil, Cuba, Peru and so on also began centres of propaganda for a national awakening as well as instruments of social mobility for the middle class. The importance of the universities can be gathered from the fact that a majority of the leaders in business, sciences, the arts and politics are and were alumnae of these universities. The national universities championed economic development and established the first scientific research institute. They sponsored art shows, symphony orchestras, writers, workshops, drama groups, academies and political debates.

As they became more and more powerful and influential the national universities attracted the attention of political groups particularly of the opposition. During the middle 1930's probably the first group to realize the importance of these universities was the Nazis. I remember well the Nazi plot of 4 September, 1938 when Chilean students led by Gonzales Jeanmarie tried to stage an armed uprising against President Alexandre Senior. The students eventually surrendered and were executed on the spot. Several of their photographs still hang on the walls of the Common Room at the School of Engineering.

Later other groups such as the Stalinists, CIA and so on moved in and the National Universities have increasingly become a field of hot and bitter contests between rival political forces.

Today students and teachers in national universities tend to rally around opposition causes, mostly, but not necessarily, left wing. For example during the Allende years in Chile much of the right wing opposition came from the national university. Gradually these universities have ceased to be regarded by government as instruments of national policy and modernization and have become more of a nuisance than an ally. Their public support has dwindled in some countries while in others they have been co-opted to condition carefully public support. At the same time private universities have arisen which benefited from an increasing share of public funding. In several countries including Mexico the top levels of the political and economic leadership are increasingly being recruited from these semi-private schools. Business administrators, economists, social engineers make up the new breed of Latin American administrators. Old national universities like San Marcos, the central university of Venezuela, the University of Mexico and others have been losing some

ground to the schools like the Universidad de Lima, Universidad de Los Aires, Colegio de Mexico, Universidad Iberoamericana and so on. This new trend is important to remember because the private schools on the whole make little attempt at providing strong science departments since they are more or less clearly oriented towards administrative and professional careers.

Where does that leave education in the earth sciences? Most Latin American leaders are aware that the earth sciences are strategic to economic development. In 1938 when President Cardenas nationalized petroleum, Mexico was the second world producer of oil yet there were only 5 Mexican petroleum engineers in the country. This was recognized as a major handicap but attempts to overcome it have been only partly successful. Latin America as a whole still depends substantially on foreign science and technology in the field of natural resources. More critically no strong local tradition in the earth sciences has developed. In Mexico for example there are important research groups in physics, biology, engineering, mathematics and computer science but no groups of comparable strength have yet developed in the earth sciences.

The Institute of Physics in my university has 20 full professors at the top level of the academic scale and every opening at any level is heatedly disputed by at least 3 or 4 young Ph.D's with an enviable curriculum of international publications. Yet in the Institute of Geophysics we have 5 Ph.D's altogether for all the solid earth, ocean and atmospheric sciences. Things are not noticeably better elsewhere. All the talk about scientific self-reliance and substitution of foreign technology is probably sincere, but as long as no effort is made to develop a strong base in the earth sciences it hardly can be taken seriously.

Where, and how can such a base be developed? Geophysics in much of Latin America was born during the International Geophysical Year through the agency of an American mid-wife. American pioneers of Latin American geophysics such as Merle Tuve were more or less oblivious to the history and evolution of Latin American universities and sometimes even scorned the advances of national universities in the area instead of cooperating with them in the establishment of long term institutional projects. Their contributions have often been spotty and erratic and the local scientific production which grew out of these contexts has been disappointingly small. I think a new departure in the earth sciences inLatin America is badly needed. The stimulus for the establishment of strong self-reliant research groups must come from within. We can no longer afford to depend on foreign consultants and foreign technology for the development of our national resources, our power projects and the solution of our pressing ecological problems. New approaches are now being considered in several countries and the results will depend on the consistency and seriousness with which they are implemented and pursued. As an example of a new development which may point the way towards the creation of autonomous research groups, I will discuss briefly the history of the RESMAC project in Mexico.

The need for improving the determination of earthquake risk in Mexico became acute during the Echeverría administration because of the implementation of large hydro and nuclear power projects in areas of the country where the seismicity was largely unknown. At the same time it was recognized that Mexico had a state-owned system of microwave communications which might provide channels for telemetering seismic data. This put us at an advantage over countries like the United States where a comparable service of the same extent would be prohibited on account of private ownership of the communications network. Thus we advocated a nation-wide telemetry system which would be unique in size and purpose and we suggested that Mexico could generate the basic design as well as the specific technology.

RESMAC was born under the auspices of the new National Research Council as a strictly national project. No outside funding was sought and the circuits were developed in the University of Mexico by an interdisciplinary group gathered in the Computer Science Institute. Four government departments shared in the funding. The enthusiasm and the professional competence generated by the project have been highly gratifying. At first we sought the professional assistance of U.S. consultants but it was soon realized that they had little to offer in the way of advice. This greatly bolstered our self-confidence and we now feel we are working with state-of-the art concepts at a level of scientific parity with similar groups elsewhere. In other words, we are not merely talking the same language but we are talking on the same level.

The experience gathered in the RESMAC project is paying off in a number of ways. First, digital technology has many strategic uses in the Mexican economy and the RESMAC team now feels confident that it now can tackle a wide range of practical problems. Second, the RESMAC concept is attractive to other Latin American nations such as Venezuela where conditions and opportunities are similar. This opens new perspectives of scientific and technological cooperation within the Latin American area. Thirdly, the individuals who participated in the RESMAC project have discovered a new relevance of research and development to personal as well as national aims. The frustration of doing second-rate work on projects pioneered by foreign scientists is gone. We have learned to manage and plan our own projects and to tackle the numerous complex problems which arise when trying to generate new science and technology. Problems which we used to read about but had never actually faced.

In conclusion, I would suggest that two advances in education in the earth sciences, as in other sciences, can only be generated by self-reliant groups who know how to do science. Nothing succeeds like success. We must learn to detect and take advantage of local conditions and to face them realistically. This often implies the need to generate technology at the most advanced levels because paradoxically the problems of underdevelopment often cannot be solved except by very sophisticated means. Standard approaches transplanted from the industrialized world fail all too often to operate in the Latin American environment. We are learning the hard way that there is no substitute for independent thinking and action when it comes to doing science in Latin America.

The petroleum corporations of Mexico and Brazil, Pamex and Petrobras, are 2 of the 50 largest corporations in the world excluding the United States. These and other Latin American oil corporations have their own training programs for their technical personnel. Teaching programs in geological engineering have existed in Mexico since about 1940 but teaching exploration geophysics is much less developed in the universities. There are specific careers in exploration geophysics in several Latin American countries today. I am afraid that no exact figures on the number of students in geophysical teaching programs are available. The newly founded Latin American Geophysical Association of which I happen to be President is compiling a survey of teaching activities in our area. However, we can safely say that the total amount of educational work now being done in the region is inadequate.

What can be done? In the first place we suffer from a communication gap between the universities and the exploration programs which are increasingly being sponsored by government and government-owned corporations. This communications gap is not visibly closing. It is therefore urgent to work through the National Research Council such as Conacyt in Mexico in order to provide specific mechanisms of contact and perhaps of contract between the corporations in charge of natural resources and the universities. I see this as a major challenge to the academic community within the next few years.

Second, we in the academic world need to give some thought to the teaching approach which should optimally prevail in geophysics. Where should geophysics be taught? In many countries these studies have sprung up in the Engineering Departments or in the Departments of Geology. I feel that this approach is historically justified but is not necessarily the best one. In my opinion an effort should be made to institute geophysics programs within the Departments of Physics. In Mexico we have attempted this solution with considerable difficulty chiefly because our physicists are not interested in classical physics and have little use for the applied fields. Nevertheless, I believe we should keep on trying and we should bring more pressure to bear on the Physics Departments to incorporate applied fields. In effect we are thus serving the future of physics in Latin America by opening the field to subjects of greater relevance to economic development such as geophysics.

We have a job to do, both within and beyond our institutions. Let us get going and let us move on. Thank you.

Mr. M. R. Dence:

Thank you very much Dr. Lomnitz. Our next speaker is Mr. P. Tanguay who will describe **"CIDA activities in Latin America".**

Mr. P. Tanguay:

First of all I want to thank the organizers of this Symposium for having included development, a perspective which in highly specialized symposiums or seminars is sometimes forgotten.

As you probably know, the Canadian International Development Agency, CIDA, is the Canadian government agency responsible for the administration of the Canadian Aid Program in Asia, in Africa, in the Caribbean and in South America. We work closely with all Canadian government departments, each department bringing its own competence and expertise to give to Canada's Aid Program the quality it requires.

This symposium deals with the economic and social role of geophysics in society with focus on Latin America. This obviously is a basic activity towards an answer to the basic question of development — that of resources. Is this planet big enough to give to all men the food and resources to keep mankind growing in number and in an improved environment with better living conditions? Obviously research is one of the basic elements in the approach to development. With this background in mind I will give a general view of CIDA's activity with emphasis on Latin America where appropriate.

CIDA is not just an operating agency (although it is part of the Department of External Affairs), but it also participates in the discussion of the overall Canadian preoccupation with the world's underdeveloped regions and focuses the government's and hence the Canadian public's attention on one specific dimension: that of the integration of underprivileged areas into the mainstream of world activities. In order to achieve better harmony, balance and equilibrium in Canada's overall relations with the rest of the world Canada must give adequate attention and assistance to those sectors of the world that are in greater need. I have a booklet entitled "Strategy for International Development Cooperation 75-80" which spells out the orientations and guidelines of the Canadian government's development cooperation program for the next five years. The booklet is in English, and French, but there are a few copies available in Spanish. You will find in this book the Canadian philosophy and approach to international development cooperation.

Canada is putting close to one billion dollars per year in development cooperation. It has some one thousand or more experts working in different countries of Africa, Asia, Latin America and the Caribbean and probably twice as many trainees coming from these countries to seek here in Canada the training they need to give continuity to their own development programs. The distribution of the CIDA funds is approximately 50% to Asia, 38% to Africa, 4% to the Caribbean and 8% to Latin America. In all, some 65 countries are involved in the aid program with priority given to the following sectors: agriculture, public utilities, transport and communication, financial institutions, public administration, health and population.

CIDA aid is commonly worked out on a bilateral basis with countries which are listed as among the poorest in the world according to the United Nations or to the World Bank listing. This creates special problems for Latin America since there is one country, Haiti, that is listed as among the poorest in the world. Despite this difficulty we have managed to work out aid programs with Peru, Colombia, Cuba, Costa Rica, Nicaragua, Brazil, Bolivia, El Salvador, Honduras, Ecuador and Guatemala, in addition to Haiti. It may be of interest to this group of geophysicists that the cooperative program with Guatemala was negotiated recently as a result of the major earthquake which occurred there in 1976. Projects with other countries are being negotiated and we hope to conclude agreements with them shortly.

This bilateral program for which I am responsible started in Latin America in 1970. The volume and intensity of activities has varied from country to country, but the greatest activity has taken place in the poorest countries of Latin America. To give you an idea of the level of funding of the bilateral aid program in Latin America the budget has risen from about eight million dollars in 1970-71 to about twenty-five million dollars in 1976-77.

For me the interesting aspect of all bilateral programs in Latin America has been the emphasis given to projects of a research nature which involve skills available in Canada that are needed in developing countries. This has and will involve a gradual change in Canada's approach to international cooperation, where historically, priority has been given to the poorest countries of the world. Consequently, many of the activities in Latin America have been in the nature of pilot projects which will be used as a basis for developing more extensive programs.

Not all of Canada's international cooperation is carried out in Latin America through the bilateral program. In addition there are the multilateral and special programs. If we take these into account the level of activity in Latin America rises to about 60 million dollars a year. All cooperation considered we now have

some 95 projects operational in Latin America and 53 projects in the planning stage. By far the greatest proposition of these are taking place in the field of agriculture where there are some 50 projects. Other sectors include education (25), health (15), social infrastructure (3) and transport (3).

In concluding this English language portion of my talk I would like to leave you with the understanding that we are changing our approach to international cooperation in Latin America. While still maintaining a general priority for the poorest countries we will not abandon our interest in countries who are at the "take off" stage, and who are still interested in maintaining cooperation on a bilateral basis.

La CIDA, por ejemplo, está interesada, no solamente en proporcionar plata a proyectos o a organizaciones o instituciones Latino Americanas, pero también en entrar en las preocupaciones, la filosofía del desarrollo en América Latina. Y ésto es muy importante, porque en la política externa de Canadá, según la expresión del Primer Ministro, "the third option", es que Canadá no puede más ignorar sus vecinos más cercanos, no solamente en una relación de independencia de estos países, pero de verdadera cooperación, y es en este sentido que ahora estamos reexaminando el programa de cooperación de Canadá con América Latina. Nuevas formas de cooperación. Y hemos iniciado, por ejemplo, con el Pacto Andino, un tipo de cooperación que no se sitúa directamente en las formas tradicionales de "Aid to development", ayuda al desarrollo, y esta filosofía tiene como base la mutualidad, se dice, de interés. Por ejemplo, qué formas podría tomar la cooperación industrial entre países de América Latina y Canadá. Qué formas específicas podría tomar la cooperación cientifica y tecnológica, la cooperación a la integración regional, la cooperación comercial; y en junio de este año hemos invitado a esta ciudad a unos veinte latinoamericanos para discutir con nosotros nuevas formas de cooperación basadas en una filosofía de mutualidad de intereses.

Varias sugerencias han salido de esta reunión, por ejemplo, la cooperación de Canadá en la formación de centros de exportaciones de productos latinoamericanos a Canadá. Otro ejemplo: la formación aquí, en Canadá, de un Centro Latinoamericano de Exportación. Una Banca, un grupo de especialistas canadienses que podrían ser llamados por industrias, por el comercio latinoamericano para aprender más sobre las exigencias canadienses, productos agrícolas, productos industrializados. La como se dice, the matching de instituciones de investigación aplicadas al desarrollo, el intercambio de especialistas en la Administración Pública, la Fiscalidad, la Explotación Forestal, de la Pesca, sectores en los cuales nosotros tenemos, yo creo, una competencia determinada muy calificada.

Yo creo que es la primera vez que en público se comunican estas preocupaciones, o este modo nuevo para nosotros de considerar el "approach" al desarrollo como un proceso integrado y en el cual los dos interlocutores se hablan francamente en términos de interés, de compatibilidad de intereses, de compatibilidad científica, de intercambio y este tipo de cooperación puede llegar, por ejemplo, a proyectos de este tipo. Colombia, Perú, Venezuela, Brasil, otro país que tiene competencia en un campo determinado, se une en un proyecto común para ayudar a un tercer país más pobre, por ejemplo, Haití, Honduras. La competencia de América Latina en la agricultura tropical podría ser un campo de cooperación tripartita.

El campo de ustedes es también un campo abierto a este tipo de cooperación y yo creo que con sugerencias de varios sectores que todos trabajen al desarrollo, podremos llegar a un programa muy interesante, muy inovador, original, de cooperación internacional.

Discussion

Prof. S. Radicella:

Creo poder interpretar lo que deben pensar otros colegas latinoamericanos aquí presentes. Personalmente estoy vinculado a estas actividades científicas desde hace veinte años y tengo estrecho contacto con lo que en algún momento nosotros llamamos "los países centrales". Sin embargo creo que es la primera vez en los veinte años que tengo de investigación cientifica, que escucho hablar a un representante de un Gobierno de un país razonablemente central, en los términos en que lo ha hecho usted.

Creo que son muy importantes muchas de las cosas que usted ha manifestado y hay un aspecto que quisiera recalcar aún más, es el de ir descubriendo nuevas formas de cooperación científica como base del desarrollo tecnológico y como base del desarrollo económico social.

Uno de los problemas que nosotros enfrentamos siempre, en nuestros países, es que el parámetro, o digamos el metro con el cual se mide nuestro desarrollo tecnológico, nuestro desarrollo científico, es el mismo metro con el que se mide el desarrollo científico en los países centrales.

Entonces, es inevitable que muchas veces nuestros proyectos no sean de interés, digamos así, para los países centrales. Por qué? Porque no se ha encontrado una forma de diálogo, un idioma común, con el cual poder conversar sobre este tipo de problema.

Cuando nosotros tenemos que elevar un curriculum del investigador principal de un proyecto, a un eventual subvencionador externo, nos encontramos con que el curriculum de nuestro investigador no contempla 20, 30 ó 40 publicaciones, sino trabajo de campo, y el trabajo de campo muchas veces no es considerado un antecedente suficiente.

Si se trata de encontrar nuevas formas de interacción científica (yo prefiero denominarla interacción antes que cooperacion científica), tenemos que tener bien en mente cuales son las realidades científicas y de formacion de cada uno de los países. Muchas veces yo me he encontrado con científicos de muy buena calidad en nuestros países que no responden a los niveles medios exigidos en los países centrales, pero que son de mucho valor. Entonces, en la búsqueda de formas de interacción, el idioma nuevo al cual creo que se refería usted, es sumamente importante, y creo que este puede ser realmente de mutuo beneficio.

Mr. P. Tanguay:

To be very honest I mentioned very nice ideas, but we are in a process of finding specific and concrete ways of realizing this.

Ing. R. Salgueiro:

Yo desearía referirme al aspecto educativo que usted mencionó, a la inversión que hace el programa CIDA en este importante rubro. Probablemente es en el campo de

ciencias de la tierra donde existe una deficiencia única en la enseñanza, particularmente de especialistas para determinados países, por ello sería importante que este rubro sea considerado dentro de los proyectos que tienen en estudio. Gracias.

Mr. M. R. Dence:

Thank you very much Mr. Tanguay. Our next speaker is Mr. E. Feller who will present a paper entitled **"The Latin American Cooperative Science Programs of the United States National Science Foundation".**

Mr. E. Feller:

Thank you for inviting me to this meeting to share with you in your discussions of present and future research in the earth, geophysical and related sciences in the Americas. Thank you also for allowing me to present to you the Latin American Cooperative Science Programs as well as other interests of the United States National Science Foundation (NSF).

NSF established the Latin American Cooperative Science Program in 1973. This program is intended to assist U.S. scientists who want to extend their ongoing domestically funded research interests to a cooperative context with their colleagues in Latin America and the Caribbean. The main objective of this program is to supplement the costs of U.S. participants in joint projects involving them with their colleagues in any given nation of this hemisphere south of the Rio Grande.

The creation of the program was stimulated by the conclusion of three cooperative science agreements between the U.S.A. and Brazil, Mexico and Argentina. NSF was made the executive agency for these agreements on behalf of the U.S. Government. These agreements and their implementation set the *modus operandi* for the NSF program. Once the guidelines were established, it was decided to extend the program to all countries of Latin America, including the nations of the Caribbean.

The program usually encompasses three types of activities: cooperative research projects in basic or applied science, research oriented workshops and scientific visits for program development or projects of short duration.

The mode of administrative interaction sought with the cooperating countries is for NSF to operate in conjunction with a similar governmental agency in each country. Such an agency could be a national council for science and technology, a national research council or a national science foundation.

The process of considering proposals and issuing grants is similarly administered by the two cooperating national institutions. Each side receives and evaluates a matched proposal from its own scientists for collaboration with the scientists of the other country. Each country supports the costs associated with the participation of its own scientists. Decisions on funding are then arrived at jointly by these institutions from both countries. This ensures that the priorities of each country are respected and that the resources available to each institution are allocated in accordance with the national interest of each side. These institutions also are responsible for overseeing the progress of their respective grantees.

Perhaps an illustration of the kind of projects that have been supported under the cooperative program in the disciplines that concern this meeting will make the intent of the Latin American Cooperative Science Program clearer:

Here is a list of projects in a number of Latin American countries:

Argentina

A program development visit was sponsored to the Instituto Argentino de Nivología y Glaciología in Mendoza, Argentina. Dr. Michael Bilello of the U.S. Army Cold Regions Research and Engineering Laboratory visited with Dr. Arturo E. Corte and his colleagues in Mendoza.

Another project involves participation in a trilateral cooperative program between the Instituto Nacional de Prevención Sísmica of Argentina, the University of Chile and UCLA. It is a study about "The Structure of the Crust and Upper Mantle of the Central Andean Region". The collaborators are: Dr. Edgar Kausel for Chile, Dr. Aguirre Ruiz for Argentina, and Dr. Leon Knopoff for the U.S.

Colombia

NSF and COLCIENCIAS supported a project on "Sediment Transport Characteristics of Cohesive Soils", work which related to the soil erosion problem of the Meseta de Bacaramanga. Dr. Walter Graf, Dr. Williard A. Murray and Dr. H. Y. Fang of Lehigh University worked with Dr. Andres Navia of the Universidad Industrial de Santander.

Another project in Colombia, which involves Dr. Robert P. Meyer, University of Wisconsin, with Father Jesus E. Ramírez of the Universidad Javeriana, is "Studies of Western Andean Structure in Colombia; Low Velocity Zones and Obduction".

Costa Rica

In Costa Rica the program is supporting one cooperative project entitled: "Seismic and Volcanic Studies in Costa Rica" and brings together Drs. Tosimatu Matumoto and Gary Latham of the University of Texas, with Dr. Jorge Umaña of the Instituto Costarricense de Electricidad.

Chile

In addition to the project mentioned previously under Argentina which involves Dr. Edgar Kausel with Dr. Leon Knopoff, the program supported a phase of the cooperative project "Glaciological and Glacial-Geological Studies on Ice Caps in Southern Chile". This involved Dr. John H. Mercer of Ohio State University cooperating with Dr. Cedomir Maragunic of the Universidad de Chile and the Instituto Antártico Chileno. This portion of work concentrated on the Muñoz Gamero Península.

Dominican Republic

Dr. John F. Lewis of the George Washington University undertook the cooperative mode with Ing. Ivan Tavares of the Museo Nacional de Historia in continuing his "Geological Investigations in the Central Dominican Republic"; this was a study of ages and types of basement rocks, metamorphic and tectonic events, plutonism and volcanism.

Guatemala

Dr. David K. Davies of the University of Missouri in collaboration with Dr. Samuel B. Bonis of the Instituto Geográfico Nacional are now in the third year of a project on "Continental Volcanic Sediments in Guatemala".

Also in Guatemala, support was given to Dr. Jo Ann Kropp Glittenberg of the University of Colorado for program development efforts on the sociological aspects resulting from the last earthquake.

Mexico

Mexico illustrates the case of three interrelated grant actions. NSF supports three distinct projects involving three different U.S. institutions with a single Mexican institution, complementing each other in pursuit of a set of common goals.

These are long term grants that have continued for three years thus far. The Mexican principal investigator is Dr. Guillermo Pl Salas of the recently renamed Consejo Nacional de Recursos and on the U.S. side the collaborating individuals, institutions, and project titles are: Dr. Kenneth F. Clark of the University of Iowa in "A Mineral Resource Investigation Program, Sierra Madre Occidental, Mexico"; Dr. Paul E. Damon of the University of Arizona in "Dating of Cenozoic and Mesozoic Metallogentic Provinces within the Republic of Mexico"; and Dr. Maurice A. Chaffee, succeeded by Dr. Glenn H. Allcott of the U.S. Geological Survey in "Techniques of Geochemical Exploration in the Sonoran Environment, with Emphasis on a Search for Copper". This last project has just been renewed for two additional years and an expansion of activities.

Another project involving the U.S. Geological Survey, under Dr. William Back, in cooperation with Dr. Heinz Lesser Jones of the Secretaría de Recursos Hidráulicos is a "Chemical Hydrogeologic Study of Tropical Carbonate Aquifers". This is a study which compares the Yucatan Peninsula and the Sierra del Burro with Florida and the Edwards Limestone region in southern Texas.

Peru

The last example is a project in Peru, which involves Dr. Robert G. Morris of Northern Illinois University with Dr. Fernando Zuñiga y Rivero of Petróleos del Perú. The collaborative work is on a "Sedimentary and Tectonic History of Cretaceous Rocks in Northwest Peru".

Brazil has excluded work in the earth sciences under the Latin American Cooperative Science Program so far. However, this might change in the months to come. Likewise, we expect that Bolivia and Haiti may be added to the list of countries under this program where NSF might be supporting collaborative projects in geology and geophysics.

It is important to remember that the cooperative science program is not and has not been the only NSF vehicle for supporting cooperative research in the Americas, by providing support to U.S. scientists. In fact, most of you are well aware of the multitude of programs at NSF that support a wide variety of research projects in this area. There are a number of you, here today, that at one time or another have been associated with a project financed through NSF.

Since examples are very useful, I will illustrate the diversity of interest that exist at NSF in other programs.

In the Division of Earth Sciences, basic research in the following areas is supported: — Geochemistry — Geology — Geophysics, and the Ocean Sediment Coring Program. Each of these programs has in the past, and is currently supporting research which in some way is related to Latin America, for instance; I am sure that you know the onshore and offshore geophysics studies in Peru involving the University of Wisconsin, the University of Texas, and the Carnegie Institution of Washington. Other examples are: the Carnegie Institution's work on Electrical Conductivity in the Andean Cordillera and the Carnegie Institution and the University of California at San Diego doing seismic and tectonic studies in Mexico. This last is in collaboration with the National Autonomous University of Mexico.

Other known studies supported by NSF are: International Geodynamics Program of the American Plate, the U.S. and the Caribbean Plates, Andean Tectonics, Seismology of the Caribbean, and others. Gravity mapping, establishment of seismic networks, a whole series of projects in basic geological explorations of different regions of the continent; ocean sediment coring near the coasts of most Latin American and Caribbean nations, mainly on cruises of the *Glomar Challenger* and other research vessels of the U.S. research fleet.

Under the Directorate of Research Applied to National Needs, in the program of Earthquake Engineering, support is offered for work in strong motion studies, structural design, geotechnical engineering, solid and foundation studies, land use planning, socio-economic impact of earthquakes, tsunami, and costal engineering problems. Many of these programs offer opportunities for research that are wider in scope than the narrow confines of the U.S. This program is supporting, for instance, the strong motion network project under the USGS; and also, seismic network monitoring in Mexico's Baja California, as an extension of the Imperial Valley network.

Under the International Decade for Ocean Exploration Program of NSF, support has been made available for the following projects relevant to Latin America: studies on the Nazca Plate, off Peru and Ecuador, with participation of scientists from these countries (incidentally, this research was started on the recommendation of Dr. George Woollard at the 1969 meeting of this group and has been supported at the rate of approximately one million dollars a year since); studies on the Galapagos rift; follow-up work on project FAMOUS; and the "Cayman Trough Studies" in the Caribbean. Intensive drilling projects involving Woods Hole Oceanographic Institution and the Lamont Doherty Geological Observatory were supported off the Argentine and Brazilian coasts. The Lamont Doherty Geological Observatory has also been supported to integrate the data from geophysical explorations in the South Atlantic, information which may be useful for future oil prospecting, based on the evidence of sapropelic sediments in the cores extracted under the Deep Sea Drilling Program. Land geology research was supported under the Lamont Doherty Geological Observatory for work in the region around the southern core of South America, in both Chile and Argentina.

Of interest also is the Geostill Conference recently held in Oregon where discussions were held on relating data and observations on the Nazca Plate with detection of ore deposits in the Andes.

Soon a report will be published by the University of Puerto Rico on seismicity, bathymetry, geology and mineral resources in the Caribbean Basin which brings together several studies carried out with partial NSF support.

Another interesting publication to come out will be the circum-Pacific map on minerals, geology and geophysics, where José Corvalan of Chile is coordinating the work on the southern quadrant.

Under the Division of Polar Programs, a series of geology and geophysics projects with the participation of Chile and Argentina are supported. This work contemplates the use of two research vessels: the *Hero* and the *Islas Orcadas*. These two vessels have on-board capabilities for collection of hard rock samples through piston coring, dredging, and gravity coring, bottom photography, subbottom profiling, paleomagnetic studies and so forth. Research contemplates explorations of the continental shelf near Argentina as well as the Antarctic peninsula and Chile.

Support of marine geophysics has also been very active under the Oceanography Programs of the Foundation.

This as you can see, is just a sample of research activities funded by NSF.

Let me conclude by emphasizing that there are many possibilities where collaborative efforts between U.S. scientists and their colleagues in the Americas can be realized through the various programs of NSF.

Discussion

Ing. E. Malavassi:

Yo trabajo en una Universidad que quiere abrir la carrera de Oceanografía Física. Qué oportunidad hay de que através de su ofrecimiento, pueda ayudarse a la Universidad que represento? Contamos única y exclusivamente con un millón de dólares para comenzar. Sabemos que la tarea exige un esfuerzo gigantesco.

Como podemos conseguir gente que nos ayude? Gente preparada para que nos dé el primer impulso.

Mr. E. Feller:

El paso directo que ustedes pueden tomar es el de identificar qué tipo de individuos ustedes quisieran que se asocien con su instituto y por cuánto tiempo podría ser: por unas semanas o hasta un año. Si la responsabilidad recae en sus hombros para seleccionar quién es el que ustedes quieren, entonces al individuo escogido lo estimulan a que haga su petición a través de este programa a la Fundación. La fecha de cierre para el próximo ciclo de competencia es el 15 de diciembre. Entonces el postulante defiende su caso, por qué quiere él ir a Costa Rica? Y como satisface su participación la necesidad que tiene Costa Rica? Luego, se requiere la anuencia de parte de Costa Rica, o sea de su institución. Esta no es una imposición para Costa Rica, sino que ésto es algo que ustedes desean. Y en tercer lugar, simplemente estructurar un programa que tenga pies y cabeza.

Ese es el paso inmediato con referencia a este programa. El programa cooperativo en si, se dirige a proyectos de investigación. Una vez que el instituto empiece a dar sus primero pasos y existan proyectos específicos de investigación conjunta, donde se vea una ventaja de parte de Costa Rica de hacer ciertos trabajos con alguien en Estados Unidos, se deberá estimular al investigador norteamericano a hacer una propuesta conjunta con el investigador costarricense. La propuesta de Costa Rica va al CONACYT y por parte de Estados Unidos el investigador hace su petición a este Programa de la Fundación. La evaluación la hacen independientemente, y es luego entre el CONACYT y el NSF que se toma la decisión de apoyo conjunto.

Se puede dar el caso y muchas veces se da, de que para la institución Latinoamericana no haya un costo extra.

En muchos casos la carrera de investigador ya está pagada, esto sí incide en un costo extra para la parte norteamericana que necesita suplementar la actividad del colaborador norteamericano.

Mr. M. R. Dence:

Thank you Mr. Feller. I also wish to thank the speakers this afternoon for their excellent cooperation with the clock.

THIRD SESSION
Tuesday, September 28

TROISIÈME SÉANCE
Le mardi 28 septembre

TERCERA SESIÓN
Martes, 28 de septiembre

OBJECTIVES AND METHODOLOGY OF SELECTED NORTH AMERICAN PROGRAMS

LES OBJECTIFS ET LA MÉTHODOLOGIE DE CERTAINES ÉTUDES NORD-AMÉRICAINES

OBJETIVOS Y METODOLOGIA DE PROGRAMAS NORTEAMERICANOS SELECCIONADOS

Chairman/Président/Presidente
PROF. G. P. WOOLLARD

Speakers/Conférenciers/Expositores

DR. P. VANÍČEK
DR. R. A. GIBB
DR. E. R. NIBLETT
DR. M. J. BERRY
DR. A. JESSOP
DR. A. LAMBERT
DR. T. SIMKIN
MR. D. HARLOW

Prof. G. P. Woollard:

The subject of this morning's session is Objectives and Methodology of Selected North American Programs with emphasis primarily on the nature of the programs themselves.

Our first speaker of this morning's session is Dr. P. Vaníček who will present a paper entitled **"Geophysical Applications of Geodesy".**

Dr. P. Vaníček

Introduction

My basic assumption when preparing this talk was that it should address a predominantly geophysical audience. I shall thus suppose that the scope of geophysics as well as its terminology are known. On the other hand, I shall assume that the same does not hold true for geodesy. Therefore, I shall begin with defining geodesy.

Geodesy is probably the oldest geoscience dating well back before the time of Christ. Its present role can be described as follows (Krakiwsky and Vaníček, 1974): "Geodesy is the discipline dealing with the measurement and representation of the earth, including its gravity field, in a three-dimensional time varying space." In other words, geodesy deals with the geometry of the earth and its gravity field.

There is a symbiotic relationship between geodesy and geophysics. In exchange for the geometrical information, geophysics supplies geodesy with the understanding of the physics of the earth, a necessary ingredient in any geodetic work. It is indeed a matter of personal opinion if anyone wants to regard geometry as part of physics — and thus geodesy as part of geophysics.

Stemming out of the role of geodesy is the internal division of geodesy into three sub-disciplines:

(i) position determination (positioning);
(ii) investigation of the geometry of the earth's gravity field;
(iii) evaluation of time variations in positions and gravity field (time-variations).

In the sequel, the role of each of these sub-disciplines in geophysics will be discussed separately. Also, I shall concentrate on uses of geodetic information in geophysics rather than vice versa. While doing so I shall pay particular attention to some aspects that in our experience may cause problems.

Positioning

Positioning, i.e., the determination of position of points and networks of points, is the classical sub-discipline that finds applications in many aspects of life. It is almost universally understood; so much so that many people are under the impression that there is nothing more to geodesy than positioning. I shall take it for granted that the role of positioning in geophysics is also clear.

However, I should like to focus on two aspects of positioning that are likely to be of concern to geophysicists who are not fully familiar with geodetic concepts. One is the question of coordinate systems, the other is the accuracy of geodetically determined positions.

Positions of points on the surface of the earth can be obtained using two conceptually very different techniques: terrestrial and extraterrestrial. Terrestrial positioning techniques are basically differential techniques; the positions (coordinates) of points are derived from measurements of angles, distances or elevation differences between neighbouring points through an integration process. Classically the positions are given either in horizontal or vertical coordinates. Thus we have networks of points determined only in a horizontal sense and networks of generally different points determined only in a vertical sense. The vertical coordinates (heights) of "horizontal control points" and conversely horizontal coordinates of "vertical control points" are normally known only approximately, if at all.

In the integration process for determining coordinates within each network, some initial conditions must be chosen. These are usually the horizontal coordinates of an initial point and a direction in the case of the horizontal network and a set of initial points with heights related to mean sea level using records from tide-gauges in the case of the vertical network. The necessity of choosing the initial conditions dictates the selection of coordinate systems for terrestrial horizontal and vertical positioning.

The horizontal coordinate system is normally an ellipsoidal system (ϕ,λ) or one related to it through some known conformal transformation (mapping) where the reference ellipsoid of a prescribed size and shape (horizontal datum) is positioned within the earth in a more or less arbitrary fashion. As a result its position generally differs significantly from the geocentric position of the mean earth ellipsoid used in gravity work. The distance between the origins of the two ellipsoids can be a few hundred metres (Fig. 1).

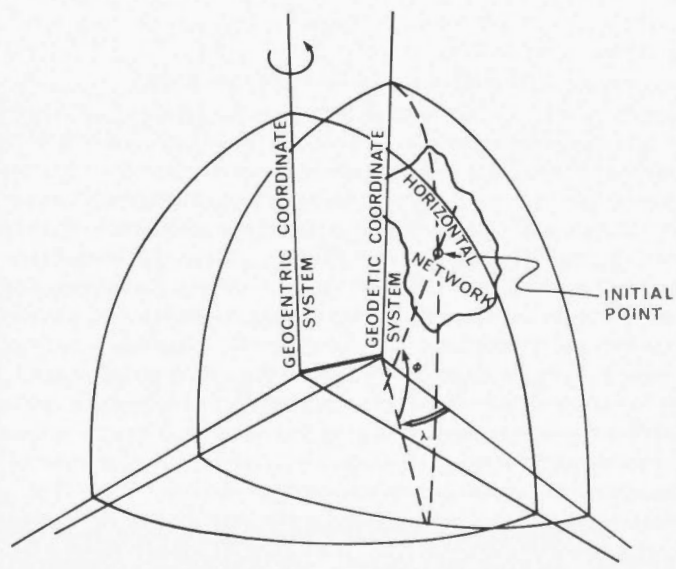


Figure 1. Geodetic and geocentric coordinate systems.

The vertical coordinate system consists of the reference surface (vertical datum) and the definition of the scale that is used to measure the height. The vertical datum is either the geoid or the quasi-geoid. The scale is either constant (for orthometric or normal height systems) or changing (for a dynamic height system). It is worth realizing that neither orthometric nor normal systems can be interpreted physically since points of the same height do not lie on the same equipotential surface. Thus, in either of these two systems water can flow from a "lower" to a "higher" point.

The integration process used in terrestrial positioning also gives us an insight into the accuracies of the coordinates. In horizontal networks the accuracy deteriorates with the distance d

from the initial point. The standard deviation of horizontal position with respect to the initial point can be computed from an empirical formula

$$\sigma \doteq k\ d^{2/3} \qquad (1)$$

where k is a constant depending on the shape of the network as well as the observing and computational procedures used. For the present North-American first order networks we have

$$k \doteq 4\ 10^{-2}\ \mathrm{m/km}^{2/3} \qquad (2)$$

in average (Simmons, 1950).

For vertical networks the same approximate formula (Equation 1) holds with the understanding that d is the distance from the nearest tide-gauge used as an initial point. For first order North-American vertical networks we have

$$k \doteq 1.8\ 10^{-3}\ \mathrm{m/km}^{2/3} \qquad (3)$$

in average (Goddard Space Flight Centre, 1973). In addition, the heights suffer from the uncertainty caused by the difference between the mean sea level (as determined from tide-gauge records) and the geoid/quasi-geoid. This uncertainty may amount easily to several decimetres (Hela and Lisitzin, 1966).

Locally, the accuracy in both types of networks is somewhat higher. The relative accuracy of horizontal positions of two adjacent first order points is typically around 10^{-2} (Bomford, 1971). The height difference of two adjacent first order vertical control points has a standard deviation of about 1 mm per square root of distance in kilometres (Baeschlin, 1960).

Extraterrestrial positioning techniques are based on observations to extraterrestrial objects such as artificial satellites or other celestial bodies. It is in the nature of these techniques that they are global in that they are not restricted by the intervisibility of points. The coordinate system used by these techniques is very nearly geocentric. Also, the positions thus determined are inherently three-dimensional.

At present, the accuracy (one standard deviation) of routine extraterrestrial absolute (with respect to the coordinate system) positioning is at best of the order of a few metres in all three dimensions but is improving every year (Anderle, 1974; Schmidt, 1974). The accuracy of relative extraterrestrial positioning is somewhat higher and depends only weakly on distance. However, even the present accuracy is superior to that of terrestrial positioning if the points are separated sufficiently, say of the order of 1,000 km.

The best results are naturally obtained by combining the terrestrial and extraterrestrial results. These combined solutions exploit the advantages of both techniques, the local strength of terrestrial networks and the global homogeneity of extraterrestrial results.

Gravity field

As we all know, the knowledge of the earth's gravity field in geophysics is one of the main sources of information on the internal structure of the earth. Because of this, the study of the earth's gravity field has always been considered as one of the natural topics of interest to geophysics. The gravity field also determines the geometry of the physical space in which geodetic observations are made. Therefore, knowledge of the gravity field is equally important to geodesy.

The earth's gravity field can be studied using different kinds of data. The most commonly used are the absolute values of gravity measured by standard techniques in gravimetry. However, other kinds of data are available from geodesy:

(i) the direction of gravity, given in terms of the deflections of the vertical;
(ii) geoidal heights;
(iii) gravity gradients.

In addition, analytic expressions for all the parameters of the earth's gravity field (magnitude and direction of gravity, gravity potential, geoidal height) are obtainable from near satellite orbit analysis.

I shall again assume that the interplay of the different parameters of the gravity field, as well as the techniques used in this context, are commonly known in the geophysical community. There is, however, one controversial point that I should like to mention here. This is the role of the reference system in the geophysical interpretation of the gravity field.

It is the accepted approach in investigating the earth's gravity field to model the bulk of gravity (or any other field parameter) using the normal gravity field. The normal field is generated by an a priori adopted "best fitting" geocentric ellipsoid, defined by four parameters, a, GM, J_2 and ω in case of the 1967 system (IAG, 1971). The meaning of these parameters is generally known. Their values are adopted so that they are as close as possible to the best "observed" values. Then, the differences between the actual gravity field and the normal field are considered to be a measure of the irregularity of the density distribution within the earth.

It was shown by Ledersteger (1960, 1966) that the observed flattening of the earth (1/298.25) is not compatible with the assumption that the earth has a layered distribution of masses that would maintain equilibrium under its present spin velocity. Efforts to explain this incompatibility through a lag in adjustment to its present lower velocity led to a discovery that the implied value of viscosity necessary to sustain the bulge would be 10^{26} poises (MacDonald, 1963). This value is far too high when compared to results determined from other geophysical evidence (e.g. Goldreich and Toomer, 1969) and therefore practically rules out the hypothesis that the observed bulge is a remnant from the past.

The argument was put forward by Kaula and O'Keefe (1963) that by referring the gravity field to the best fitting ellipsoid we deal only with part of the irregularities caused by irregular density distribution. Based on Ledersteger's work we can see that the best fitting ellipsoid in itself implies an anomalous distribution of density that gets disregarded if the best fitting ellipsoid is used for a reference. It has been therefore proposed by many geodesists/geophysicists that for global gravity interpretation a reference system based on a geocentric ellipsoid with (hydrostatic) flattening of 1/299.67 (Jeffreys, 1963) should be used. For local and regional interpretation the selection of a reference system makes little difference.

Time variations

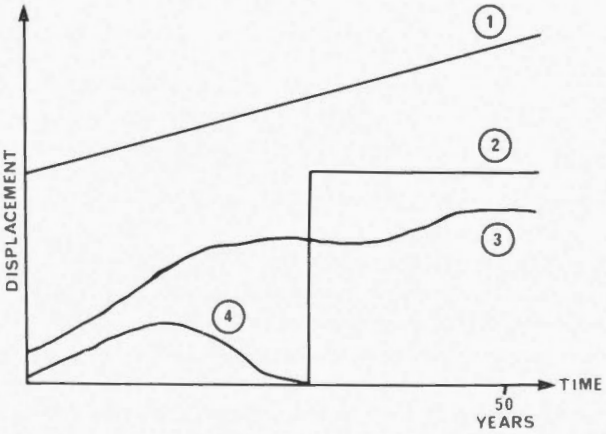
Because of the capability of determining positions geodesy is the obvious discipline that can also detect variations of positions with time through repeated observations. The same argument holds, of course, for the gravity field. The approach using repeated determinations of positions has been used in geodesy for over a century. However, it was not until recently that the geophysicists began to realize the full potential of geodetic techniques and started turning to geodesy for quantitative information on ground movements. A new field that may be called contemporary geodynamics, was born.

There are three distinctly geodetic topics involved in contemporary geodynamics:

(i) evaluation of ground movements;
(ii) evaluation of the time variations of the earth spin vector;
(iii) evaluation of time variations of the earth gravity field.

In the following I shall concentrate on the first topic alone because the second and third may be considered sufficiently well known in the geophysical community.

From the geophysical point of view the quantitative evaluation of motions that geodesy supplies represents valuable information in various studies. These include earth tides, crustal loading and rebound, tectonic plate movement and ground movements caused by other phenomena. From the areal point of view the movements are either global or regional or local and they may be classified as either predominantly horizontal or vertical. Even at the risk of being over-simplistic I believe it is helpful to look at some of the typical displacement patterns characterizing the different kinds of movements (Fig. 2), leaving out any oscillatory motions.



(1) isostatic rebound, non elastic crustal loading, tectonic creep
(2) co-seismic, caving in, landslides
(3) artificial subsidence and upheaval
(4) pre-seismic

Figure 2. Kinds of ground movements.

Evidently, the magnitude of the displacement would in reality vary vastly from phenomenon to phenomenon and from place to place just as much as their areal extent does.

The simplest to detect and depict are the constant and sudden movements (cf. Fig. 2, (1), (2)). Two position determinations appropriately spaced in time is all that is needed to detect the movements. The other two classes of movements require observations continuous in time or at least often repeated. Instruments like strain-gauges, tide-gauges and tiltmetres equipped with continuously working recorders are of a special value for this purpose. However, arrays of these instruments needed for an areal coverage are an expensive proposition.

The standard geodetic positioning techniques can on the other hand give a good areal coverage for little investment. The geodetic information may come particularly cheaply if the repeated positioning is done primarily for other purposes; the use of readily available historic geodetic records is thus singularly attractive in this context. Let us cite here at least one, recently much publicized example of an exploitation of historical levelling records in southern California by Castle *et al.* (1976). Their work led to the discovery of an aseismic uplift on the San Andreas fault thought to be of a precursory nature. Another good example of the application of the same technique is the evaluation of the subsidence in Mexico City associated with the excessive water withdrawal and drainage of the surrounding lake (Comisión Hidrologica, 1961).

It goes without saying that the best description of ground movements is achieved by combining as many kinds of observations and techniques as possible. One such combination often used is that of sea level time variations (as detected by tide-gauges) and land tilt (as detected by geodetic relevellings) for evaluation of vertical ground movements. Many examples exist in the literature, from which I shall cite just three, pertinent to the Americas (Holdahl and Morrison, 1974; Miyamura, 1975; Vaníček, 1976a).

It is important to realize that most of the techniques can only detect relative movements between points. The notable exceptions are techniques that use the sea level time variations where absolute vertical movements with respect to the geoid, for example, can be obtained. The absolute vertical movements of the tide-gauges are computed from the tide-gauge records by subtracting the variations of the sea level itself that are due to various meteorological effects, long periodic tide, polar wobble, river run-off and, most importantly, due to global eustatic water rise. When these variations are taken into account (Vaníček, 1976b), the tide-gauge records can give point vertical movements with about the following standard deviations:

3 cm/century for constant movements,
6 cm/year for episodic movements, (4)
20 cm/month for sudden movements.

The pronounced decrease in accuracy is because the effect of short lived phenomena on sea level variations is more poorly understood than that of long term effects.

Speaking about the attainable accuracies, it is instructive to have a look at the performance of geodetic positioning techniques discussed earlier. Table I shows the approximate standard deviations of relative movements of two points that can be currently obtained using the available geodetic techniques. The table shows a marked deterioration of accuracy of terrestrial techniques with increasing distance, a point which has been dis-

TABLE I
Accuracies in Movement Determination

Technique	Inter-point distance			Type of movement
	10 km	100 km	1000 km	
first order levelling	1 cm	5 cm	25 cm	vertical
first order horizontal network	10 cm	50 cm	250 cm	horizontal
VLBI, lunar ranging	20 cm	20 cm	20 cm	horizontal
best satellite positioning	50 cm	50 cm	50 cm	vertical/ horizontal

cussed previously. This is why the extraterrestrial methods are considered better suited for global or even regional studies of movements.

We should point out that for smaller areas the horizontal terrestrial techniques can be improved considerably by using special instrumentation and procedures. In local horizontal networks designed to monitor horizontal differential movement along active faults (Schubert and Henneberg, 1975; Chrzanowski *et al.*, 1976), the accuracy can be improved at least five times.

Summary

The obvious observation is that geodetic involvement in geophysics has significantly increased in the past decade. The increase can be attributed mainly to the common interest in contemporary geodynamics. This trend is bound to accelerate with the advent of global geodetic positioning systems with centimetre accuracy that is looming just over the horizon (King-Hele, 1976). Geodetic results are then likely to become one of the most important sources of information in seismology, global tectonics and other crustal studies.

On the other hand the time is coming also for the practicing geodesists to formally acknowledge that the positions of control points they work with are changing with time. The magnitude of the ground movements in many regions will become larger than the noise level in the positions. To develop a meaningful and applicable approach to working with time-varying positions will require assistance from the geophysicists.

Hence we shall doubtless see a much closer cooperation evolving between the geophysicists and geodesists on a variety of problems of theoretical as well as practical nature. The fruit of this cooperation can only enrich our two disciplines.

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Prof. G. P. Woollard:

Thank you very much Dr. Vaníček. Our next speaker is Dr. R. A. Gibb who will present a paper entitled **"Gravity Mapping in Canada"** by R. A. Gibb and M. D. Thomas.

Dr. R. A. Gibb:

In Canada, the national gravity mapping program is organized and directed by the Gravity Service of Canada. This service is operated by the Gravity and Geodynamics Division of the Earth Physics Branch (formerly the Dominion Observatory), Department of Energy, Mines and Resources, Ottawa, which has a history in gravity measurements dating back to the beginning of the century. Most gravity measurements on land and frozen water surfaces have been made by the Gravity and Geodynamics Division, but a large proportion of those acquired on the open sea has been collected by the Atlantic Geoscience Centre of the Geological Survey of Canada, Department of Energy, Mines and Resources, Dartmouth. Gravity and related data collected by these agencies are stored in the National Gravity Data Base at the Earth Physics Branch, Ottawa. Throughout the years, contributions to this data base have also been made by various provincial government departments, universities, and mineral and petroleum companies.

The objectives of the Gravity Service of Canada are: to ensure the availability of data and information describing the gravity field of Canada; to provide a uniform reference standard for gravity measurements in Canada; to provide data and information on the structure and figure of the Canadian landmass from studies of gravity anomalies; to contribute to man's knowledge of the earth's evolutionary processes for the benefit of the resource development industry, earth scientists, standards laboratories, national defence and other government agencies; to participate in international gravity studies; to provide scientific and technical advice and services to the public and private sectors.

Within the Gravity Service the objectives of the gravity mapping program are: to collect and disseminate data and information on spatial and temporal variations in the gravity field; to develop instrumentation and methodology for acquiring these data; to provide storage, retrieval, display and management services for these data.

In this paper we first review the progress made in the gravity survey of Canada. We then describe the general specifications and methodologies employed in the four major categories of gravity survey conducted by the Earth Physics Branch. Finally we briefly review gravity standards, data reduction and gravity map production in Canada.

Review of progress

As far as can be determined, the first gravity measurement in Canada was made in 1820, near Winter Harbour, Melville Island, by Lieutenant Edward Sabine, a member of Sir William Parry's expedition in search of the northwest passage (Sabine, 1821). He used Kater pendulums to obtain his results which were subsequently used in studies of the figure of the earth. It was not until 1891, however, that a gravity measurement was made in Canada with a relatively modern apparatus, which was to play an important role in gravity measurements in Canada for approximately another half century. The apparatus was the Mendenhall invariable half-second pendulum developed by the United States Coast and Geodetic Survey (Mendenhall, 1892). This pendulum was tested during an expedition to Alaska with one of the measurements being made at Port Simpson, British Columbia. Canadian interest in the measurement of gravity was heralded in 1902 when a half-second pendulum modelled after the Mendenhall apparatus was obtained from the United States Coast and Geodetic Survey by the Observatory Division of the Astronomical Branch, Department of the Interior. That same year, O. J. Klotz, later to become director of the Dominion Observatory, measured gravity at Ottawa, Montreal and Toronto (Klotz, 1908). Apart from one measurement in Labrador in 1905, no further gravity observations were made in Canada until 1914 when 18 observations were made as part of a planned coverage of the whole country and Ottawa was selected as the base for all Canadian work (McDiarmid, 1915). Presenting reasons for covering the Canadian landmass in this fashion, McDiarmid reiterated the "reasons for the prosecution of pendulum work" given by C. S. Peirce of the United States Coast and Geodetic Survey at a conference on gravity determinations held in Washington in 1882 (Peirce, 1883). His reasons were for geodetic studies, for application to metrology, for geological studies, for application to the use of gravity as a unit in the measurement of forces, for plumb line deflection studies, and for a need to measure gravity because it is a fundamental quantity. McDiarmid concluded that "what was true in 1882 applies with equal force in 1914, and especially in a country such as Canada where a geodetic survey is only in its infancy". Here, then, were sown the seeds of a national gravity mapping program. Unfortunately, the multidisciplinary structure of the Dominion Observatory did not always allow for a concentrated effort in pursuing the goals outlined by McDiarmid, and consequently this factor in conjunction with the slow and laborious procedure of obtaining pendulum measurements resulted in only about 150 observations being included in the 1939 Gravity Map of Canada, most of which had been made in the populated south (Miller, 1940). During the period 1929 to 1934, the Eötvös torsion balance which measures the horizontal and curvature gradients of gravity was used briefly as a prospecting tool. However, it was not until 1944 when the gravity meter supplanted the pendulum that a new era in gravity mapping began in Canada. This innovation coupled with the use of float-equipped aircraft for landings on the lakes which are so common in Canada resulted in rapid resurvey of parts of southern Canada previously covered by the pendulum observations, and in the coverage of large areas of northern Canada. Thus at the end of 1956, when the first Gravity Map of Canada based essentially on gravity meter measurements was in preparation, some 15,000 observations had been made (Innes, 1957). Station spacing during the period 1944 to 1956 was quite variable, generally ranging from 10 to 50 km and an average of 1,100 new observations was made each year. Approximately half of these stations have since been discarded and replaced by new stations established with improved elevation control and modern gravity meters. A graph of number of observations per year depicting progress in the gravity mapping program of the Earth Physics Branch for the period 1944-1975 is shown in Fig. 1. Fig. 2 is the cumulative total observations per year obtained by the Gravity Service from all sources for the same period.

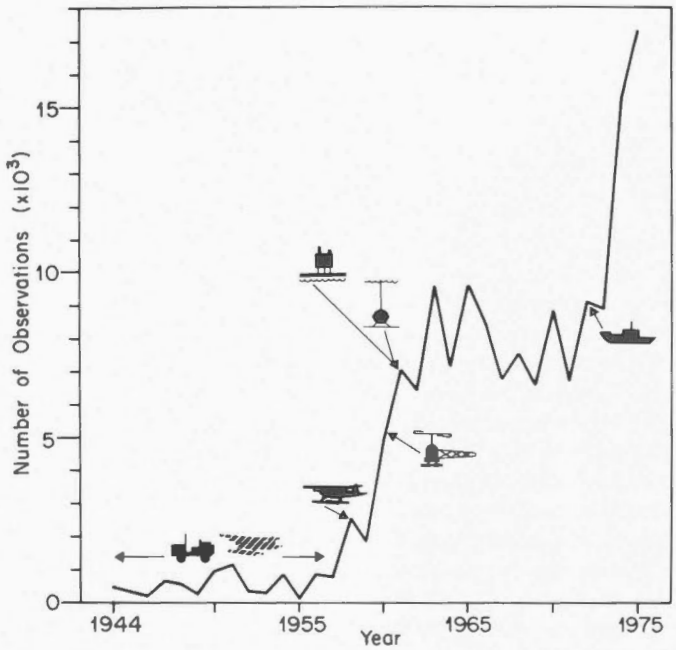


Figure 1. Graph of number of gravity observations per year measured by the Gravity Service, Earth Physics Branch for the period 1944 to 1975. Appropriate symbols indicate highlights as follows: 1944 to 1957 — surveys by car with limited use of fixed-wing aircraft; 1958 — greatly increased use of aircraft for systematic surveys; 1960 — introduction of helicopters; 1961 — first ice-surface and underwater surveys; 1972 — introduction of systematic sea-surface surveys by the Gravity Service.

In 1957 the mapping program was modified to measure gravity at intervals no greater than 15 km to obtain a more uniform distribution of stations. With the increased use of fixed-wing aircraft in 1958 and the introduction of helicopters in 1960 an average of 7,000 new stations was observed annually in the period 1958 to 1967 and a third edition of the Gravity Map of Canada

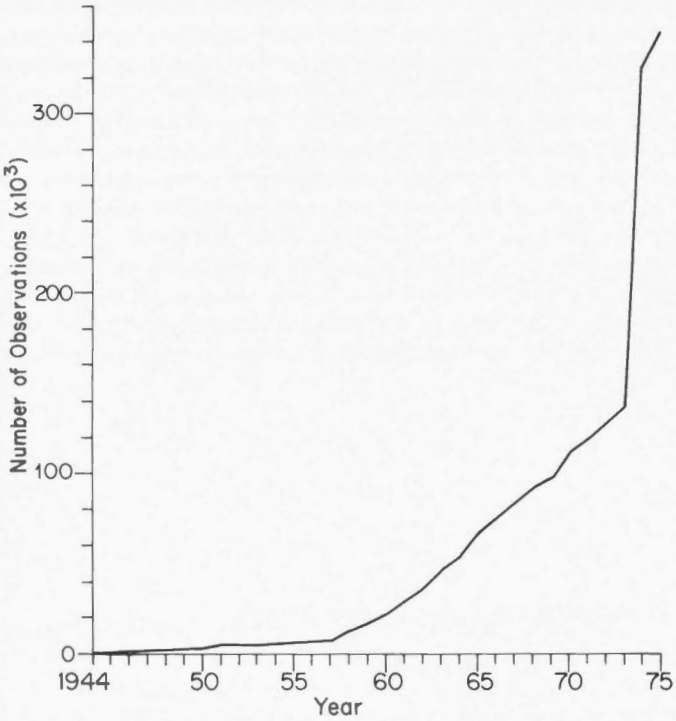


Figure 2. Cumulative total gravity observations contributed to the National Gravity Data Base from all sources for the period 1944 to 1975.

was published in 1967 (Innes and Gibb, 1970). This significant increase in station production fortunately coincided with the advent of electronic computers and the division rapidly adopted computer methods for gravity data processing (Tanner and Buck, 1964). Most of the Canadian Shield had been covered by this time along with large areas of the Arctic islands and seas. Relatively little progress had been made in the Cordillera.

The fourth edition of the Gravity Map of Canada compiled from 350,000 stations was published in 1974 (Fig. 3). The methods used to prepare the map are described by Nagy (1976). The greatest change in the period 1967 to 1974 was the increase in sea-surface surveys. This trend is likely to continue for several years.

Canada has an area of almost 10 million square kilometres. The adjacent shelf seas cover an additional 3.8 million square kilometres. Within this vast region considerable variations in climate (semi-arid to Arctic), in terrain (ancient peneplains to Cordilleran peaks), in vegetation (dense bush to treeless barren lands) and in the means of communications (roads restricted to the southern populated regions) have necessitated a variety of approaches to the gathering of gravity data, both in regard to transportation and to instrumentation. Four main categories of gravity surveys are conducted: land surveys; ice-surface surveys; underwater surveys; and sea-surface surveys. The planned coverage by each type of survey is indicated in Fig. 4. The progress to January 1976 in covering these regions is also indicated (the 500 m bathymetric contour is a purely arbitrary limit in Fig. 4 as many surveys have gone and will continue to go beyond this limit). Approximately 80% of the entire region has been covered by 134,000 discrete (static gravimeter) observations and 211,000 shipborne (dynamic gravimeter) observations as shown schematically in Fig. 5.

The remaining unsurveyed areas of Canada have a common requirement for non-routine survey techniques due to difficulties of terrain or other hostile environments. On land the main unsurveyed areas are the western Cordillera of British Columbia and the Yukon and the mountainous northern Arctic Islands. There, progress will depend largely on the availability of monumented stations with known elevations and sufficient detailed topographic maps. At sea the remaining areas include parts of the Atlantic and Pacific continental shelves and parts of Hudson Bay, Hudson Strait, Davis Strait and Baffin Bay. Ice covered regions include the Canadian sector of the Arctic Ocean, the inter-island channels of the Arctic islands, Foxe Basin, and some of the large inland lakes. The sea and ice surveys are usually undertaken as cooperative efforts with other mapping agencies such as the Canadian Hydrographic Service, the Polar Continental Shelf Project, and the Geological Survey of Canada. The rate of progress will therefore depend not only on availability of ships and navigation aids but also on the concerns, priorities, and continued cooperation of these agencies. At the present rate of coverage the reconnaissance gravity mapping program is likely to continue for 15 to 20 years. In addition to the environmental constraints, the increased cost of navigation and transportation in the remaining areas compared to the remainder of Canada will mean that the area mapped each year will decrease if operations remain at about the present level.

Figure 3. Bouguer Gravity Map of Canada, 1974.
(See insert on facing page.)

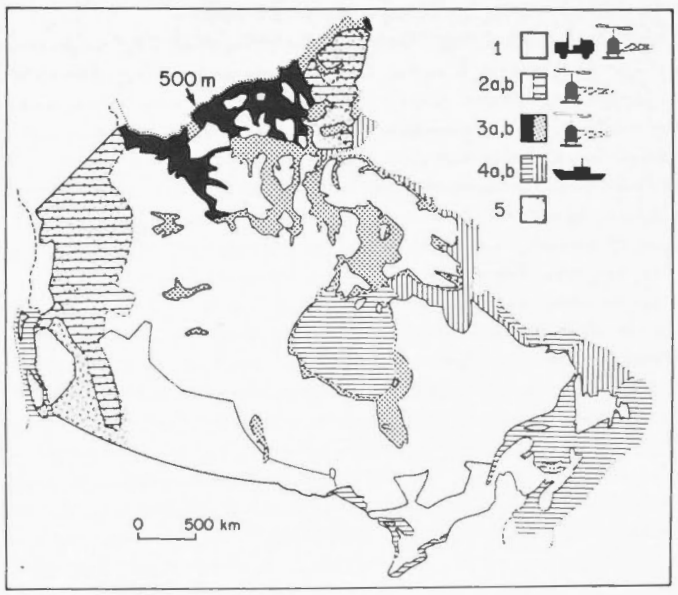
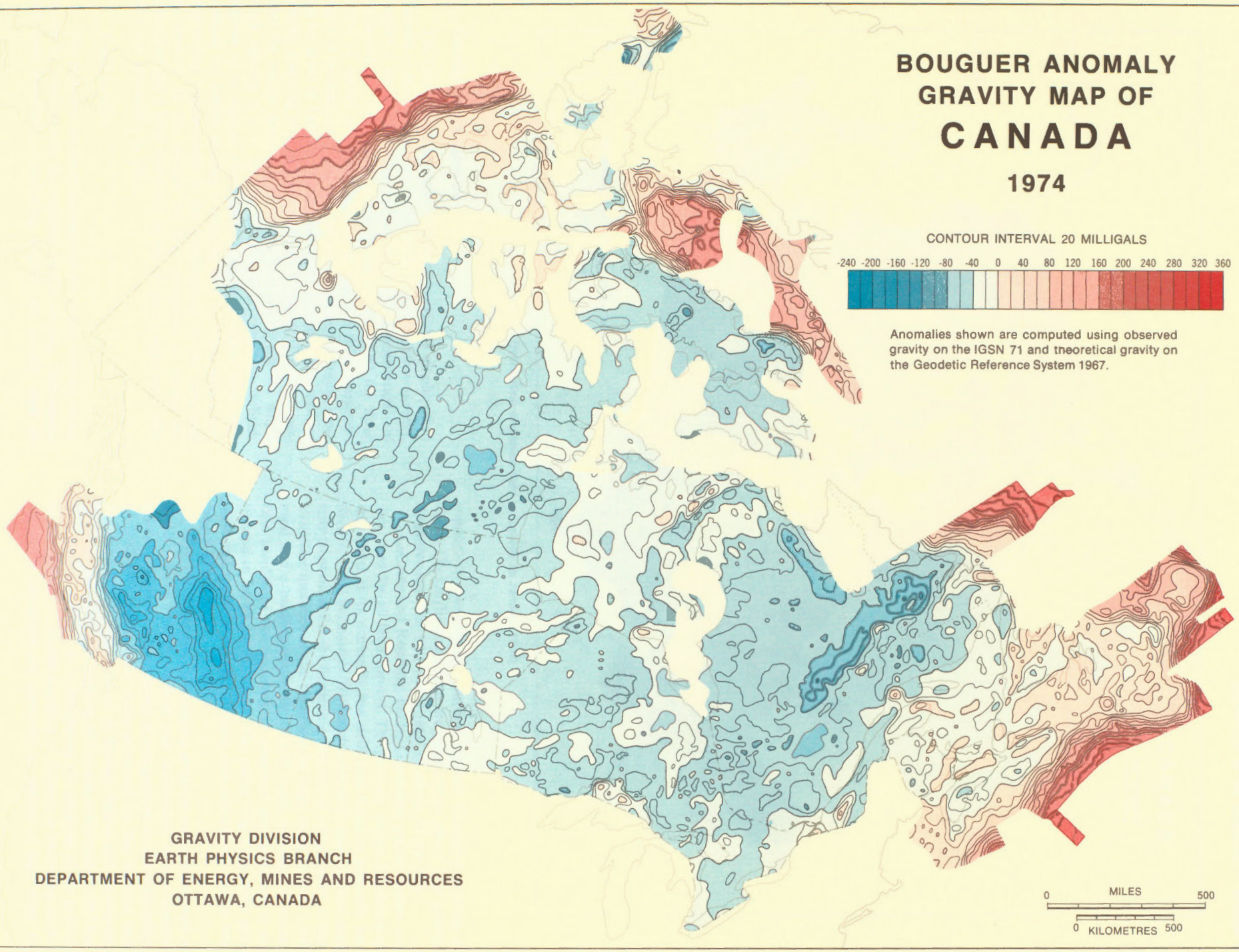


Figure 4. Gravity coverage in Canada according to type of survey (to January, 1976). Surveyed and unsurveyed areas beyond the 500 m bathymetric contour are not shown. The distribution of data in oceanic areas is shown in Fig. 5. 1 — road covered area, 100% surveyed; 2a — hinterland area, 84% surveyed; 2b — unsurveyed area, 1,315,000 km²; 3a — ice-covered area, 35% surveyed; 3b — unsurveyed area 942,000 km²; 4a — water-covered area, 75% surveyed; 4b — unsurveyed area 526,000 km²; 5 — mountainous terrain. Total unsurveyed area 2,783,000 km².

BOUGUER ANOMALY GRAVITY MAP OF CANADA

1974



GRAVITY DIVISION
EARTH PHYSICS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
OTTAWA, CANADA

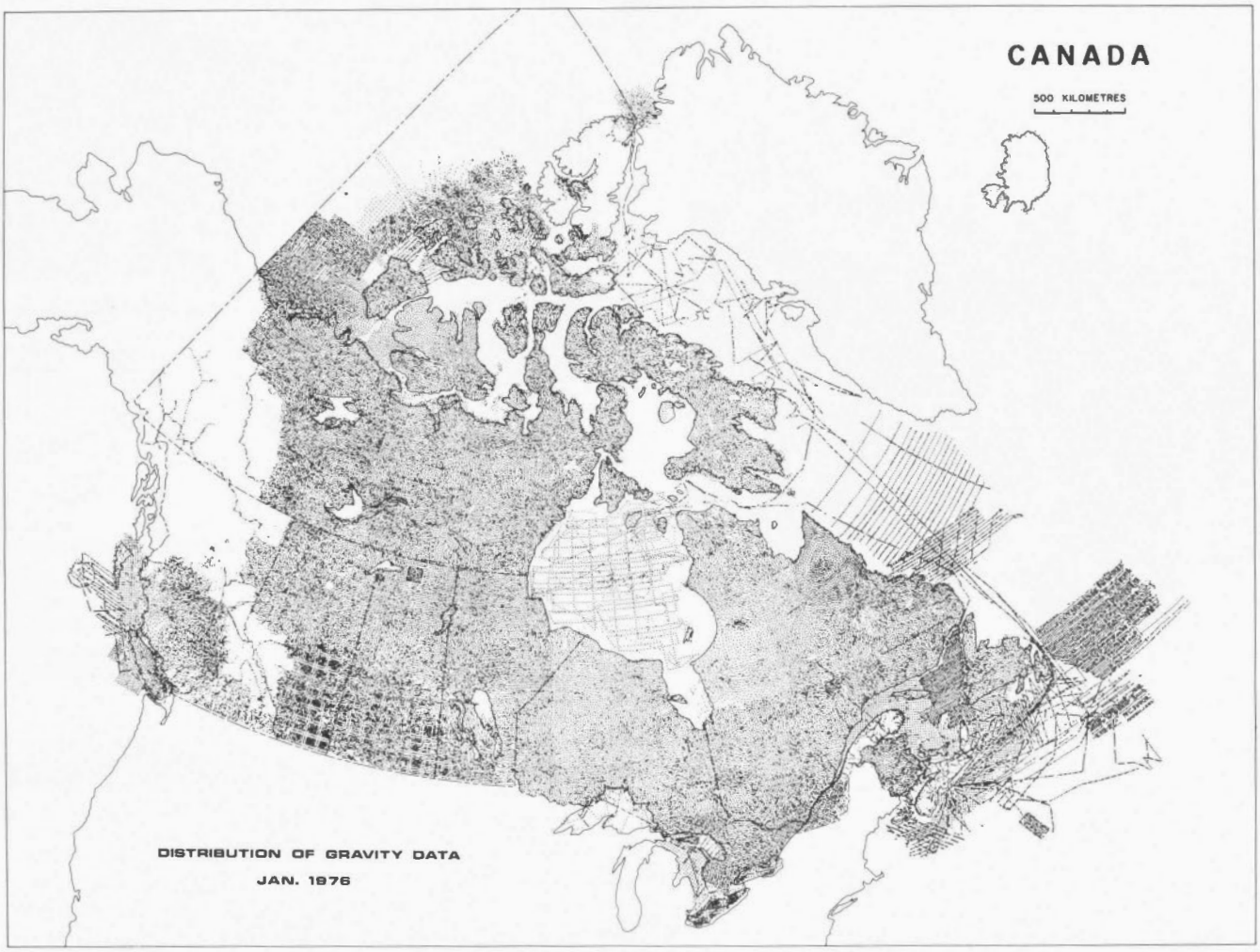


Figure 5. Distribution of gravity data in Canada to January 1976.

Gravity survey methods

The four basic categories of gravity surveying employed in Canada — land, ice-surface, underwater, and sea-surface surveys, require a variety of transportation modes, instrumentation and methodology. The specifications (Gibb *et al.*, 1974) for three scales of survey arbitrarily classed as regional reconnaissance, regional detailed, and local detailed according to the station spacing are given in Table I. The surveys which constitute the national gravity mapping program are regional in nature. For these surveys the station spacing is generally 6 — 15 km and the ship's track spacing is 1 — 20 km. In remote or otherwise difficult regions or in regions where specific regional targets have been defined the station spacing is reduced to 1 — 5 km with a corresponding improvement in the specifications of the measured parameters. In this section the four categories of survey are described and a brief statement on the division's experience with airborne gravimetry is given.

Land surveys

The principal means of conveyance are motor vehicles where access by road permits the required station density. Helicopters are used elsewhere. Fixed-wing aircraft are usually used as support-vehicles. Using a turbine-engined helicopter cruising at about 130 km/hr a one man crew can obtain about four gravity measurements per hour for a total of about 32 per day.

LaCoste and Romberg model G geodetic gravity meters are now used for all land surveys. The primary reason for choosing this meter is its extremely low drift rate which is generally less than 0.5 mgal per month. With such a low drift, base stations need only be occupied at the beginning and end of a day's work. Other attractive qualities of the meter are its large range of over 7,000 mgal and a reading sensitivity of 0.01 mgal, although in actual field conditions the accuracy of observed gravity values is estimated to be about 0.05 mgal. The meter (Fig. 6) is easily portable and together with its carrying case and battery weighs less than 9 kilograms.

The Canadian gravity mapping program can only proceed in those regions where vertical and horizontal survey control networks have been established. It is dependent on the availability of 1:250,000 topographic maps produced by the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa. The 1:250,000 mapping of Canada completed in 1967 has thus played a vital role in facilitating the progress of the gravity survey. Today, 1:50,000 mapping of Canada is becoming an increasingly important aid especially in regions of high relief. In

Figure 6. One of the authors (M.D.T.) levelling a LaCoste and Romberg model G geodetic gravity meter.

hinterland areas where monumented control points are few, gravity surveys rely largely on the use of altimeters for vertical control. This is true also in many regions covered by road networks, since there are large areas where systematic modern levelling has not been conducted. In the Canadian Shield where lakes abound, lake levels established by airborne profile recorders supplement the coverage provided by monumented control.

The Gravity and Geodynamics Division uses Wallace and Tiernan surveying altimeters to obtain station elevations for most land surveys. Two altimeters are normally employed and are observed at each gravity station. The wet and dry bulb temperatures of a psychrometer are also recorded in order to correct the altimetry for varying temperature and humidity. Wherever possible, every 60 to 80 minutes, the altimeters are read at a monumented control elevation or lake level as a check on instrument drift caused by diurnal atmospheric pressure changes. A base altimeter is operated on occasions when prevailing weather conditions are variable and is used as an indication of when resurveying might be necessary. Experience with regional surveys where traverses may range up to 200 km from base indicates that a relative accuracy of ±5 m can be achieved using altimeters.

For barometric stations the error in elevation of ±5 m is the largest single contributor to error in the gravity anomalies. When translated into an error in Bouguer anomaly based on a density of 2.67 g/cm^3 it contributes approximately 1 mgal. In an attempt to

TABLE I

Summary of General Specifications for Gravity Surveys

1. Regional reconnaissance surveys
   - Gravity station specing 6-15 km
   - Track spacing 1-20 km
   - Standard deviation of horizontal positioning 200 m
   - Standard deviation of elevation 5 m
   - Standard deviation of water depth 3 m
   - Standard deviation of Bouguer anomaly 2 mgal (land surveys*)
   - Standard deviation of free air anomaly 2 mgal (offshore surveys — continental shelves)
   - Standard deviation of free air anomaly 3 mgal (offshore surveys — deep oceans)
2. Regional detailed surveys
   - Gravity station spacing 1-5 km
   - Standard deviation of horizontal positioning 50 m
   - Standard deviation of elevation 3 m
   - Standard deviation of water depth 2 m
   - Standard deviation of Bouguer anomaly 1 mgal (land surveys*)
   - Standard deviation of free air anomaly 1 mgal (offshore surveys)
3. Local detailed surveys
   - Gravity station spacing < 1 km
   - Standard deviation of horizontal positioning 2 m
   - Standard deviation of elevation 15 cm
   - Standard deviation of water depth 1 m
   - Standard deviation of Bouguer anomaly 0.1 mgal (land surveys*)
   - Standard deviation of free air anomaly 0.4 mgal (offshore surveys)

* Land surveys include ice surveys over inland lakes.

improve the situation the division has experimented with an automatic system for monitoring barometric pressure, air temperature and humidity known by the acronym HATS (Humidity Altitude Temperature Sensor). Information recorded at intervals of 10 minutes may be gathered for periods of up to one week without servicing the instrument and stored on a cassette recorder powered by a 12-volt battery. These sensors are intended primarily for use in areas covering no more than about 1,000 square kilometres. Three or more of them will be distributed throughout the region and it is hoped that they will provide sufficient information on the pressure surface to correct the roving altimeters.

The regions of high relief — the Cordillera and mountains of the northern Arctic islands — are the main areas still awaiting gravity surveys (Fig. 5). In surveys of similar terrain, for example in southern British Columbia, 1:50,000 topographic maps were a necessity not only for vertical and horizontal control but also to provide sufficiently detailed contour information to compute terrain corrections which often attain several tens of milligals. Altimetry is used sparingly in such terrain and station elevations have so far been obtained mainly from monumented control. In some areas of British Columbia the number of monumented vertical control points available for gravity determinations has been increased to meet the specified station density by special surveys mounted by the Surveys and Mapping Branch in response to requests for assistance. In recent years a photogrammetric technique has been tried in the Coast Mountains with reasonable success. Large cloth targets were laid down at station sites (Fig. 7) and were photographed vertically from the air at a height of about 760 m. With the station thus identified, its position was transferred to high altitude aerial photographs which were then treated photogrammetrically to provide the station elevation and

Figure 7. Gravity observation at a station in the Cordillera, British Columbia identified by a white cloth target. The target was photographed at an elevation of 760 m. Photogrammetric processing is later used to obtain the elevation and position of the station.

Figure 8. Through-the-ice depth sounding on the Arctic ocean.

horizontal position. The predicted height accuracy is 2 m. The accuracy of this method is fully discussed by Allam and Wong (1976).

Ice-surface surveys

Turbine-engined helicopters are generally employed over frozen water surfaces. Cruising at 160 km/hr over the ice, a two-man crew can make four gravity observations per hour for a daily total of about 32.

LaCoste and Romberg model G geodetic gravity meters operated in the damped mode to counteract surface accelerations arising from ice movement are used for all surveys on freshwater or sea ice. The low drift rate of the meter is particularly advantageous in surveys on offshore ice where base stations on land may not be reoccupied for periods of up to two weeks. Depending on ice conditions the accuracy of an observed gravity value is generally better than 0.3 mgal. During a recent survey on Great Slave Lake 36 station sites were marked and reoccupied; the average difference in observed gravity was 0.046 mgal and the standard deviation was 0.041 mgal. On the sea ice of the Beaufort Sea, where drifting ice must be taken into consideration and where the accuracy in reoccupation of a station position is dependant on the quality of the electronic navigation system used, a survey in early 1976 produced repeatability errors of up to 0.5 mgal which represents the probable upper limit of error in observed gravity for surveys of this kind.

The elevation of stations in a sea ice survey is taken as sea level and for inland lakes the lake ice level is normally determined by levelling from adjacent monuments. However, if Bouguer anomalies are to be computed the water depth must be determined. Depths are obtained with through-the-ice sonar sounding sets provided by the Canadian Hydrographic Service. The sets comprise an Edo model 9040-24S transmitter-receiver-recorder unit connected to a C-Tech transducer. The latter is laid on the ice surface (Fig. 8) and transforms electrical energy into sound energy. The sound energy pulse is then radiated vertically downward in the form of a conical beam a portion of which is reflected at the sea or lake bottom and is returned to the transducer. This particular model is capable of measuring depths up to about 1,300 m. Experience with the instrument on the Arctic ice and on James Bay and Great Slave Lake has shown that it measures depths with an accuracy of ±2% of the true depth. To minimize this error it is now customary to calibrate the sounder by cutting a hole in the ice and lowering a bar check (a 23 cm diameter steel disc) on a graduated cable and comparing cable and sounder depths to the disc.

Electronic navigation systems are used to determine horizontal positions for ice-surface surveys and will be described in the following section dealing with underwater surveys.

Underwater surveys

Gravity measurements over the continental shelves, inland seas and some of the large lakes are obtained from vessels such as the *CFAV Sackville* with a displacement of 1.04 Gg (1,130 tons) and length of 62.6 m. Such ships are operated by the Ministry of Transport and the Department of the Environment. Cruises are often multidisciplinary so that in planning the gravity survey consideration must be given to other demands on ship time. In a cruise dedicated to underwater gravity readings about 15 minutes are usually required to position the survey vessel and to lower, level, read and raise the underwater meter and about 45 minutes are needed to travel between stations when the spacing is 15 km. In good weather about one observation can be made per hour (Goodacre *et al.*, 1969).

The underwater gravimeters used by the Gravity and Geodynamics Division are manufactured by LaCoste and Romberg and are essentially heavily damped land gravimeter units suspended in gimbals and enclosed in a watertight container. The meters are lowered to the sea or lake floor, and are levelled automatically and operated by means of a remote control unit on the ship. A connection between the meter and the control unit is effected by means of a multiwire armoured cable which also sup-

ports the meter while it is being lowered and raised (Fig. 9). With these meters gravity readings may be repeated to within about ±0.3 mgal (Goodacre *et al.*, 1969). This value includes any error resulting from electronic repositioning. Normally the underwater meters are used in depths up to 600 m in Canada although they can be used in deeper waters.

Water depths in underwater surveys are measured by means of sonar sounders installed aboard the survey vessel or with a pressure transducer housed inside the meter. In a survey (comprising three separate cruises) of the Nova Scotia continental shelf in 1970 water depths obtained with a Westrex precision depth recorder (echo sounder) were compared by the least squares method with those recorded by a pressure transducer within the meter (Stephens *et al.*, 1971). A discrepancy of less than 1% from a straight line of slope one was obtained and although the standard deviation of depths obtained on the third cruise was as high as ±2.2 m that for depths of other stations of the survey was less than ±1.4 m. The corresponding errors in Bouguer anomalies would be ±0.35 mgal and ±0.22 mgal respectively (Stephens *et al.*, 1971). In deeper waters the errors are larger; for example in the Labrador Sea, Valliant *et al.* (1974) quote a standard deviation of 5 m for depths obtained using a Gifft-Alpine depth sounder.

Horizontal positioning for all underwater surveys as well as for ice-surface and shipborne gravimeter surveys is usually determined by electronic navigation systems. The main factors influencing the accuracy of any one system are the geometric disposition of its stations, the geometry of the system with respect to the survey area, the distance of the survey area to the baseline and atmospheric conditions. The best results have been obtained from relatively restricted surveys on inland lakes and in James Bay. In Great Slave Lake a Motorola MRS Mini-Ranger system provided positions with an accuracy of 25 m while in James Bay a Decca Lambda 6F system produced positions estimated to have errors ranging from 50 m to 300 m and averaging about 100 m. Away from shore the resolution deteriorates. For example in the Beaufort Sea a Decca Lambda 6F system gave positions varying in accuracy from 100 to 500 m with the overall average accuracy estimated to be better than 300 m. The worst results have been produced on the east coast of Nova Scotia which is served by Decca chains; within 150 km from the baseline the errors are believed to be less than 1,000 m, but beyond this limit they increase to a value of about 5 km along the continental margin (Stephens and Cooper, 1973). Such an error in the north-south position of a station would produce an error of 4 mgal in the gravity anomaly. Other electronic navigation systems that have been used by the Gravity Service include Loran C, Decca Hi-fix, Decca Mini-fix, and Magnavox 600 Doppler Sonar with satellite navigation updating. On occasions other survey methods such as sextant or theodolite resection, range-bearing radar, and transit and distance measurement have been used.

Sea-surface surveys

Gravity measurements over the deep oceans, continental shelves, and inland seas are obtained from ocean going vessels such as the *CSS Parizeau* (70 m) and the *CCGS Narwhal* (77 m)

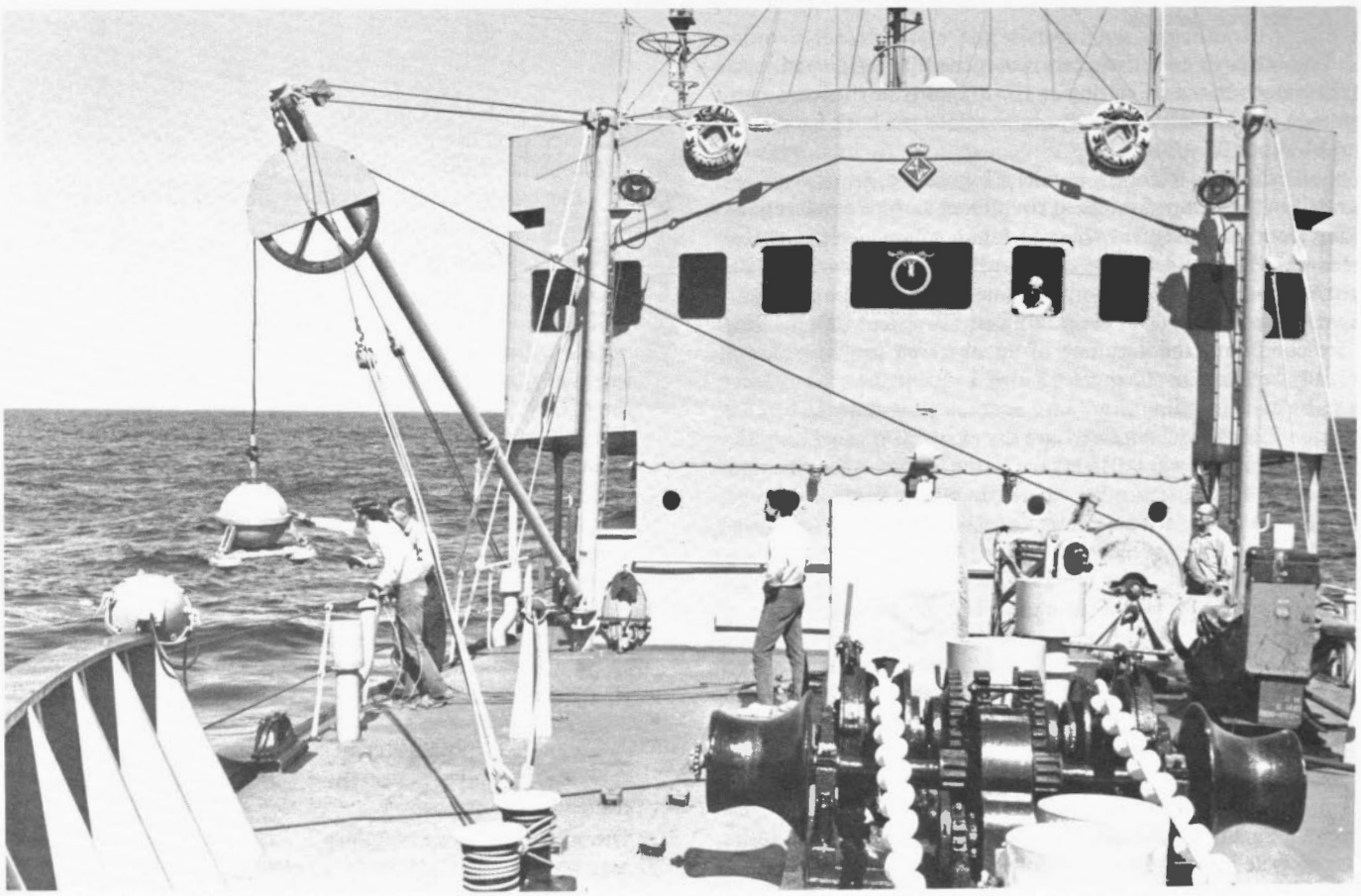


Figure 9. LaCoste and Romberg underwater gravity meter being hoisted aboard after a sea-floor gravity observation.

which are owned and operated by the Department of the Environment and Ministry of Transport respectively. Charter vessels have also been used. During cruises a variety of scientific investigations are conducted in cooperation with hydrographers of the Canadian Hydrographic Service and with geophysicists, geologists and oceanographers of other government agencies and other institutions.

The Gravity and Geodynamics Division uses a LaCoste and Romberg model S air-sea gravity meter mounted on a three-axis inertial platform. The fundamental design of this meter is described by LaCoste (1967) and an evaluation of the system is described by Valliant and LaCoste (1976). The Atlantic Geoscience Centre uses a Graf-Askania model GSS2 gravimeter, the essential features of which are outlined by Haworth and Loncarevic (1974). In 1972 both meters were tested for accuracy (Valliant *et al.*, 1976a) by comparing their readings against gravity values obtained with an underwater meter on a portion of the Nova Scotia shelf known as the Halifax test range (Goodacre, 1964). If errors are defined as the difference between surface and underwater values compared on a common datum (sea level) the mean error for the LaCoste and Romberg meter observed during a traverse varied from traverse to traverse to form a nearly normal distribution whose mean is 1.8 mgal and standard deviation 1 mgal; the corresponding statistics for the Graf-Askania meter are 2.1 mgal and 3.4 mgal respectively (Valliant *et al.*, 1976a).

Rates of production for sea-surface surveys vary according to the type of cruise. During a cruise dedicated to gravity work a ship sailing at 18.5 km/hr (10 knots) can obtain about 440 line kilometres of data in a day. With the LaCoste and Romberg meter the gravity data are collected every 10 seconds and filtered with a 60-point convolution filter supplied by the manufacturer (Valliant *et al.*, 1976a), and then subsampled at one minute intervals for profiles and 5-minute intervals (1.5 km) for regional mapping. With the Graf-Askania meter the gravity field is measured and recorded automatically in digital form every minute (Haworth *et al.*, 1976).

The methods of obtaining water depths and horizontal positions in sea-surface surveys are similar to those described for underwater meter surveys. However, there is an additional method for horizontal positioning which has been tested recently with encouraging results. Data collected in 1973 with the LaCoste and Romberg three-axis inertial gravimeter platform have been analyzed to determine whether the platform can provide adequate position information (Valliant, pers. comm.). The results suggest that navigation with the platform is possible with an rms error of approximately 100 m when ancillary positions are available at 30-minute intervals for gyro updating. With updates at two-hour intervals the rms error amounts to about 430 m. In the tests Hi-Fix was used to provide positions for updates, but coupled with satellite navigation the platform has the potential to provide positional information over an almost unlimited range.

Airborne gravimetry

In the not too distant future it is conceivable that regional gravity mapping in Canada will be conducted from an aircraft. With such a method data could be obtained rapidly over land, water and ice. At the moment, however, the state of the art is capable of accuracies sufficient for geodetic work only; with fixed-wing aircraft these are better than 10 mgal (LaCoste, 1967). In 1975 the Gravity and Geodynamics Division tested a LaCoste and Romberg air-sea gravimeter installed in a North Star aircraft (Fig. 10) during four return flights from Ottawa to the Bruce Peninsula. The speed of the aircraft varied between 220 to 280 km/hr. Analysis of the data indicates that the present system with further development might be capable of achieving accuracies of 5 to 10 mgal (Valliant *et al.*, 1976b).

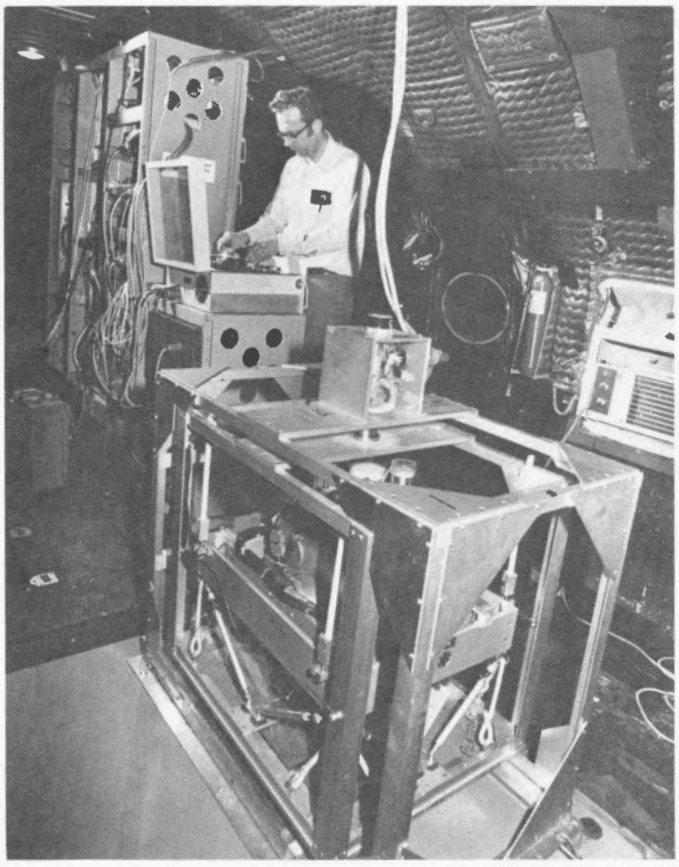


Figure 10 LaCoste and Romberg air-sea gravimeter system installed for tests in a North Star aircraft.

Gravity standards

The reference standard for relative gravity observations in Canada has recently been converted to the new world system of absolute gravity values adopted by the International Union of Geodesy and Geophysics (McConnell and Tanner, 1974). This system, known as the International Gravity Standardization Net 1971 (IGSN71), consists of 1,854 stations around the world (Morelli *et al.*, 1974). The datum for IGSN71 is provided by absolute measurements, the scale is controlled by both absolute and pendulum measurements and the internal structure is provided by some 24,000 gravimeter observations.

National gravity network

In Canada all gravity measurements in the National Gravity Data Base are tied to the National Gravity Network (Fig. 11) which comprises approximately 3,400 control stations having an absolute accuracy of ±0.1 mgal, and a relative accuracy of ±0.05 mgal (McConnell and Tanner, 1974). Most of the control stations have been established with LaCoste and Romberg gravimeters, although a limited number of older connections were made with

Worden and North American gravimeters. The network is solidly tied to the 20 stations of IGSN71 that are located in Canada. These are spread throughout Canada and provide datum and scale for the adjustment of the Canadian net to the new absolute standard. The Geodetic Reference System 1967 has also been adopted in Canada to replace the International Ellipsoid of 1930 as the reference surface for the computation of theoretical gravity.

Gravity meter calibration

Calibration lines such as that between Montreal and Resolute Bay continue to be the most convenient means of evaluating the performance of gravity meters and determining scale correction factors. Other calibration lines have been established in various parts of Canada to meet local requirements. The LaCoste and Romberg underwater gravity meters and the S meter are currently calibrated on a line between Ottawa, Montreal and Sept-Iles. At sea, dynamic gravimeters can be evaluated on the Halifax test range (Goodacre, 1964) and on signature lines established at convenient locations around Canada's coastlines.

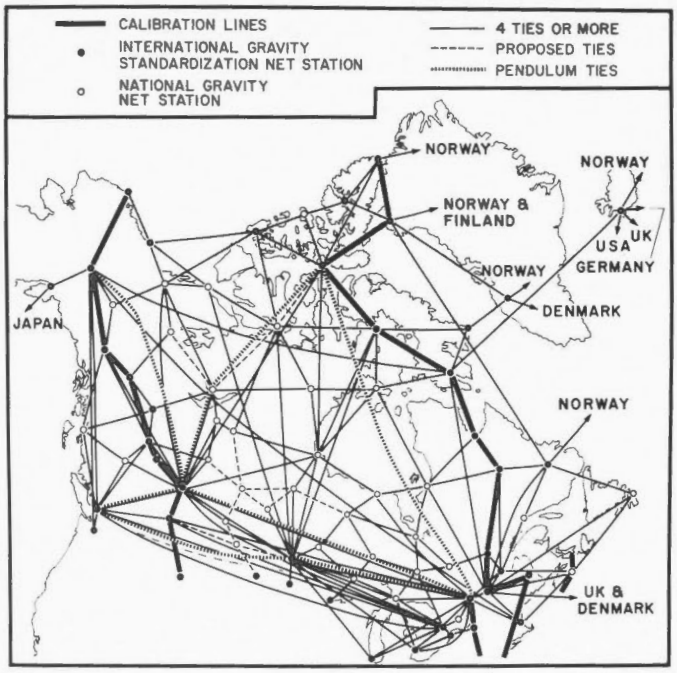


Figure 11. The principal control stations of the National Gravity Net.

Gravity data reduction and map production

It is common practice to reduce the gravity data in the field, in both land (including ice) and water surveys, using programmable calculators and onboard minicomputers. This provides a means of evaluating the performance of the various instruments and also enables erroneous and suspect data to be checked before moving to a new area. The preliminary gravity anomalies obtained in this fashion may also indicate features which require examination in greater detail. A full reduction procedure is carried out on return to headquarters in Ottawa. All observations are reduced to a sea level datum and Bouguer anomalies are computed using a standard density of 2.67 g/cm^3.

The gravity and related data are stored in the National Gravity Data Base maintained by the Gravity and Geodynamics Division in Ottawa. The evolution and design of this data base which now contains approximately 345,000 observations, have been described by Buck and Tanner (1972). Current design and operation are discussed by McConnell (this volume). Information may be retrieved from the data base in several formats — listings, punched cards, magnetic tapes, and plots depending on the customer's preference. Plots are available at any specified scale and a variety of map projections. Customers who use this service include exploration companies and consultants to the petroleum and mineral industry, provincial and federal agencies responsible for mapping and resource inventories, research geophysicists, geodesists and geologists, and the international scientific community.

The Gravity and Geodynamics Division publishes the results of its surveys in a series of maps, generally at a scale of 1:500,000, known as the Gravity Map Series. These are usually accompanied by a report describing the gravity surveys, the gravity anomalies, and their correlation with geology. The Atlantic Geoscience Centre publishes its data in the Natural Resources Map Series. This series (scale 1:250,000) is produced by the Canadian Hydrographic Service. Reports are published jointly by the Departments of Energy, Mines and Resources and Environment in a series of Marine Science Papers. Data are also released through the open file systems of Earth Physics Branch and the Geological Survey of Canada.

Acknowledgements

We wish to express our thanks to our colleagues in the Gravity and Geodynamics Division who provided us with much of the information reported herein. We particularly thank J. B. Boyd, R. K. McConnell and H. D. Valliant for critical reviews of the manuscript.

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Prof. G. P. Woollard:

Thank you very much Dr. Gibb. Our next speaker this morning is Dr. E. R. Niblett who will present a paper entitled **"Research in Geomagnetism in Canada".**

Dr. E. R. Niblett:

The search for the magnetic pole

Canada is particularly well suited for research in geomagnetism. Its enormous landmass contains the north magnetic pole and is bisected by the auroral zone. With Alaska included it forms the only major landmass in the world in which magnetic disturbance and related upper atmospheric phenomena are accessible for study from polar regions to sub-auroral latitudes. Its geological history extends from Archean time to the present and provides an opportunity for studies of paleomagnetism and continental evolution over a time span well exceeding 2,000 million years. The rich mineral deposits in the Canadian Shield have led to the development of an exploration industry in the country which has succeeded in producing and implementing advanced new techniques for discovery involving geomagnetic and geoelectric methods.

Since World War II research in geomagnetism has expanded enormously in this country in universities, in government and in the engineering and exploration industries. In most of the 10 provinces there is at least one university actively engaged in some aspect of geomagnetic research: paleomagnetism, magnetic depth sounding and magnetotellurics, the earth's main field and core hydrodynamics, magnetic pulsations, auroral studies and so on. Federal government agencies such as the National Research Council, the Department of Energy, Mines and Resources and (until recently) the Department of National Defence have long participated in large programs more or less national in extent. These include aeromagnetic surveys and magnetic charts, observatory networks, magnetic and electric field observations in balloons, rockets and satellites, auroral studies and other special studies in high latitude regions. Annual summaries of Canadian research in geomagnetism and aeronomy are prepared by the Canadian National Committee for the International Union of

Geodesy and Geophysics. They appear in the Canadian Geophysical Bulletin (Farquhar, 1975) which is published and distributed by the Earth Physics Branch, Department of Energy, Mines and Resources.

In view of its size and location it is not surprising that Canada has had quite a long history of research in terrestrial magnetism. This began in the far north more than 150 years ago with the magnetic observations of British seamen and explorers which made it possible to determine accurately, for the first time, the position of the north magnetic pole. These early observations were made by Franklin, Parry and Sabine between the years 1818 and 1826 during voyages commissioned by the government of Great Britain for discovery of a northwest passage through Arctic waters to the far east. The northwest passage was never found and these explorations ultimately took the lives of Franklin and most of his men. The magnetic observations were successful however, and gave a first pole position of 70°05'N latitude and 96°46'W longitude on the western side of Boothia Peninsula. This position was later confirmed in 1831 by Commander Ross another British seaman who made observations at the actual site. Later pole positions were determined by the Norwegian explorer Amundsen in 1904 and by officers of the Dominion Observatory (now called the Earth Physics Branch) in 1948, 1962 and 1973. The five pole positions obtained between 1831 and 1973 are shown in Fig. 1; the pole has drifted about 450 miles northward during this interval and the northerly motion is continuing today. This drift reflects the nature of the secular variation of the earth's main magnetic field in northern Canada.

Geomagnetic surveys were attempted in several British expeditions for exploration and discovery during the first half of the nineteenth century. The investigations of Gauss, Von Humbolt and other European scientists had by this time created widespread interest in the subject. Accurate values of declination were also of prime importance for navigation and the need for data from all parts of the globe was well recognized. The Royal Society in London was therefore able to persuade the British government to finance magnetic observations in many parts of the world. In the Canadian interior Captain George Back of the Royal Navy crossed 700 miles of the barren lands between Great Slave Lake and Chantrey Inlet on the Arctic coast in 1834. He took magnetic observations en route along that remote and formidable river which now bears his name. Lieutenant John Lefroy under orders from Colonel Sabine conducted a survey along the old voyageur canoe route from Montreal to Lake Athabasca in the company of one of the fur brigades of the Hudson's Bay Company. He then made his way to Fort Simpson and down the Mackenzie River to Fort Good Hope, turned southward again to the Peace River and thence to Edmonton, returning to Cumberland House via the North Saskatchewan. His survey spanned nearly the whole of Canada northwest from Montreal and took nearly two years (1843-44) to complete.

The early surveys were conducted in the face of difficulties and hardships we can scarcely imagine today. The work of Lefroy, Back and others enabled Sabine to compile a declination chart for Canada as early as 1844.

Magnetic observatories

In 1840 officers of the British Army established a magnetic observatory at Toronto following plans laid out by Colonel Edward Sabine. This observatory remained in operation until 1898 when the introduction of an electrical street railway in the city forced its removal to the rural community of Agincourt nine miles to the northeast. Agincourt Observatory survived until 1969 when it in turn fell victim to the construction of factories and a super-highway in its immediate vicinity. A new modern observatory was constructed near Ottawa in 1968 to continue the long series of observations (129 years) obtained at Toronto and Agincourt.

Between 1844 and 1853 the operation of the Toronto Observatory was entrusted to John Lefroy who successfully introduced photographic recording. After several years of data had been accumulated Sabine in England noticed a strong correlation between the mean intensity of geomagnetic disturbance at this observatory and the number of sunspots visible on the solar disc. The result was published by the Royal Society in 1851 and provided the first clear indication of a relationship between transient variations of the geomagnetic field and solar activity.

PATH OF THE UNPERTURBED NORTH MAGNETIC DIP POLE

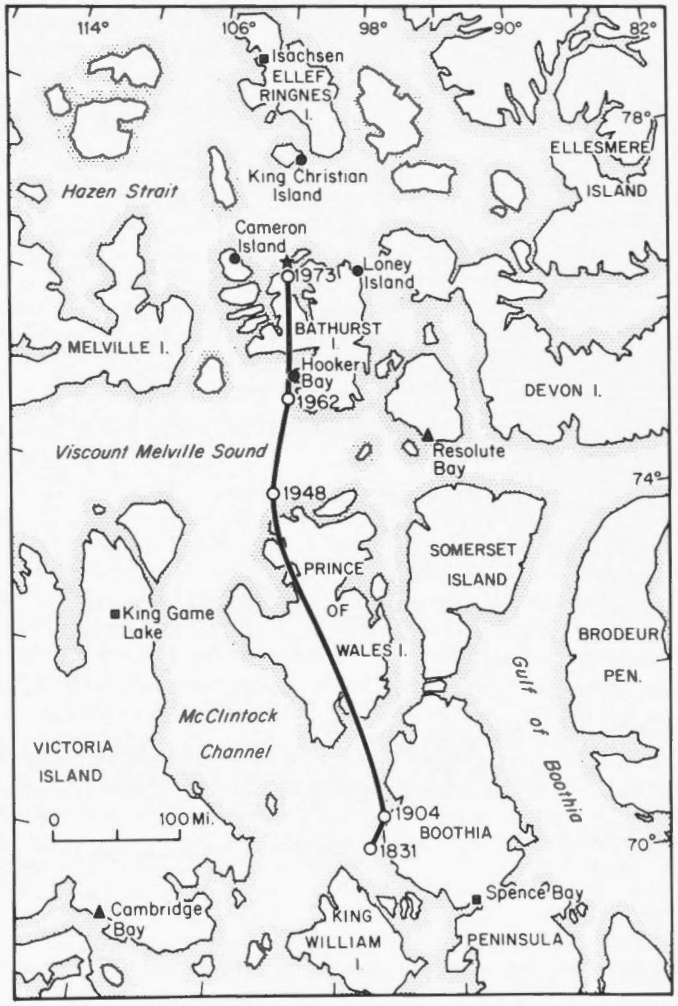

Figure 1. Peregrination of the north magnetic dip pole. 1831 to 1973. The 1973 position was derived from observations at Resolute Bay observatory, at Isachsen and King Game Lake in the repeat station network and at special observing sites at King Christian Island, Cameron Island, Loney Island and Hooker Bay. The extrapolated 1975 pole position is indicated by a star.

In 1916 a second observatory was built at Meanook in Alberta about 150 km north of Edmonton. High latitude observations of geomagnetic disturbances in Canada and elsewhere during the International Polar Years of 1882-83 and 1932-33 had clearly indicated that the auroral and polar regions were areas of great interest for research in terrestrial magnetism. However, the severe climate and the formidable problems of transportation and communication delayed the establishment of magnetic observatories in the Arctic until after the Second World War when aircraft capable of flying routinely in northern conditions became readily available. Baker Lake Observatory (latitude 64°20′) commenced photographic recording of three magnetic components in 1951 and Resolute Bay (latitude 74°42′) in 1953. The network was expanded during the International Geophysical Year (IGY) with the establishment of permanent observatories at Victoria on the west coast and Churchill on Hudson Bay. Since then observatories have been added at Mould Bay, Alert and Cambridge Bay in the Arctic, Great Whale River in the auroral zone, St. John's on the east coast, and Yellowknife on Great Slave Lake.

The Canadian observatory network as it exists today is shown in Fig. 2. Descriptions of the observatories along with data summaries for each year are provided in the Annual Reports for Magnetic Observatories of the Earth Physics Branch, e.g. Loomer (1976).

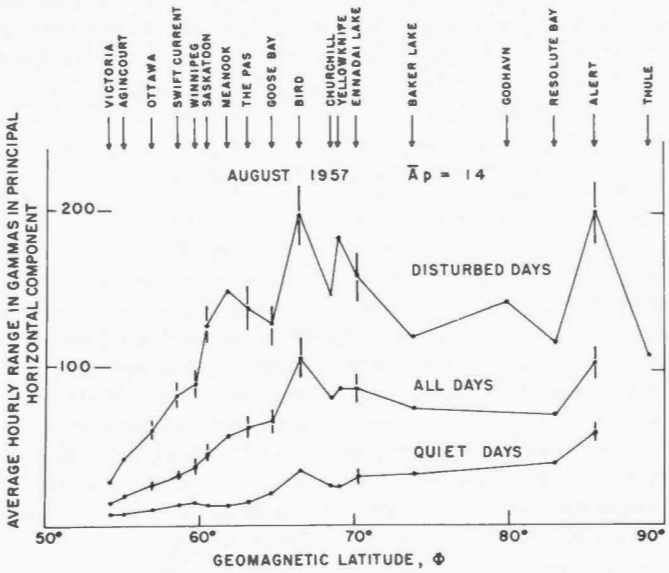

Figure 3. The latitude distribution of irregular magnetic activity in Canada as determined during a one month interval of the International Geophysical Year (after Whitham *et al.*, 1960).

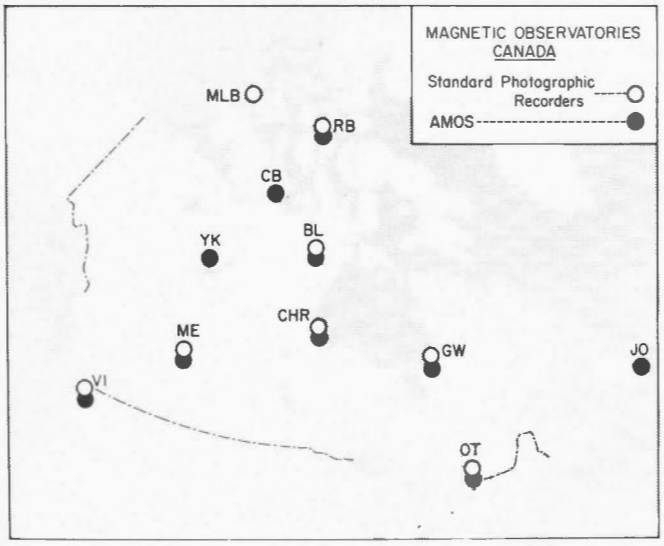

Figure 2. The Canadian magnetic observatory network.

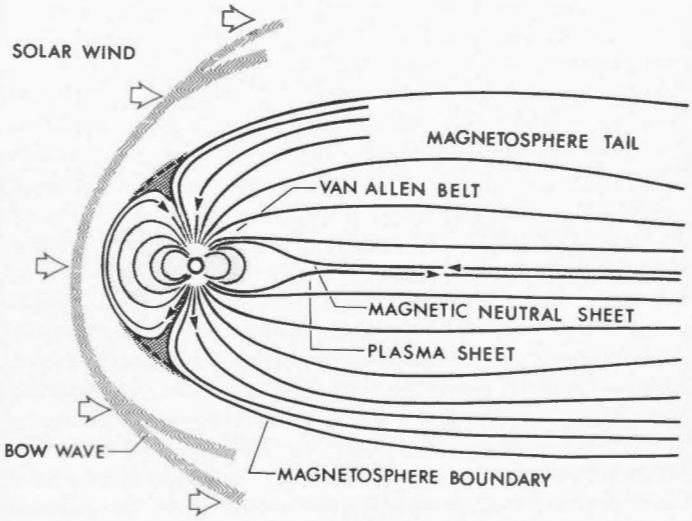

Figure 4. Structure of the magnetosphere.

A well distributed network of observatories is important in Canada where both the magnetic field itself and the character of geomagnetic disturbance vary rapidly with latitude. The manner in which geomagnetic activity depends on latitude is illustrated in Fig. 3. The peak in activity at the auroral zone is clearly evident; the secondary peak in the far north at Alert is in a sense fictitious because it reflects a very large local induction anomaly, not a true latitude effect.

Two very distinctive zones of geomagnetic behaviour exist in Canada: the auroral zone and the polar cap. Their boundaries are defined by the structure of the magnetosphere, a noon-midnight meridianal section of which is shown in Fig. 4. Because of the compression of the geomagnetic field by the solar wind on the sunward side the field lines at polar cap latitudes are swept back to form the enormously elongated magnetosphere tail. The dipole character of the field is therefore greatly distorted at distances of several earth radii and a pair of field-free clefts or cusps is formed along the noon meridian on the sunward side of each polar cap into which the solar wind can penetrate very deeply. The cusp regions provide access to the ionosphere for low energy charged particles and make possible the creation of the Van Allen radiation belt and the auroral electroject. The line of intersection between the outer boundary of the Van Allen belt and the ionosphere coincides approximately with the auroral oval. The polar cap is the region on the polar side of the cleft and is characterized by open field lines. Electric fields embedded in the

solar wind can enter the polar ionosphere through the cleft region and give rise to current systems in the polar cap which produce the so-called interplanetary magnetic field effects. The Canadian observatory network includes Mould Bay and Resolute Bay in the polar cap, Cambridge Bay in the cleft region, Baker Lake in the transition region with both polar cap and auroral characteristics, Yellowknife, Churchill and Great Whale River in the auroral zone and the remaining four observatories distributed between the east and west coasts in the sub-auroral region.

This network has provided data for many geophysical applications: the removal of time variations from aeromagnetic survey data; the evaluation and study of secular change; studies of the aurora and auroral current systems; the morphology and latitude distribution of magnetic bays and pulsations; the structure, ionization and physical processes associated with the ionosphere and magnetosphere; and the study of overhead current systems across the polar cap. Canadian observatories along with north-south profiles of temporary geomagnetic recording stations across the auroral zone have made an important contribution to recent advances in our understanding of the magnetosphere and the physics of the upper atmosphere. Government laboratories and several universities have been deeply involved in aeronomical problems of this kind.

During the period of the International Magnetosphere Study (IMS) (July 1976 — December 1978) the University of Alberta will operate a north-south profile of eight temporary geomagnetic recording stations across the auroral zone in western Canada and the Earth Physics Branch will operate a similar chain of eight stations centred on Fort Churchill. Data from the permanent observatories at Meanook, Yellowknife, and Cambridge Bay will augment the coverage of the western chain, while records from Whiteshell, Churchill, Baker Lake and Resolute Bay will extend the data available on the Churchill line of stations. Data from these two profiles will be deposited in the World Data Center in Boulder, Colorado for selected intervals during IMS. These ground-based magnetic observations will support rocket, balloon and satellite probes of the ionosphere and magnetosphere and should provide the information required for detailed study of complex current systems and structure in these regions, and for study of solar-terrestrial interactions. A summary of Canadian-based activities planned for IMS is given by Currie (1976).

The University of Alberta has operated its meridian line of approximately ten magnetic observatories between Edmonton and Cambridge Bay, N.W.T. for several years. This profile has contributed valuable data for the study of polar magnetic substorms, electrojet and field-aligned current systems and micropulsations. A review of polar magnetic substorms and their generating mechanisms has been given by Rostoker (1972) and of micropulsations by Jacobs (1970). Studies of magnetic disturbances, micropulsations and the structure and dynamics of the magnetosphere have also been pursued for many years at the University of British Columbia, Calgary University, the Earth Physics Branch and until recently the Pacific Naval Laboratory of the Department of National Defence.

Until 1946 absolute magnetic field measurements depended on classical methods using suspended or pivoted magnets in various configurations. A set of measurements of three components required over an hour to complete with such instruments and they were unsuitable for work in high latitudes where the horizontal force is small and large disturbances in all components are common. After World War II when the Dominion Observatory planned to extend its magnetic observatories and survey operations to the far north the need for improved techniques of absolute field determination became obvious. An electrical sensor, the fluxgate, provided a satisfactory solution to the problem. At the Dominion Observatory portable fluxgate systems were developed which could measure a set of three components (D, I, and F) in about 15 minutes and which had adequate sensitivity to perform reliably in weak horizontal fields (Serson and Hannaford, 1956). By 1950 fluxgate magnetometers with the sensing coil mounted parallel to the optical axis of a theodolite telescope had replaced classical systems for ground magnetic survey work and were being introduced as standard absolute instruments at Canadian observatories. Proton precession magnetometers were available for absolute determination of F by 1960 though fluxgate systems are still used for measurement of declination and dip.

Fluxgate magnetometers were also developed as continuous recording instruments for three field components (D, H, Z or X, Y, Z) during the 1950's (Serson, 1957). These electrical systems were deployed at a large number of temporary recording sites during the International Geophysical Year. At the permanent observatories they supplemented, but did not replace, the classical photographic systems of the LaCour or Ruska type. Though somewhat inferior for long-term stability and overall quality the fluxgate recording magnetometers had the great advantage of permitting observations of magnetic disturbances as they occurred so that real-time knowledge of geomagnetic conditions could be made available.

In recent years fluxgate recording systems have become more sophisticated with solid-state circuitry (Trigg *et al.*, 1971) and with digital as well as analogue outputs which permit unattended operation for many weeks (Anderson, 1974). Proton precession magnetometers have been incorporated in these digital systems to provide an absolute reference against which the three recorded components may be compared. Most Canadian observatories are now equipped with automatic systems of this kind and a few are operating as unmanned stations with only occasional visits for changing the recording tapes and taking absolute observations.

Micropulsations in the shorter period ranges (Pc1 and Pc2) are not normally recorded in the Canadian magnetic observatory network. However, several universities, notably British Columbia, Alberta and McGill, and the Pacific Naval Laboratory have operated short period micropulsation systems for a number of years using induction coils with appropriate amplifiers and recording devices. UBC has commenced working with arrays of induction magnetometers in Canada and United States for a concentrated study of Pc1 and Pc2 during IMS. The University of Victoria and the University of Tokyo will collaborate in this ambitious project.

Geomagnetic surveys and magnetic charts

The Topographical Survey of Canada, a federal government agency, began a systematic magnetic survey program in 1880 to provide accurate values of declination. Declination was important at that time in land surveys which usually depended on the compass for azimuth determinations. Shortly after the turn of the century scientific interest in the geomagnetic field, its distribution over the globe, and its secular variation was stimulated by L. A. Bauer and J. A. Fleming at the Carnegie Institution in Washington. Realizing that Canada was well located to make an important contribution to world magnetic survey and to research

in geomagnetism, the federal government in 1907 instructed the newly formed Dominion Observatory to organize a magnetic survey program in Canada.

At that time the railways, the marginal seas and inland rivers and rough trails through the bush or prairies afforded the only means of transportation. Surveys on a national scale presented a formidable problem. Field work in those days was done by C. A. French and R. G. Madill of the Dominion Observatory and required expertise in canoeing, trail riding and wilderness survival as well as skill with magnetic instruments. Many of the observation stations established by French and Madill are still revisited at regular intervals for evaluation of the secular variation.

An accurate description of the magnetic field and its secular variation over Canada is no longer required for land surveys, but still has important applications in sea and air navigation, in the removal of regional trends from large-scale aeromagnetic maps used in mineral exploration and interpretation of crustal structure, and in providing data for world magnetic charts and determination of the International Geomagnetic Reference Field. Ground surveys at a network of repeat stations are adequate for mapping the secular variation, but airborne methods are required to provide a data base suitable for mapping the geomagnetic components. Accordingly P. H. Serson and his colleagues at the Dominion Observatory began the development of a 3-component airborne magnetometer system in 1948. Three fluxgate sensors were mounted on a stabilized platform controlled by gyroscopes, accelerometers and servomotors to remove or diminish the effect of aircraft accelarations (Fig. 5). This magnetometer was flying in long-range aircraft as early as 1953 and has surveyed the whole of Canada, Iceland, the Scandinavian countries and parts of the Pacific and Atlantic Oceans since then. Phase I of the aeromagnetic survey program had as its objective the acquisition of data for regional magnetic charts at a scale of one inch per 100 miles. Flight lines were spaced about 100 km apart at an altitude ranging from 2 to 6 km and D, H and Z components were averaged over successive 5-minute intervals corresponding to about 30 km along the flight line. This phase was completed in 1963. In Phase II the survey objective was enlarged to include mapping of broadscale magnetic anomalies for the study of deep crustal structure. The flight line spacing was reduced to about 50 km or less and 30-second and one minute averaged values were obtained along the flight lines as well as five-minute averages. Phase II coverage of Canada was completed in 1976. These two programs have provided a comprehensive and well distributed data base for the construction of magnetic charts of Canada at a scale of 1:10,000,000 and regional aeromagnetic anomaly maps. The data have been used for analysis of large crustal anomalies, their interpretation in terms of crustal structure and composition and their implications regarding tectonic history (e.g. Coles *et al.*, 1976; Haines and Hannaford 1972; Haines *et al.*, 1971). A vertical force anomaly map covering western Canada and the adjacent Pacific is illustrated in Fig. 6. Three distinct patterns are evident: the familiar north-south trending linear anomalies typical of oceanic crust, the northwest-southeast trends in the anomaly pattern over the Cordillera and the large complex anomaly pattern which is associated with the Precambrian basement rocks underlying the Great Plains and the western Rocky Mountains. Magnetic charts for Canada are now available for 1975. They were derived from a least squares determination of the normal field of approximately 54,000 component observations.

Figure 5. The gyro-stabilized platform and fluxgate sensor assembly for the 3-component airborne magnetometer system.

The airborne magnetometer system now includes a proton precession magnetometer to cross-check and standardize the fluxgate measurements and an in-board computer to assist with the averaging process and the recording of data in digital form.

A low-level aeromagnetic survey program over the Canadian Precambrian Shield was begun in 1960 to provide basic data and information for the mineral exploration industry. With organization and funding shared by federal and provincial governments plans were implemented for detailed total intensity coverage (½ mile line spacing, 1,000 ft. altitude) of the entire Shield. The Geological Survey of Canada arranged flying contracts and reduction of data for production of aeromagnetic charts on a scale of 1 mile to the inch or 4 miles to the inch. By the end of 1976 over 90% of the Shield area had been covered in this ambitious program. Low level surveys have also been completed over substantial portions of the Cordillera in British Columbia and Yukon, over Baffin Island and parts of the Arctic Ocean and Queen Elizabeth Islands. Under the direction of the Atlantic Geoscience Centre in Bedford, N.S. over 100,000 miles of shipborne magnetometer surveys have been completed. Areas covered include Bay of Fundy, Grand Banks, Labrador Sea, Baffin Bay, Hudson Strait and Davis Strait and other portions of the eastern continental shelf.

Paleomagnetism and rock magnetism

Research in rock magnetism and paleomagnetism is carried out in government laboratories and at a large number of Canadian universities. Work began in the early 1950's after Professors Blackett and Runcorn in England and Professor Thellier in

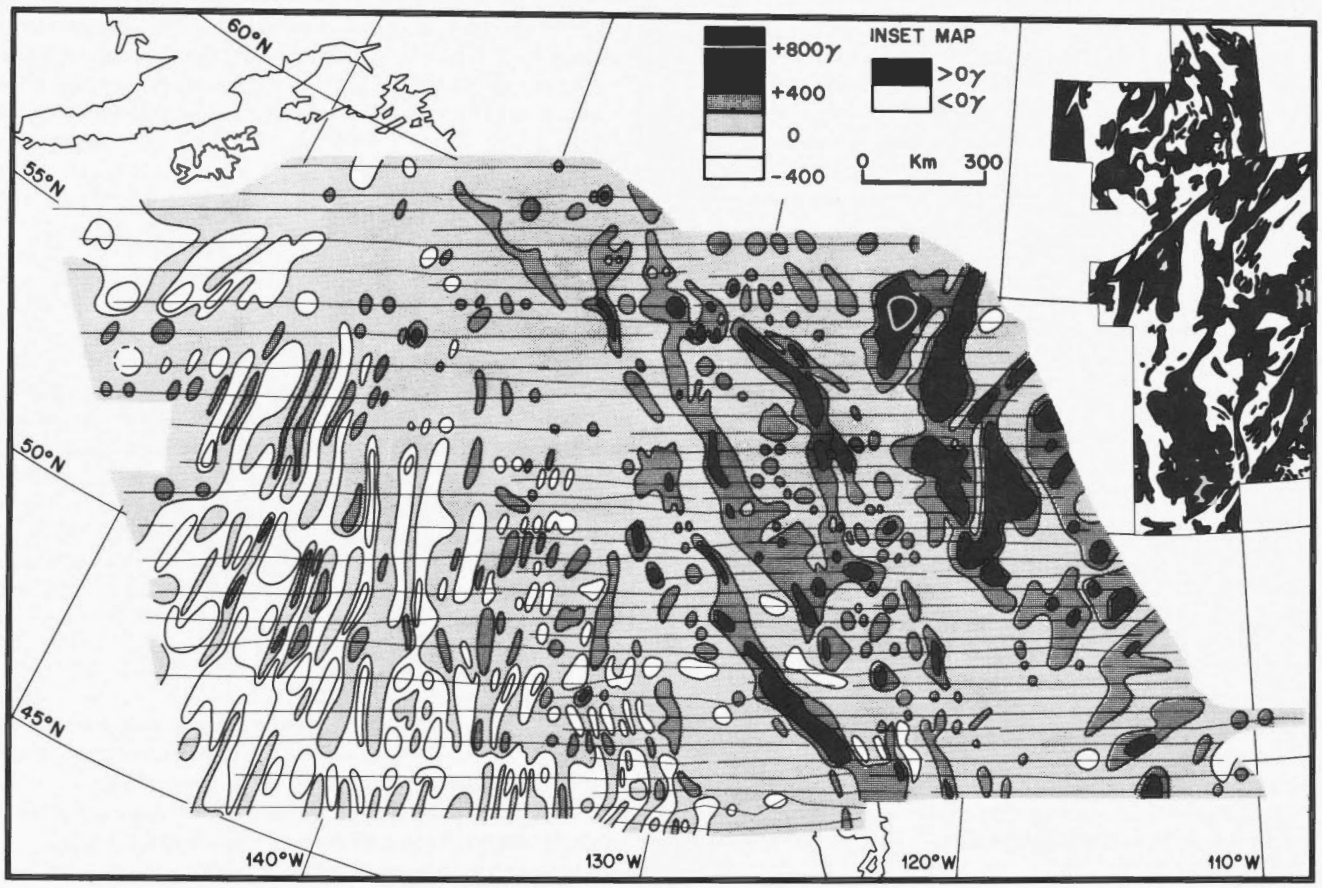

Figure 6. Vertical force magnetic anomalies over the eastern Pacific and western Canada (after Haines *et al.*, 1971).

France had shown that it was possible to measure weak remanent magnetizations in rocks and thereby learn something of the character and behaviour of the geomagnetic field in the remote past.

When paleomagnetic evidence is obtained from relatively young sedimentary formations or lavas that have been little altered it is reasonable to assume that the remanent magnetization reflects the direction of the earth's field at the time the rocks were formed. Such an assumption is seldom valid for rocks of Precambrian age which have often suffered heating, deformation or metamorphism many times throughout their long history. The original magnetization is usually lost and replaced by one or more secondary magnetizations, each associated with different thermal events. Complex laboratory techniques are required to identify and separate these polyphase magnetizations and to associate each with the appropriate interval in geological time.

Despite these difficulties paleomagnetic research in Canada has been much concerned with the study of Precambrian rocks, partly because of the enormous size and economic importance of the Canadian Shield and partly because the Precambrian offers the stimulating challenge of investigating the geomagnetic field, polar wander and continental drift in the early stages of the earth's history.

The Precambrian Shield of North America, Greenland and Northwest Scotland is usually referred to as Laurentia. Approximately 100 localities in this shield have been carefully sampled for paleomagnetic work and have provided pole positions which are reliably dated. From these pole positions Irving and Lapointe (1975) have constructed a single apparent polar wander path for the main body of Laurentia (Fig. 7). The path is complex and is characterized by sharp bends (hairpins) and loops, each loop extending over a period of the order of 100 m.y. Only the Grenville Province occupying the southeastern portion of the Shield does not appear to fit this reconstruction. The Grenville poles have been arranged in a separate track implying that prior to 1,000 m.y. BP this province was not part of Laurentia as it is today.

At the present time too few reliable observations are available to define unambiguously an apparent polar wander path over a time interval of two billion years. The preliminary reconstruction by Irving and Lapointe implies that, except for the Grenville Province, the main body of Laurentia has remained more or less intact throughout the Proterozoic. Its mean rate of continental drift would be about 5 cm/year, comparable with present rates. The sharp bends or hairpins are large-scale effects signifying large changes in continentai motion which have been found to correspond well in time with major orogenies between 2,400 m.y. BP and 600 m.y. BP. Other reconstructions are, of course, possible and as more reliable data become available modifications to the apparent polar wander path may be expected.

There have also been many paleomagnetic studies of younger Canadian rocks to determine apparent polar wander and continental drift during Phanerozoic time and to help with

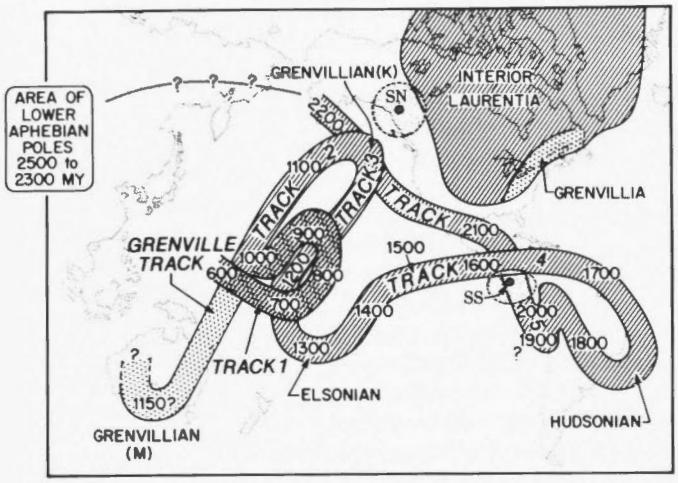

Figure 7. A possible polar wander path relative to Laurentia from −2,200 to −600 m.y. The main tracks are numbered and calibrated at intervals of 10^8 years. The hairpins are named by the orogeny to which they are thought to correspond. SS and SN are poles from the Sudbury nickel irruptive (after Irving and Lapointe, 1975).

geological dating and structural correlation of sedimentary and volcanic formations. Such studies are contributing important information on the evolution of the Cordilleran, Appalachian, and Innuitian (high Arctic) orogenic systems. The world-wide distribution of pooled oil reserves has been investigated in an attempt to rationalize their occurrence in terms of paleolatitudes, paleoclimates and tectonic activity (Irving, North and Couillard, 1974). Paleomagnetic data from eastern North America and western Europe have indicated that these regions with their adjacent continental shelves formed a single block during the Upper Paleozoic. Latitude displacement between North America and Europe corresponding to an early stage in the development of the North Atlantic Ocean is evident from the Triassic data, and the separation of the two land masses was well advanced during the Cretaceous. The sequence of events leading to the formation of the North Atlantic Ocean is described by Roy (1972).

Electromagnetic induction in the Earth

Magnetotellurics and magnetic depth sounding methods have received much attention in Canada during the past 15 — 20 years. The main objective of such investigations has been to obtain information about the electrical conductivity of the earth in crustal layers and in the uppermost part of the mantle. In the magnetotelluric method it is assumed that relationships between natural time variations in the geomagnetic and geoelectric (telluric) fields are governed by Maxwell's equations and that the fluctuating electric currents flowing beneath the surface are created by the process of electromagnetic induction. These field variations and the electric currents associated with them can penetrate into the earth to depths which depend on their frequency and on the electrical conductivity of the rock. Within the framework of certain rather broad assumptions, relationships between the horizontal components of electrical and magnetic fields at the surface may be derived which permit the estimation of electrical conductivity at depth provided the field variations are recorded over a fairly wide range of frequencies (Cagniard, 1953; Wait, 1962). In the geomagnetic depth sounding method only horizontal and vertical components of the magnetic field are used. A number of recording magnetometers are deployed along a profile or in a large array and operated simultaneously for a few weeks or until sufficient data are accumulated. Estimates of conductivity at various depths may be derived from the ratio of vertical to horizontal magnetic field and its dependence on frequency (Rikitake, 1966). As with the magnetotelluric method geomagnetic depth sounding is based on the classical theory of electromagnetic induction. In both methods the interpretation of field data is usually achieved by calculating the electromagnetic response of a particular model (horizontally layered earth with constant conductivity in each layer, uniform conductivities on either side of a vertical boundary or more complex two and three-dimensional structures) and comparing the model with the observed response measured during the field experiment.

Many Canadian universities and the federal government have been engaged in studies of this work. Convenient instruments for magnetic depth sounding experiments have been developed recently by Gough and Reitzel (1967) and large magnetometer arrays with over 40 stations in operation at one time have been deployed in the Cordillera and Great Plains regions of Canada and the United States by the University of Alberta and other institutions. Important theoretical studies and field experiments in magnetotellurics have been conducted at Alberta and at the University of Toronto. Other universities and the Earth Physics Branch have concentrated on magnetotelluric experiments and small profiles of recording magnetometers (usually 10 stations or less) for geomagnetic depth sounding in various regions. For many years the University of Victoria has conducted theoretical studies (e.g. Weaver, 1973) and scaled analogue model experiments in the laboratory to determine the electromagnetic response of various simulated models of crustal structure (Dosso, 1973). At the University of Alberta numerical methods have been used extensively to solve complex modelling problems with a computer (Jones, 1973). The results from both analogue and numerical models are useful in interpreting electromagnetic depth sounding data obtained during experiments in the field. An experimental investigation of the usefulness of the magnetotelluric fields for earthquake prediction is in progress at the Earth Physics Branch (Honkura *et al.* 1976).

Canadian studies in electromagnetic depth sounding have produced some interesting results. Large crustal and upper mantle structures having very high electrical conductivity have been located in the Cordillera regions of western Canada and United States (Porath *et al.* 1971), in the Black Hills region of the Great Plains near Montana and North and South Dakota (Alabi *et al.*, 1975; Kao, 1975) and in many of the islands which form the Arctic Archipelago (Niblett *et al.* 1974; DeLaurier *et al.* 1974). The cause of these huge anomalies in the earth's upper layers is not known except that they reflect either regions of anomalously high temperatures at depth (as in the Cordillera) or structures of special composition to account for their high conductivity. Dissolved salts, hydrated sediments, sulphide and graphite mineralization are all highly conducting materials. Recent work by Hyndman and Drury (1976) at Dalhousie University has shown basalts of oceanic origin may also possess conductivities high enough to produce some of the anomalous effects observed in magnetic depth sounding experiments.

When the geographical distribution of large induction anomalies is considered it is found that the majority are located near present continental margins or in regions which can be iden-

tified as old plate boundaries (Garland, 1975; Law and Riddihough, 1971). Thus they appear to be associated in a fundamental way with rift systems and mobile belts and their study may be expected to add an important contribution to our understanding of global tectonics.

Fig. 8 shows the effect on magnetic field variations of a very large and approximately 2-dimensional induction anomaly located near Alert on the northern end of Ellesmere Island and the adjacent Lincoln Sea.

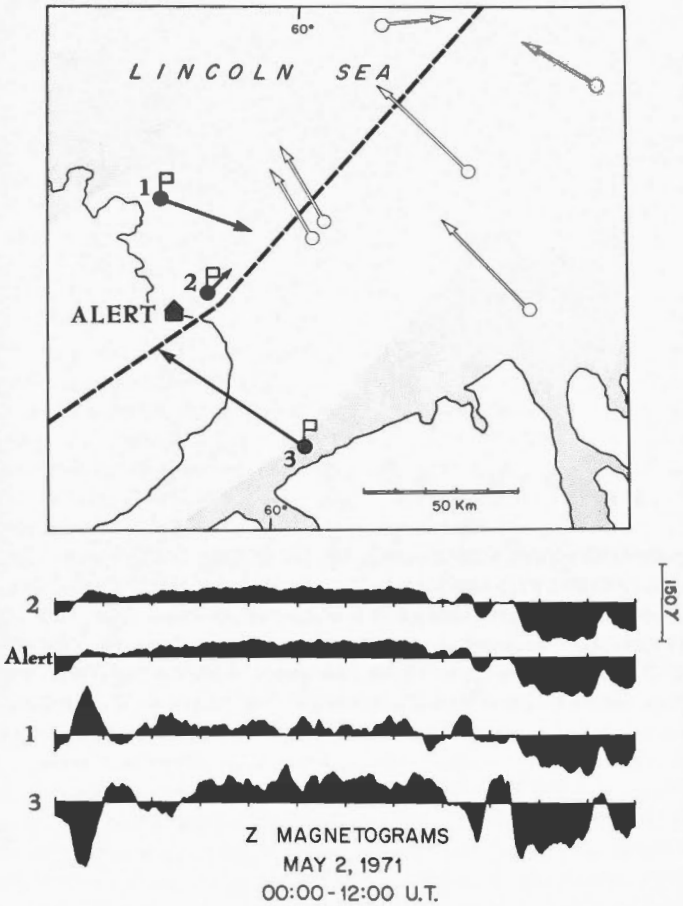

Figure 8. The Alert induction anomaly extends for over 600 km across the northern end of Ellesmere Island and beneath the continental shelf of the Lincoln Sea. It has been attributed to a massive elongated conducting body lying at a depth of several km in the crust. Electric currents flowing in this conductor produce the anomalous and strongly localized magnetic fields which are observed at the surface. The vertical component magnetograms above illustrate the anomalous effect along a profile of stations close to the Ellesmere coast. The Parkinson arrows at the various stations were derived from the recorded geomagnetic variation data and point toward the location of the anomaly axis (dotted line).

Magnetotelluric and magnetic depth sounding methods have traditionally depended upon natural field fluctuations in the period range from about 1 sec to many hours. Such low frequencies are useful for investigating structure in the deep crust and upper mantle but provide little information on near surface features at depths appropriate for mineral exploration. Recently magnetotelluric techniques have been extended to much higher frequencies (1 Hz to 20,000 Hz) and have become a powerful tool for mineral and geothermal exploration and determination of permafrost depths (Strangway *et al.*, 1973; Pham, 1975). The development of theory, instrumentation and exploration techniques in this high frequency range (audio magnetotellurics) has been actively pursued at the Universities of Toronto, Alberta, École Polytechnique de Montréal and McGill.

Conventional magnetotelluric methods depend on naturally occurring electromagnetic variations. Goldstein and Strangway (1975) have investigated the possibility of using audio-frequency magnetotellurics with a controlled electric dipole source. Other instruments using a magnetic dipole source are being developed commercially and appear to have good potential in geophysical exploration. Over the past three decades Canadian companies and the Geological Survey of Canada have made important advances in the development and use of electrical and magnetic methods for exploration and prospecting, particularly in airborne EM systems (see for example Dyke *et al.*, 1975). Additional examples are very high sensitivity fluxgate magnetometers, proton precession magnetometers for ground and air survey, new resistivity survey techniques and other electrical methods (e.g. Scott, 1975). The Earth Physics Branch and the universities mentioned above have also made substantial contributions in survey instrumentation and techniques. The Geological Survey of Canada has recently obtained good results with vertical magnetic gradiometer systems for high resolution aeromagnetic surveys (Kornik *et al.*, 1975). Summaries of current Canadian work in exploration geophysics are given in the Canadian Geophysical Bulletin (Farquhar, 1975, Ch. 8; Carmichael, 1974, Ch. 9). The 1974 bulletin also lists Canadian manufactures of geophysical instruments and Canadian companies offering airborne geophysical surveys. A review of current progress in exploration technology is given by Hood (1977).

Theoretical studies of the earth's main magnetic field

The outstanding characteristic of the geomagnetic field is its similarity to the field of a centred dipole. William Gilbert realized this essential feature nearly 400 years ago and inferred that the origin of the field must lie within the earth. Over two centuries later Gauss proved that this was so. Paleomagnetic results have shown that the geomagnetic field has existed for more than half the earth's history and that its intensity over that interval has been roughly the same magnitude as it is today. Moreover, the field has reversed itself many times throughout its long life. The field at the earth's surface contains significant non-dipole components which complicate to some extent its distribution over the globe; it is also subject to gradual and unpredictable changes with time (the secular variation) the effects of which accumulate over tens and hundreds of years, but which average out to zero over thousands of years. Paleomagnetic evidence has demonstrated a persistent tendency for the axis of the geomagnetic dipole to align itself parallel or nearly so to the axis of the earth's rotation.

The dynamical behaviour of the field — its secular variation and its reversals — strongly suggests that the mechanism for its origin and maintenance must lie within the earth's fluid core. Most geophysicists support the idea that the field is sustained through some kind of dynamo action in the core in which electric currents are generated by motion of the conducting fluid. Either thermal convection or the earth's precession appear to be the only available sources of energy adequate to drive the dynamo. Though many theories have been put forward the distribution and character of the core motions and the induced electric and

magnetic fields associated with them are still a matter of conjecture and controversy. While the mechanism of the geomagnetic dynamo is not fully understood the constraints put on it by our observations of the geomagnetic field at the surface have provided much insight into its character. Much of the recent Canadian research on these problems has been based at Memorial University in Newfoundland and the University of Alberta. At Memorial theoretical estimates have been made of the power requirements for a stationary geomagnetic dynamo and of the power available to the core through precession (Rochester, 1974). This work shows that unless hydromagnetic turbulence plays an important role in the operation of the dynamo the power available from precession is too small. The possibility of a precession-driven dynamo therefore appears to be remote. At the University of Alberta investigations of internal gravity waves, inertial waves and hydromagnetic waves in the core and their possible contribution to the dynamo process have received much attention (Aldridge, 1975). J. A. Jacobs (1971, 1972a, 1972b) has discussed the physical properties of the earth's core in some detail and decided that insufficient data are available to distinguish conclusively between precession and convection as mechanisms for generation of the magnetic field. For thermal convection in the outer core to exist it is necessary that the actual temperature gradient in this body equal or exceed the adiabatic gradient. For the outer core to remain fluid it is also required that the melting point gradient equal or exceed the adiabatic. Whether or not these conditions can be met depends critically on the composition of the core. While it is almost certain that the main constituent is iron the amounts of other elements present such as silicon, oxygen and sulphur are not known.

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Prof. G. P. Woollard:

Thank you very much Dr. Niblett. Our next speaker is Dr. M. J. Berry who will talk on **"The Contribution of Canadian Seismological Research to Society".**

Dr. M. J. Berry:

On a global basis approximately 85% of all earthquakes occur at the edge of the lithospheric plates with the Pacific rim being undoubtedly the most active. In this century for example 32 earthquakes with magnitudes greater than 8 have occurred in the relatively narrow band along the western coast of the Americas. From north to south, these have occurred at the north end of the Strait of Georgia, Canada (1946), San Fernando, California (1971), Veracruz, Mexico (1973), Guatemala (1976), Managua, Nicaragua (1972) and within the last two decades there have been many damaging and indeed catastrophic earthquakes in Costa Rica, Ecuador, Peru, Chile, and Venezuela. In the interior of the North American continent, we have of course had damaging earthquakes at Charleston and New Madrid in the east and central United States and in the St. Lawrence Valley of Canada.

Other regions of the Western Hemisphere such as certain parts of the Caribbean also have frequent earthquakes. Less pronounced but nonetheless significant seismicity occurs in the north east and central parts of North America and in the northern regions of South America.

So the occurrence of earthquakes is a well-known phenomenon and the damage that they can do is dramatic and increasingly well publicized.

There are many reasons for studying seismicity. These include the use of earthquakes as a source of seismic energy enabling seismologists to study the structure of the Earth. Earthquakes are also the most dramatic evidence we have of the dynamic nature of our spaceship Earth and the study of geodynamics is of fundamental significance to all of the earth sciences. Finally the study of earthquakes enables us to assess the degree of seismic risk to which man and his structures will be subjected. With an appreciation of this risk we are in a position to choose from among several courses of action the best manner in which to mitigate the expected casualties and damage.

In this paper I shall define seismic risk as the probability of occurrence of a degree of seismic ground motion during a specified period and seismic hazard as the consequences of the ground motion measured in terms of casualties and property damage per unit area per year. In these terms an appropriate objective for a national seismology program would be to assess the degree of seismic risk as a basis for the reduction of the seismic hazard to levels consistent with the social and economic goals of the government and people.

Fig. 1 shows some approaches that may be taken in the assessment of seismic risk. There are many ways in which we can categorize these. For the present discussion I have chosen to use as variables the degree of assurance required of the estimate and the prediction period or time available for action. In principle one can choose any period of time within which to make a prediction. The objective of the Chinese program, for example, is to predict the magnitude to within 1 unit, the location to within 50 km and the time of occurrence to within 3 days of all hazardous earthquakes greater than magnitude 5. I shall call this short-term prediction. Intermediate term prediction attempts to do the same sort of thing for earthquakes having a limited range of magnitudes, but in a larger region and in a time frame of one or more months. Long-term prediction seeks to describe seismic ground motion that a large region might experience within a period of decades or more. This last approach usually attempts to identify the rate of recurrence of earthquakes that may be expected in the long-term or alternatively to assess the degree of strong ground motion that may be expected to be exceeded in an interval of time at a certain level of probability.

For long-term prediction if one chooses a moderate degree of design conservatism, for example 10^{-2} per annum, extrapolations of historical and instrumentally determined seismicity can provide reasonable estimates of the seismic risk. If one wishes to make a prediction with a greater degree of design conservatism, e.g. 10^{-3} per annum, not only the historical and instrumentally determined seismicity but also the tectonics and geological setting of the region must be considered. At this degree of conservatism it may be possible to use a knowledge of global seismotectonics to make some reasonable statements, but if one wishes even greater degrees of design conservatism one must in some fashion obtain a detailed knowledge and understanding of the regional seismotectonics. For regions which experience interplate seismicity this knowledge may well be available, but for the intraplate setting of eastern and central North America and eastern South America this detailed understanding has yet to be achieved. For intermediate term predictions one must combine a knowledge of past seismicity with monitoring of relevant physical parameters. I am referring here of course to detecting accelerating rates of seismicity, strain accumulation, variations of seismic velocity with time and other parameters as seen appropriate.

For short-term prediction one must necessarily monitor and detect both accelerating and localized changes in measurable and relevant physical parameters. If one is prepared to accept a low level of assurance in a prediction, that is a large number of false predictions, one can proceed in a purely phenomenological fashion mapping all parameters that seem possibly relevant. A systematic change in any one or group of these can be used as the basis for a short term prediction of an earthquake. For societies that demand higher degrees of assurance that such predictions will come true a hypothetical physical model of the earthquake process must be available with which one can assess the significance of the observed changing parameters. If a very low false alarm rate is required then of course a proved physical model of the earthquake process must be available.

Fig. 2 shows approaches that can be taken in the mitigation of seismic hazards and again is within a framework of the long, intermediate or short time available for action resulting from the

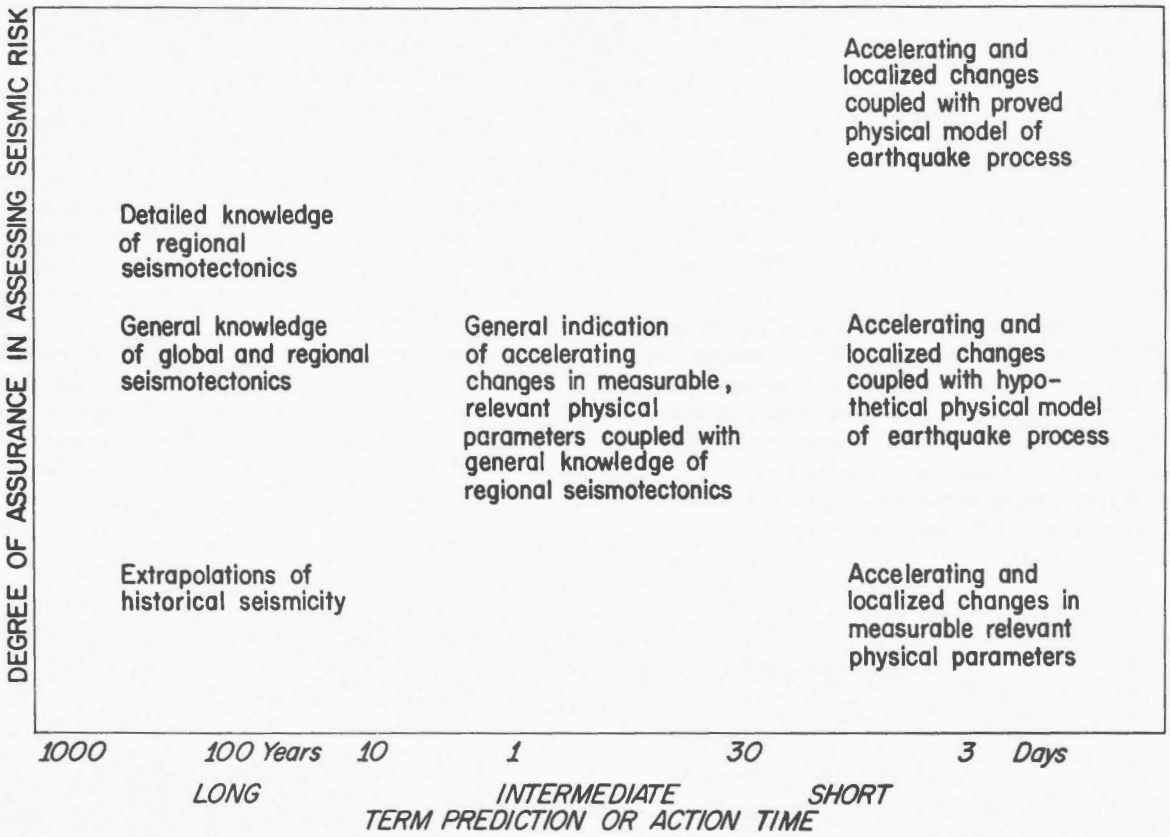

Figure 1. The assessment of seismic risk.

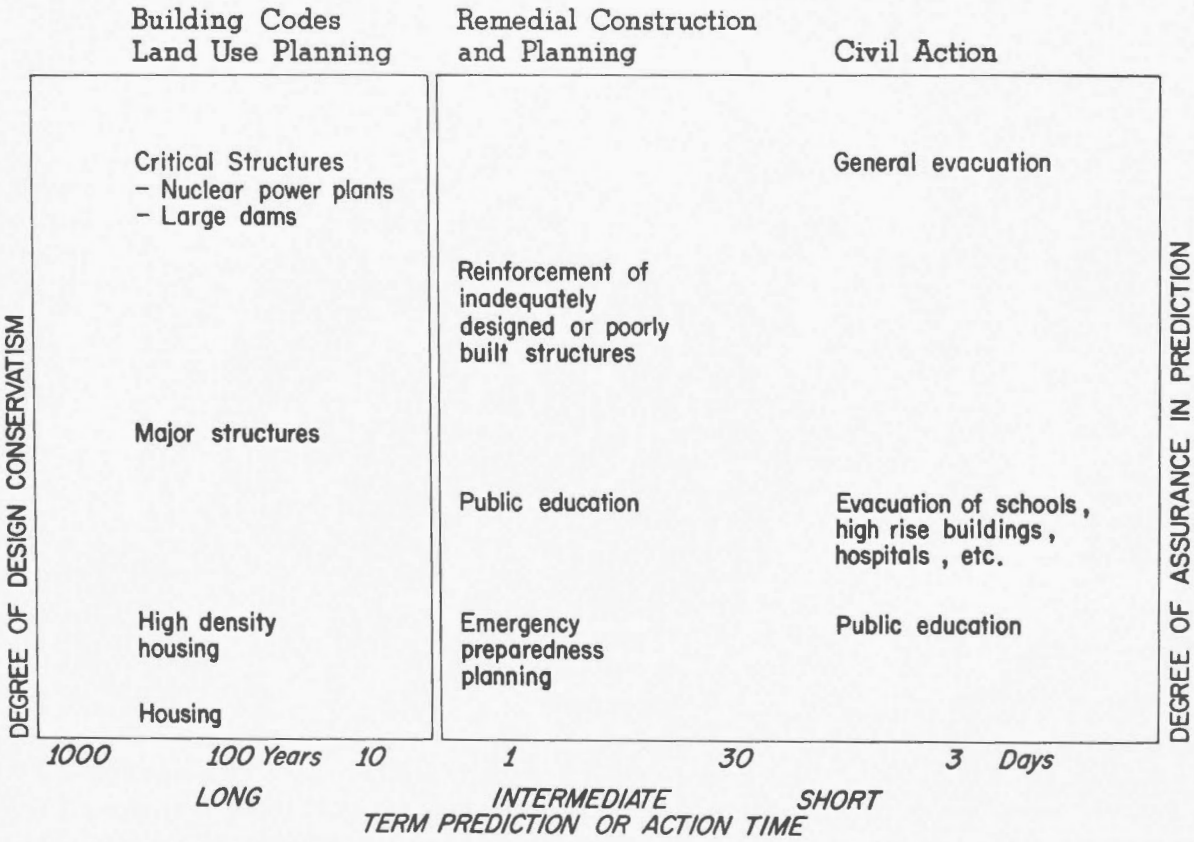

Figure 2. The mitigation of seismic hazards.

prediction and the degree of design conservatism used or for the intermediate and short term predictions.

For long-term predictions the appropriate action is clearly the implementation of appropriate building codes and land use planning. The degree of design conservatism that should be applied in setting standards for various buildings logically will be chosen on the basis of the true hazards associated with the buildings. In a quantitative and realistic sense this is a very difficult thing to accomplish and at present has only been attempted by the Institute of Earth Physics of the USSR Academy of Sciences in Moscow.

Nonetheless, in a qualitative way we can order structures from the least hazardous to the most hazardous. This ranking with local variations will most likely proceed from collections of single dwelling houses to high density housing, to highrise structures and finally to critical structures such as nuclear power plants and large dams. To achieve roughly uniform hazard for each of these the degree of design conservatism appropriate to the estimation of seismic risk for each will also have to increase.

If one can make intermediate term predictions thereby providing a much shorter action time, appropriate action may be to undertake major emergency preparedness planning to undertake public education programs which have a sense of urgency and to look critically at poorly built structures with a view to their reinforcement.

If short term predictions are possible thereby providing a very short action time, immediate public education programs should be undertaken and the evacuation of schools, highrise buildings, and hospitals, etc., could be considered. If a short-term prediction with a high degree of assurance is possible an immediate general evacuation of buildings may be appropriate. It is relevant to point out that the sociological problems associated with what I have called short-term predictions are only now being recognized.

There is therefore a wide spectrum of conceivable action available to us in the mitigation of seismic hazards. The range is circumscribed by our ability to properly assess the seismic risk and by the socio-economic pressures that exist in our society.

I shall now very briefly sketch how these general ideas have been implemented in Canada. Fig. 3 shows the seismicity across the country: as in the rest of the Americas, many of our earthquakes occur along the west coast. There is also a concentration of earthquakes in the St. Lawrence and Ottawa Valleys and scattered seismicity throughout much of the Arctic.

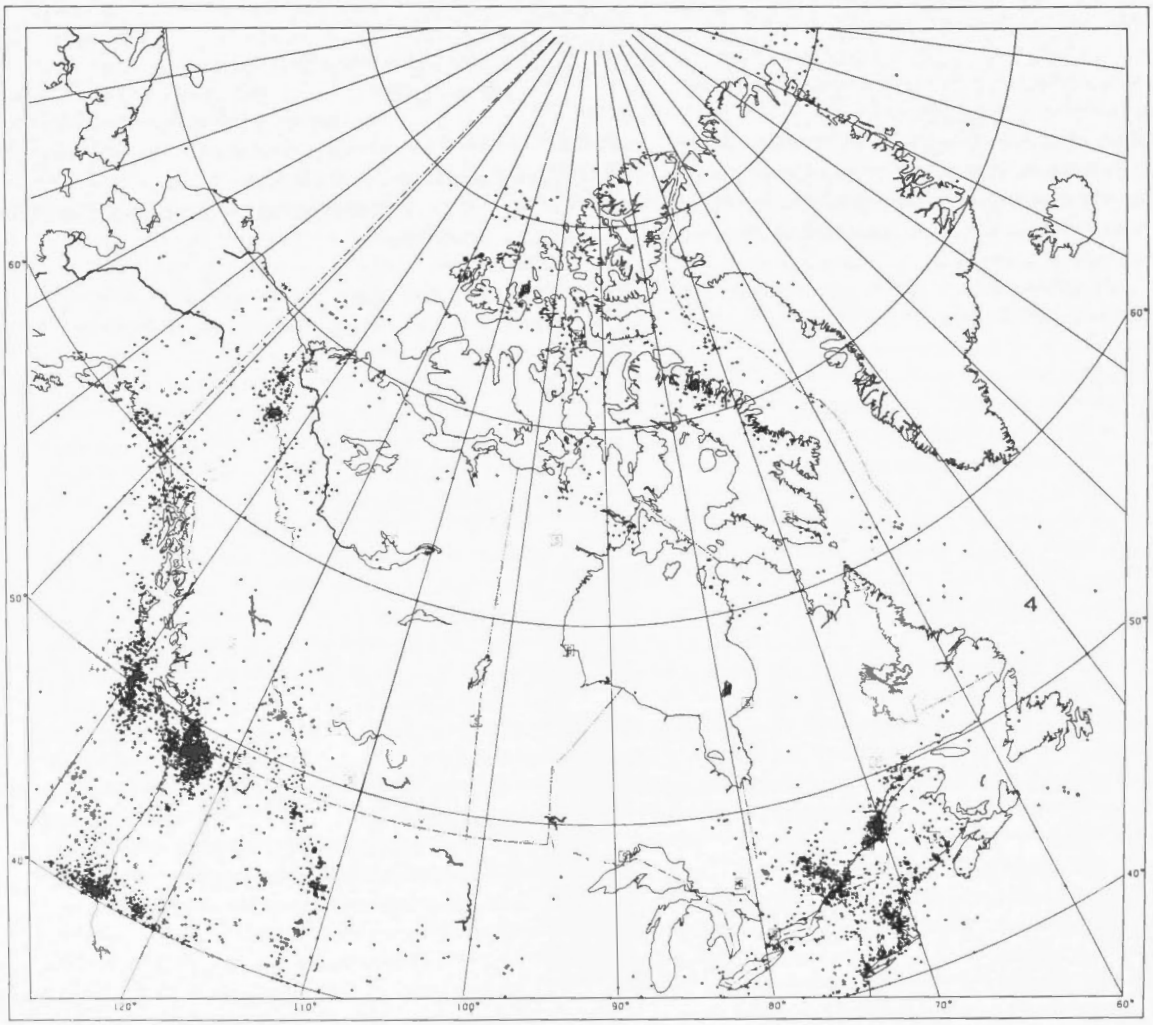

Figure 3. Canadian seismicity.

To detect and locate Canadian earthquakes and to study seismicity generally the Seismological Service of the Earth Physics Branch of the Department of Energy, Mines and Resources operates a network which includes 20 standard stations, 12 regional or single component stations, a medium-aperture array and two telemetered networks based in Ottawa and Victoria. In addition the strong motion network includes over 111 instruments deployed on the west coast and in the St. Lawrence and Ottawa Valleys. The importance of a well distributed network of stations is demonstrated by the fact that the current catalogues of Canadian earthquakes show that over one third of Canadian earthquakes occur in the north. This northern seismicity was largely undetected until the station at Resolute was opened in 1953. Clearly the building of critical structures should not be undertaken in regions that lack either a good historical record or a period of monitoring by an adequate network. Existing maps of seismicity may not be a reliable measure of the true seismic risk in a region.

Fig. 4 shows the seismic risk map of Canada as incorporated into the National Building Code. It shows four zones which in a rough and qualitative sense may be interpreted in terms of zero, minor, moderate and major damage respectively at the 1% probability per annum level. The zones are defined in terms of the acceleration of ground motion that can be expected with a probability of 10^{-2} per annum. The stated objectives of earthquake design in the National Building Code of Canada is to design buildings to prevent major failure and loss of life. In each zone structures designed in conformance with its provisions should be able to resist moderate earthquakes without significant damage and resist larger earthquakes without collapse. For the purpose of the code collapse is defined as that state that exists when the exit of occupants from the building has become impossible because of failure of the primary structure. The objective of the provisions is to reduce the probability of fatalities to an appropriately small value and to accept some structural damage in major earthquakes.

For more critical structures than those considered by the National Building Code, such as nuclear power plants, a greater degree of design conservatism is required. These more conservative estimates are not appropriately derived from the straight-

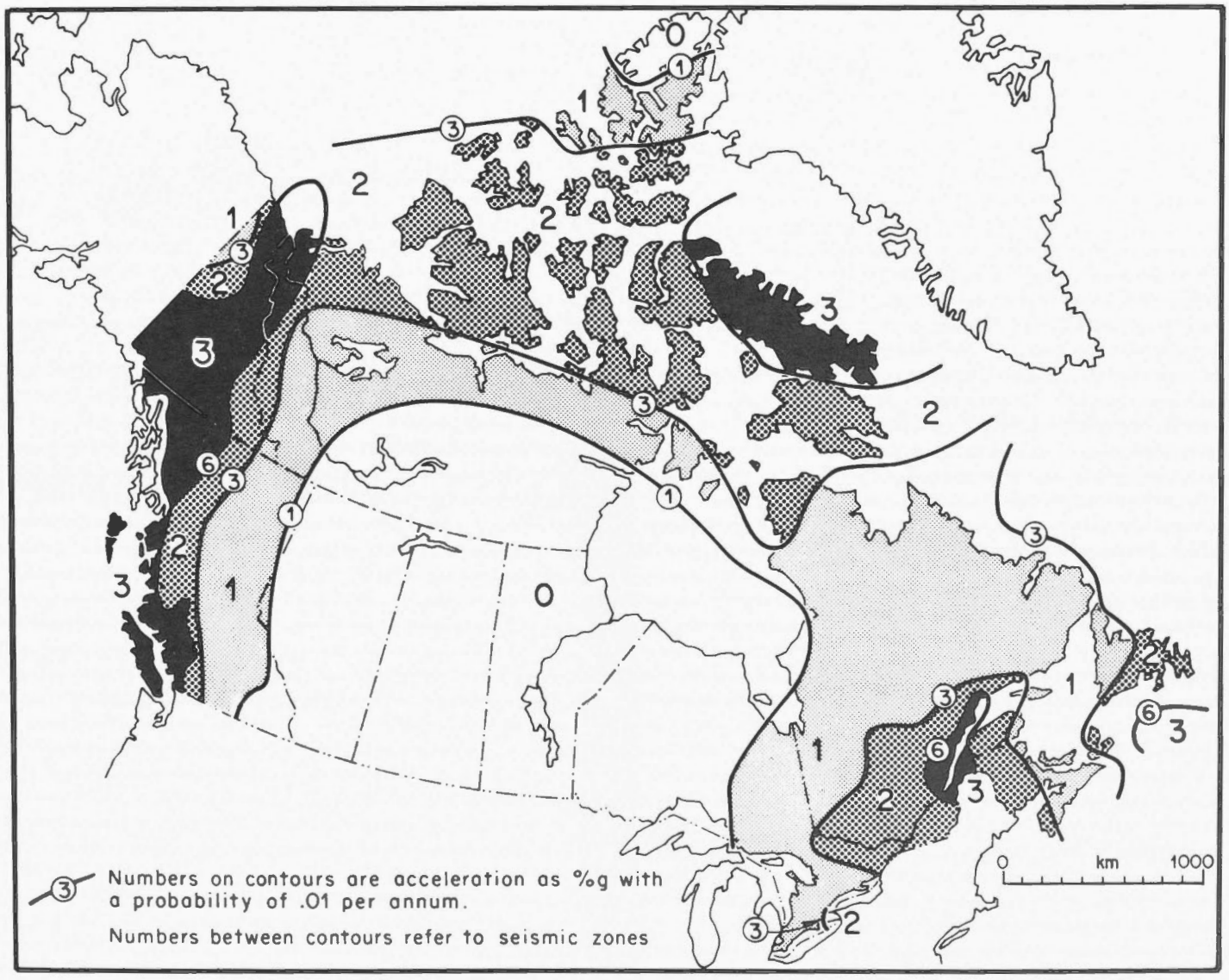

Figure 4. Revised preliminary seismic zoning map (1970).

forward statistical extrapolation based on a relatively short historical period as this can produce unrealistic results. We have found it convenient to use the approach of seismic regionalization. Here one defines zones of earthquake occurrence which ideally are delimited by using a complete understanding of the seismotectonics of the region. In the intraplate setting this is seldom possible at the present state-of-the art and hence the rationale for the boundaries of the zones is necessarily based on the nature of the seismicity that has been experienced during the historical and instrumental period. We have active research programs underway to attempt to understand the seismotectonics or the basic geological processes causing the zones, but at present we are forced to use the seismicity itself to define these. For each zone we have constructed the rates of earthquake occurrence which we use to predict, in the long term sense, the seismic risk with a reasonably high degree of conservatism. The approach allows us to define earthquakes which may be appropriately located about a site in question. The effects of these earthquakes at the site are calculated and become the design basis seismic ground motion for which the critical structure is designed. The approach allows for the input of whatever information and understanding of the seismicity is available and we believe is an acceptable approach when more conservative estimates are required for building design purposes.

At the present time in Canada we are not able to make intermediate or short term predictions. We do, however, have a multidisciplinary study underway in one of our more seismically active regions in order to study the earth processes associated with earthquakes. Whether this work will enable us to make reliable predictions in the future is a question that will only be answered in the years to come.

Before I close I should mention a class of seismic risk caused by man's activities. Induced seismicity can arise from three general sources: mining, high pressure injection of waste fluids or fluids for the secondary recovery of oil, the construction of large dams and the impoundment of large reservoirs. Induced seismicity is not well understood at the present time. However, the ambient state of stress in the upper crust is clearly a significant parameter in determining whether induced seismicity will follow a change in the state of stress by a major dam, etc. It seems reasonable that a crude measure of how close the crustal rocks are to their breaking strength is provided by the presence or absence of earthquakes. This reasoning would suggest that one has a higher degree of probability of induced seismicity in a region experiencing earthquakes than in a region that is largely aseismic. Despite this, however, there are many examples of induced seismicity in regions which were formerly considered to be aseismic. The recent UNESCO conference on the assessment and mitigation of earthquake risk recommended that prior to and during the construction of a dam the region should be carefully monitored to establish the background seismicity, and that experiments should be undertaken to determine the state of stress in the upper crustal rocks before the dam is built. In the words of one Canadian geophysicist the idea is to determine if the pistol is loaded before one pulls the trigger.

In conclusion it is clear that many parts of North and South America are subject to significant seismic risk and that relatively few regions can be considered to be without some degree of risk. The degree of seismic hazard is not simply correlated with this, but is a function of the seismic risk and the distribution of population and critical structures. The measures taken to mitigate the seismic hazards will of course vary from region to region. Any program of seismic hazard mitigation should include a careful consideration of building codes, land use planning and a measured program to upgrade existing structures to at least basic levels of safety. Most regions would probably benefit from a program of public education and some regions might benefit from a research program in building practice. For example the use of heavy roofing materials in regions subject to a high degree of seismic risk is clearly inappropriate and any steps taken to change traditional building practices such as these would obviously bring about long term beneficial results. Other regions may require very conservative estimates of seismic risk for the construction of what might be considered more intrinsically hazardous structures. Short-term earthquake prediction is at present in its infancy. Ultimately it might provide great benefits in substantially reducing the loss of life if not property damage. However, this will not be without a major effort involving heavy financial and manpower resources and probably many failures causing considerable social disruption. Further in the future is the possibility of mitigating the seismic risk itself in certain key areas by relieving the build up of dangerous stresses in the crust by fluid injection techniques.

Prof. G. P. Woollard:

Thank you very much Dr. Berry. Our next speaker this morning is Dr. A. Jessop who will present a paper entitled **"Geothermal Studies in Canada".**

Dr. A. Jessop:

Geothermal studies in Canada can be divided into three parts: the study of fundamental geothermics, the study of geothermal energy potential, and the study of the thermal aspects of permafrost. Government agencies, universities and industrial agencies have all taken part according to their interests.

Fundamental geothermics have been carried out both in the federal government and in a few universities. The objectives have been the measurement of heat flow and heat generation throughout all of Canada and the interpretation of the observations in terms of origins and tectonic structures of such features as the Canadian Shield and the western cordillera.

A study of geothermal energy potential has only recently begun in Canada and there are several countries in the American continents where far more is known about the national geothermal resources. Perhaps the main reasons for our late start are that geothermal resources do not make themselves as obvious as they do in some parts of the world and that we have been well supplied with other sources of energy.

Permafrost is a phenomenon that is of little interest to scientists in Central and South America except perhaps in the far south or in the high Andes. The thermal aspects of permafrost have become of significance in the last few years because of the behaviour of frozen materials in proximity to pipelines, oil wells and other constructions. There is much to be learned concerning the behaviour of frozen or freezing soils and both government and industrial agencies are working in this field. For the interest of those who live in warmer climates there are several places in northern Canada where permafrost, that is ground permanently below 0°C, extends to depths greater than 600 metres.

The study of fundamental geothermics began in Canada about 30 years ago at the University of Toronto, where some of

the very early heat flow measurements were made (Misener *et al.*, 1951). These early measurements made use of mining properties and boreholes in northern Ontario and in Quebec. Work continued at the Univerisities of Toronto, Western Ontario and Alberta and in 1962 the first geothermal group in the federal government was set up at the Dominion Observatory, now known as the Earth Physics Branch. Since that time work has also been done at Dalhousie University in Halifax. Fig. 1 shows the distribution of measurement sites within Canada. Since all but a few of these measurements are made in boreholes drilled for other purposes, the distribution is very uneven. There are concentrations of sites in the mining areas of British Columbia, Ontario and Quebec, and in the northern sedimentary basins of the Mackenzie Delta and the Arctic Islands. On the other hand there are few sites in the areas around Hudson Bay where little drilling is done and on the Prairies where all holes are either producing oil and gas or are carefully plugged.

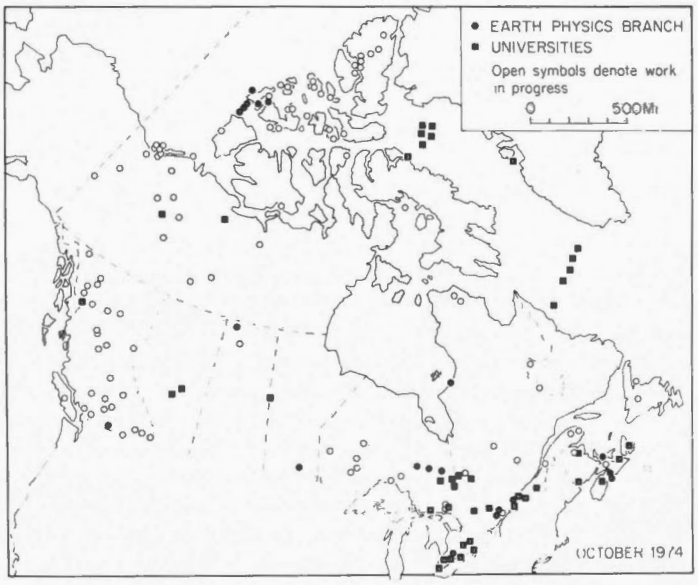

Figure 1. Sites of heat flow measurement in Canada.

The techniques of measurement used by the different agencies are very similar. For continental measurements temperature is measured as a function of depth in boreholes, and the temperature gradient is calculated. The thermal conductivity of the rock cores is measured in the laboratory and the temperature and conductivity are multiplied to produce the value of heat flow. Fig. 2 shows the temperature, conductivity and heat flow for a hole at Winnipeg, Manitoba. There is evidence of disturbance of temperature by moving water in the upper 200 m and the inversion of temperature in the upper 60 m indicates a change in surface temperature due to climate change in the last 100 years. Although the heat flow is usually uniform this particular borehole shows a variation of heat flow with depth which indicates some long-term disturbance in temperature (Jessop and Judge, 1971).

Some measurements have also been made in lakes, in fiords of the west coast and in inter-island channels of Arctic Canada. For this work a spear-like probe two to three metres in length is allowed to penetrate into the sediment. The probe contains temperature measuring elements throughout its length and so a temperature gradient is obtained. The conductivity of the sediment may be estimated or it may be measured. The standard way of measuring conductivity of soft sediments is by means of the needle probe, a thin heater that also contains an electrical thermometer. The rise of temperature of the probe as a function of time yields the thermal conductivity of the surrounding sediment.

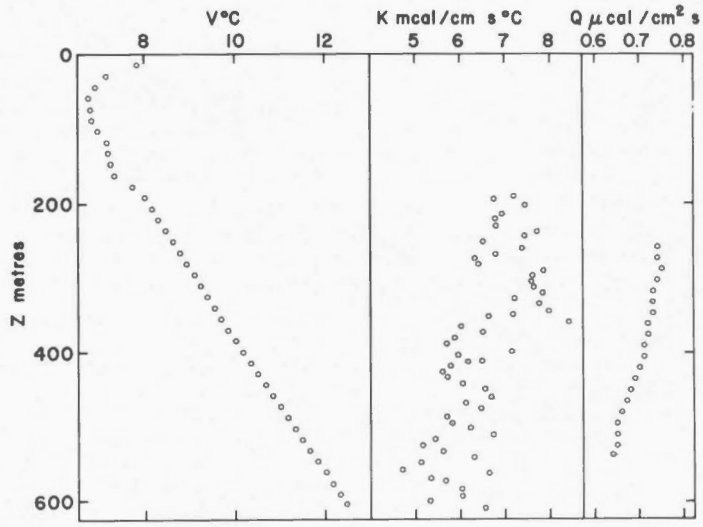

Figure 2. Temperature and conductivity data and calculated heat flow from a borehole at Winnipeg, Manitoba.

Another important thermal parameter is the rate of production of heat within the rocks. All rocks contain small quantities of radioactive elements, notably uranium, thorium and potassium. The amounts of these elements may be measured by counting gamma rays of different energies and the number counted in a given time yields a knowledge of the amount of the isotopes present. The amount of heat produced is normally less than 10 $\mu W/m^3$, but in the thickness of the continental crust this amounts to a large portion of the observed heat loss at the surface (Lewis, 1976).

In the United States heat flow and heat generation have been plotted together to produce a relationship that is best expressed by a series of straight lines, as shown in Fig. 3. It was found that the United States could be divided into three main *Geothermal Provinces:* the Basin and Range Province (line BR in Fig. 3), the Sierra Nevada (line SN) and a large area consisting of the whole eastern United States (line EU) (Roy *et al.*, 1968). Some work in Canada has been aimed at determining whether those particular parts of the country could be regarded as parts of the same geothermal provinces that are observed in the United States. It was found not surprisingly that the Canadian Maritime provinces show the same thermal characteristics as the eastern part of the United States, which includes the Appalachian system. However, it has also been found that the Superior Province of the Canadian Shield, a very old and stable portion of the crust, does not seem to belong to the same thermal province, but seems to be distinctly cooler (line CS) (Jessop and Lewis, 1977).

At the University of Western Ontario two special studies have been made. One of these involved a remarkable series of boreholes at a mining property in western Quebec where it was possible to measure temperatures and temperature gradients in about 80 boreholes within an area approximately 2 km by 3 km. Conductivity of rocks was also measured and it was found that

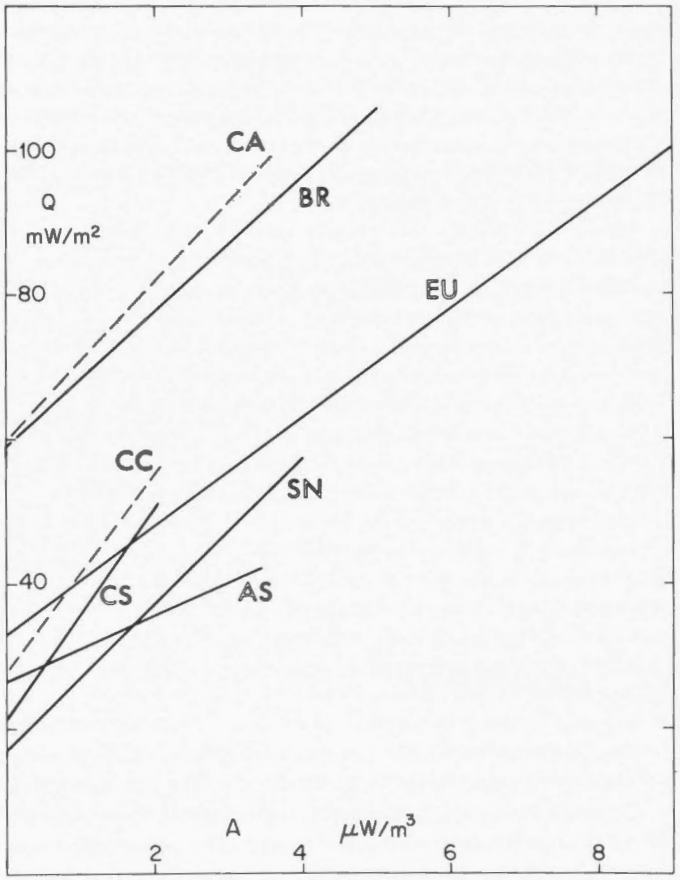

Figure 3. Heat flow and heat generation for geothermal provinces.
BR — Basin and Range Province, EU — Eastern United States,
SN — Sierra Nevada, CS — Canadian Shield,
AS — Australian Shield,
CA — Canadian Shield, heat flow corrected for Pliestocene climatic effects,
CC — Canadian Shield, calculated line for Archean time.

the calculated heat flow varies significantly across this small area. The geological structure of the area is complex and it was found that the variation in heat flow could be explained by the movement of groundwater between rock layers (Lewis, 1975). Given the data from any single borehole there would have been no reason to suspect that the resulting heat flow did not represent the area around the site. The majority of heat flow measurements are made in single holes, and the inescapable conclusion is that all heat flow measurement sites must be examined very carefully with regard to geological structure and possible water movement, so that the heat flow value may be rejected if for any reason it was suspected of being erroneous. Unfortunately there is a tendency for drill holes on mining properties to be in areas of complex geology with shear zones and opportunities for water movement. These are often the only boreholes available.

In the early days of the work at the Earth Physics Branch some boreholes were drilled especially for heat flow measurements. These were carefully placed to avoid possibilities of water movement or other disturbances, but in spite of these precautions problems arose in two of the holes. The remainder include some of the most reliable measurements that have been made anywhere in the world, but unfortunately this drilling program could not be continued. It takes a great deal of care to obtain a good heat flow measurement. In some areas good heat flow measurements are impossible and it is necessary to substitute a number of less reliable observations.

The second special study at the Univerisity of Western Ontario consisted of extremely detailed observations of temperature conductivity, and heat generation within a single borehole of about 600 metres depth. Small variations in apparent heat flow with depth were observed and these were interpreted in terms of variations of heat generation and possible movement of water through porous layers. This borehole was one of the special heat flow holes mentioned above (Hamza and Beck, 1975).

At the University of Toronto a study has been undertaken of the feasibility of making measurements of heat flow through the floors of shallow lakes where seasonal fluctuations of water temperatures are to be expected. Since a lake-bottom probe measures the temperature in only the first two or three metres of sediment, seasonal fluctuations are a serious problem as they may entirely mask the normal thermal gradient. From work completed so far it seems that the variation of temperature of the lowest water is fairly predictable and that shallow lakes in the Canadian Sheild can be used for obtaining numerous heat flow results, but possibly not of the best quality (Allis, 1975).

A recent project of the Earth Physics Branch, in association with the Massachussetts Institute of Technology has been the revision and completion to 1975 of the World Heat Flow Data Compilation (Jessop *et al.*, 1976). The data are available in computer-compatible format from the World Data Centre and a map has been published showing heat flow, volcanoes and earthquake epicentres (Grim, 1976).

The search for Canada's geothermal resources has only begun in the last few years. Canada has no known geysers or fumaroles, but there are zones of recent volcanoes in the western cordillera. One of these zones, the Garibaldi Volcanic Belt, lies just north of Vancouver and most of the work has been directed at a specific site in this zone called Meager Creek.

There are many hot springs in western Canada. Some of these are found in the folded sedimentary rocks of the Rocky Mountain and are not related to volcanic features, but others are located in the volcanic zone and geochemical analysis indicates that some are fed by hot sources (Souther, 1976).

As part of a new effort of research into and development of renewable energy resources the federal government has been applying geophysical and geological techniques in order to locate geothermal resources. Coordination of the geothermal program is the responsibility of the Earth Physics Branch but scientists from both that Branch and the Geological Survey of Canada are involved. Most of the work is done by consultants and universities under contract. During 1976 reconnaissance geochemistry of hot spring waters and self-potential experiments have been done in the Yukon Territory. Age-dating techniques have been applied to volcanic centres in the Garibaldi belt and detailed geological mapping has been completed on Meager Mountain, a complex volcanic centre just to the north of Meager Creek. A detailed hydrological and geochemical study of the Meager Creek areas has been done and a magnetotelluric survey has been done in the adjacent Lillooet Valley. In the previous year electrical resistivity and shallow drilling were done by consultants for British Columbia Hydro and Power Authority and a picture of the hot water flow in the Meager Creek Valley is beginning to emerge. It seems possible that the source of the hot water lies beneath Meager

Mountain where the rugged terrain will make further geophysical work difficult.

Geothermal resources are also being sought in the sedimentary basins of Canada. Early in 1976 a preliminary study of the existing thermal data of the western Canadian sedimentary basin was completed by Sproule Associates Ltd. of Calgary. A large file of temperature data compiled from oil and gas well records was examined for high temperatures and temperature gradients. In selected promising areas the occurrence of porous formations was noted. Fig. 4 shows the profiles that were examined, with an estimate of the temperature of the deepest aquifers. The highest temperature shown is 175°C, but this is found beneath an uninhabited area. High temperatures are found throughout a broad area to the east of the Rocky Mountains and the prospects for space heating of buildings from this source seem to be good provided that economic factors are favourable (Jessop, 1976).

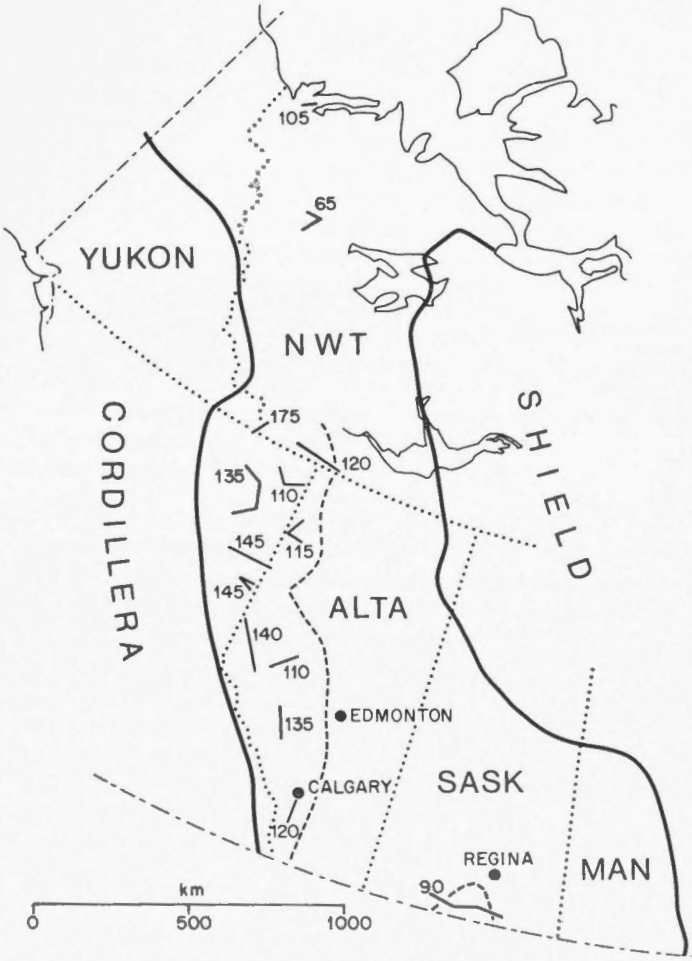

Figure 4. Temperature of water in lowest aquifers of the western Canada sedimentary basin. The dashed line marks the eastern limit of the zone where water of 80°C or higher may be found.

Although permafrost research has not been described in detail this is another broad field in which geothermal research is playing its part in solving some of the problems of providing our future energy supplies. We believe that geothermal research in all three forms presented here is an essential part of the national effort to increase our understanding of the structure and behaviour of our planet and to make the best use of our resources for the benefit of the population.

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Prof. G. P. Woollard:

Thank you very much Dr. Jessop. Our next speaker is Dr. A. Lambert who will present a paper entitled **"Canadian Research on Crustal Stability".**

Dr. A. Lambert:

There is now more than ever before a need to acquire information on the stability of the earth's crust, a need that has been brought about by the large increase in population and the trend towards ever larger and more daring engineering projects. It is a known fact that no part of the surface of the earth is "stable" a priori, that large earthquakes can occur far from the boundaries of lithospheric plates and that man himself has sometimes unwittingly modified the stress conditions in the crust resulting in the triggering of potentially destructive earthquakes. In Canada, apart from the problem of earthquake occurrence in populated areas, we require crustal stability data for dealing with such problems as the siting of nuclear power stations and large reservoirs, the disposal or storage of radioactive wastes and the management of large drainage basins such as the Great Lakes basin.

The main purpose of this talk is to describe the field techniques and experimental approach used by government agencies and the universities in Canada in the study of the stability of the crust. Measurements of present movements of the earth's crust

and its present state of stress will undoubtedly provide the basis for explaining the observed phenomenon and for predicting the future response of the crust in different areas.

The significance of the observed deformations will become apparent only through a knowledge of the plate tectonic setting derived from a study of the geological record. For example, the coast of British Columbia is today the site of present lithospheric plate convergence or subduction which accounts for its relatively high level of seismicity compared to the rest of Canada. The remainder of the country is situated in a so-called intra-plate tectonic environment which accounts for its relatively low level of seismicity.

In the present century evidence of on-going crustal deformation in Canada has come mainly from the monitoring of seismic events, from first order relevelling and from mean water level measurements. The distribution of seismic events in Canada is well known through data from the Canadian seismic network. The main features in the more populated southern part of the country are: (1) a high concentration of seismic activity in coastal and offshore British Columbia probably related to the plate tectonics of the area, (2) a region of moderate activity in the Ottawa and Montreal area and (3) a concentration of activity on the St. Lawrence River, northeast of Quebec City. Unfortunately an equivalent map of the rate of cumulative seismic and aseismic deformations taking place in Canada is not yet available. Such a map is now being compiled from existing first order relevelling data using a method that has been devised at the University of New Brunswick to produce contour maps of vertical crustal velocities from scattered, as well as connected relevelled segments (Vaníček and Christodulidis, 1974). Because the acquisition of crustal stability data over a landmass the size of Canada is a very expensive and time consuming task such an optimum use of existing data is mandatory before planning new observations. Preliminary results from first order relevelling and mean water level measurements show that the large scale pattern of current crustal movement is more or less consistent with that from studies of past sea levels (Walcott, 1972). These modern data also show, however, some significant unexpected local anomalies in vertical crustal velocity (Frost and Lilly, 1966; Gale, 1970; Vaníček and Hamilton, 1972; Vaníček, 1976) (Figs. 1 and 2). In order to better understand the anomalies and their possible relationship to local seismicity a cooperative program of measurements involving the Geodetic Survey and the Earth Physics Branch is now underway in selected areas where anomalous movements have already been detected or where seismic risk is high. The aim is to concentrate on as many different types of measurements as possible in specific areas where earthquakes are expected.

Research is also being carried out in government agencies and the universities on the feasibility of detecting small displacements in the 1 to 10 cm range by laser ranging to satellites and by very long baseline interferometry.

Driving forces

The basic objective of a program of research in crustal stability must be to understand the physical mechanism of crustal deformations so that the response of the crust to natural and man-made forces can in some sense be predicted. We require not only information on current crustal movements but also some knowledge of the driving forces. Without a knowledge of the driving forces we are restricted to developing merely a kinematic description of the crust. For the purposes of this discussion forces on the crust can be divided into two categories: *tectonic stress and crustal loading*.

Tectonic stress

A knowledge of the tectonic stress field in the crust is important to understanding the causes of seismic and aseismic crustal deformations and their relationship to the processes that drive plate motions. From the known motions of the global lithospheric

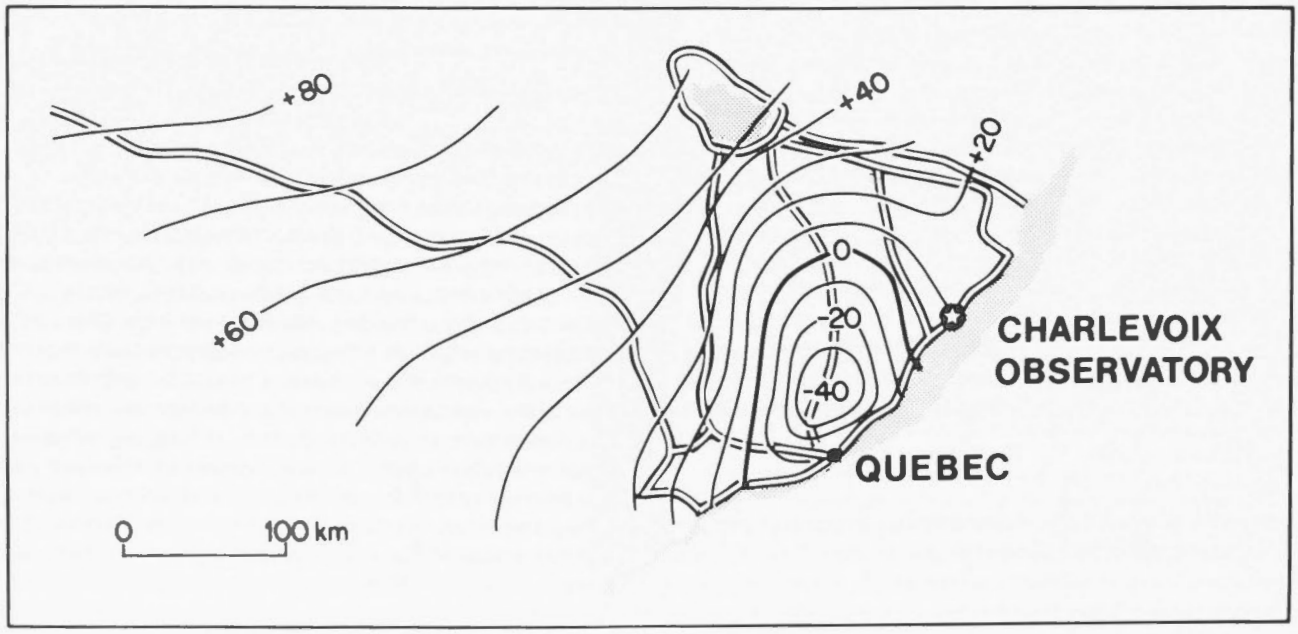

Figure 1. Relative crustal movement near Quebec City redrawn from Gale (1970) and Vaníček and Hamilton (1972). Solid contours indicate velocity in centimetres per century. Double lines represent the relevelled net.

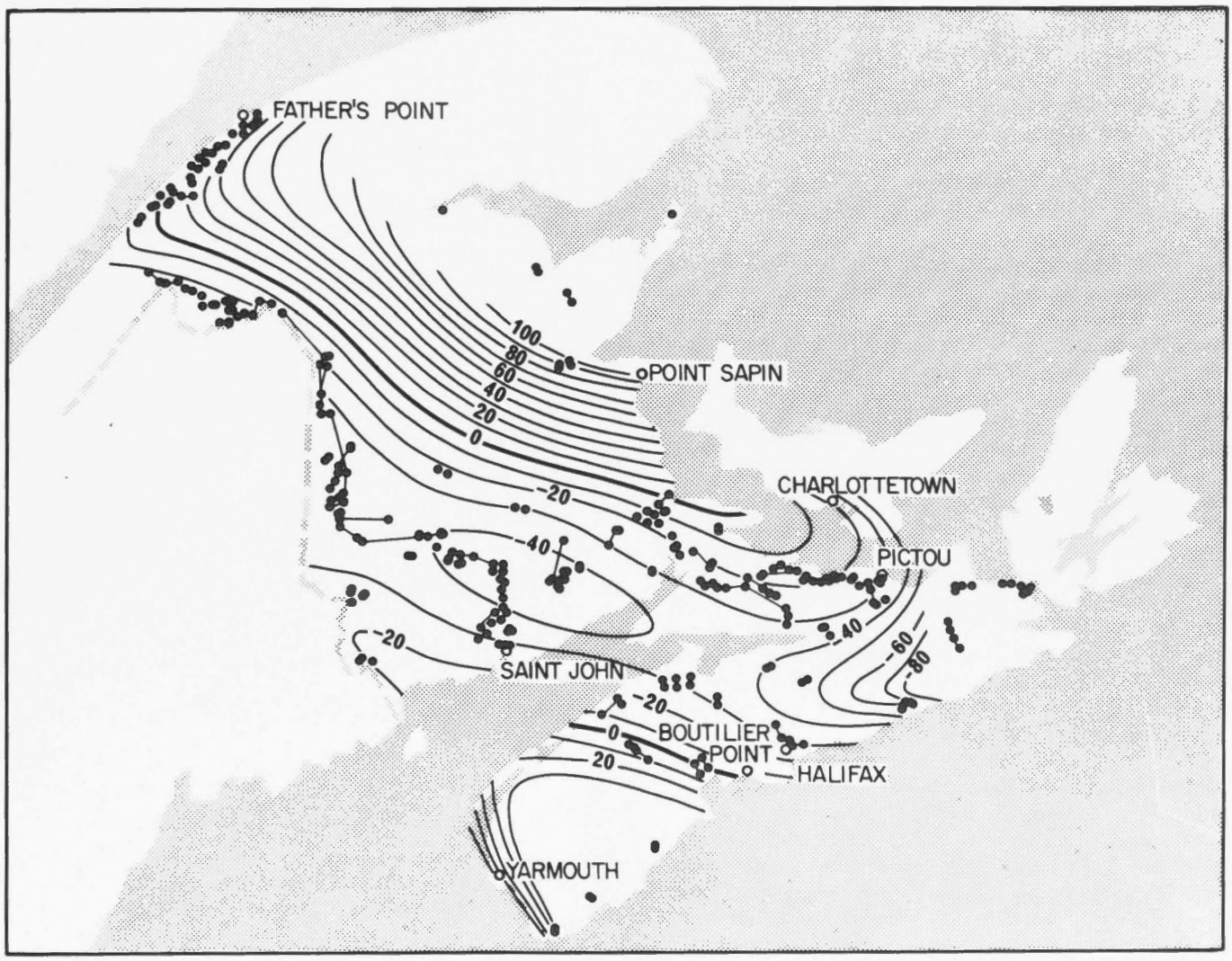

Figure 2. Pattern of vertical crustal movement in Maritime Canada redrawn from Vaníček (1976). Contours indicate velocity in centimetres per century. Results are from relevelled segments and tide gauges whose locations are shown. Lack of data leads to larger uncertainty in uplift rates in the extreme northern and southern parts of the region.

plates some idea of the expected intraplate stresses can be obtained using an elastic shell model of the lithosphere (Richardson *et al.*; 1976). However, from global modelling only the gross features of stress can be obtained whereas the regional and local variations may be important. Unfortunately, direct data on crustal stress in Canada is scanty and there is presently no coordinated effort to obtain data in any useful quantity. Data on the state of stress in the crust may be obtained from three main sources: (1) observations of the deformation of man-made structures and postglacial geological features, (2) earthquake fault plane solutions, and (3) in situ stress measurements by the technique of overcoring or hydrofracture. In eastern Canada a number of postglacial features have been identified that indicate the direction of the applied stress field (Sbar and Sykes, 1973; Saul and Williams, 1974). However, data on earthquake fault plane orientations is so far too sparse for any conclusions to be reached regarding the regional stress pattern in eastern Canada. On the British Columbia coast evidence on stress directions from some of the large magnitude earthquakes and from studies of sea floor magnetic anomalies indicates a fairly consistent pattern of north-south compression north of latitude 49° (G. Rogers, personal communication; Riddihough, 1977). The distribution of in situ stress measurements in Canada is poor. However, a number of high quality determinations have been made using the technique of overcoring (Herget *et al.*, 1975). The method involves bonding a triaxial strain cell to the inside of a borehole about 4 cm in diameter. This first borehole is then overcored using a 9 cm diameter bit in order to remove the ambient stress. The measured strains are then interpreted in terms of the in situ stress field. Unfortunately, the geophysical interpretation of in situ stress determinations is complicated by factors other than the applied tectonic stress field (Ranalli and Chandler, 1975). The most difficult problem is to separate the applied or tectonic stress from the remanent stress induced in the rock during its thermal history. Perhaps one of the main obstacles to a theory of crustal mechanics is the lack of a quick and inexpensive method of measuring in situ tectonic stress in aseismic areas.

Crustal loading

Crustal loading and unloading is an important cause of crustal deformation especially in the Canadian context. The correlation between large scale free air anomalies and topography over Hudson Bay suggests that the crust is still depressed below its equilibrium level and has not yet returned to isostatic equilibrium (Walcott, 1970). It is reasonable to suppose that at the present time there is a general movement of mantle material toward the old centre of depression and away from the peripheral areas. Therefore a tendency to move toward isostatic equilibrium is an important driving force on the crust in Canada. An area of anomalous downward crustal movement north of Quebec City, for instance (Fig. 1), has been interpreted (Dunbar and Garland, 1975) as possibly being due to the decay of an enhanced forebulge which formed beyond the leading edge of the ice sheet in a region of weak lithosphere. Other important loading phenomena are transgression of the oceans on the continental shelves, sedimentation and other changes in topography. These loading forces can be estimated by an examination of the recent geological record and from correlation studies between topography and the gravity field.

Measuring crustal movements

In Canada the responsibility for obtaining primary geodetic and geophysical data relating to crustal movements rests with agencies of the federal government. The Geodetic Survey of Canada provides primary vertical and horizontal control, the Canadian Hydrographic Service supervises the operation and maintenance of water level gauges and the Earth Physics Branch monitors seismic activity, maintains Canadian gravity networks and operates polar motion and earth tide observatories. Although in Canada we do not have the problem of crossing national boundaries adequate data coverage does require the coordination of different agencies each with its own priorities. We are fortunate in Canada that inter-agency cooperation in this important field is improving.

It is impossible to mention all the research work carried out by federal government agencies and the universities related to the measurement of crustal movements. The remainder of the paper will therefore be concerned with work done in two specific geographic areas where cooperative projects are underway in order to illustrate the kinds of measurements being applied to crustal stability problems in Canada.

Induced seismicity at Manic 3, P.Q.

During the filling of the Manic 3 reservoir from August to December 1975 a marked increase in the number and magnitude of seismic events occurred at a location about 10 km north of the dam. The seismic activity increased until in October 1975 a magnitude 4.3 event occurred (Leblanc and Anglin, 1976). Based on the likelihood of an even larger event occurring in the future, plans were made to vastly increase the geophysical monitoring around the epicentral area in order to detect possible associated crustal movements. At the present time five different sorts of geophysical control have been deployed (Fig. 3): (1) a telemetered network of five short-period vertical seismometers, (2) a horizontal trilateration network consisting of 10 control points and 24 connections plus five short precise baselines in the epicentral area, (3) a precise gravity network consisting of 11 stations and 15 connections (seven stations co-located with horizontal control points), (4) first order levelling to all points accessible by road, and (5) monitoring of electrical conductivity by continuously recording magnetotelluric stations.

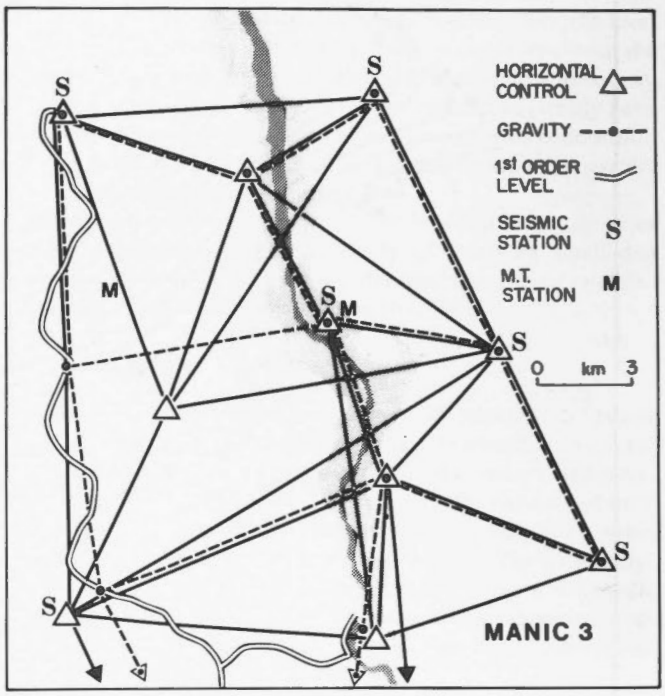

Figure 3. Geophysical and geodetic control in the vicinity of the Manic 3 reservoir, Province of Quebec.

One of the most difficult operations was the establishment of the horizontal control network. This operation required the construction of 10 to 20 metre high geodetic towers at the control points most of which were inaccessible by road. The construction phase of the operation was somewhat experimental as it was the first time that the Geodetic Survey had assembled towers at the base camp and flown them by helicopter to their hilltop sites (Fig. 4). The horizontal distance measurements were carried out using an AGA model 8 geodimeter and the angles were measured using a Wild T3 theodolite. The linelengths in the network were determined within a 95% confidence limit of 3 cm.

The Manic 3 experiment also marked the first time that a precise gravity network using LaCoste and Romberg model D gravimeters had been established by air. Precise gravimetry is the only practical way of detecting vertical movements in this remote area. The gravity stations were constructed by fixing brass pins into the bedrock in order to accurately relocate the station in subsequent surveys (Fig. 5). Two instruments were read simultaneously and each gravity connection consisted of 10 gravity ties with each instrument. In this network we were able to achieve 95% confidence limits of about 50nm/s^2 (5 μgal) for the relative station values. We would thus be able to detect any differential vertical movements greater than 2 cm.

The levelling measurements were carried out to Canadian special order standards which require that discrepancies between forward and backward levelling be less than 3 mm/km. A Zeiss NI1 self-levelling instrument and matched invar rods were used at Manic 3 to achieve this precision.

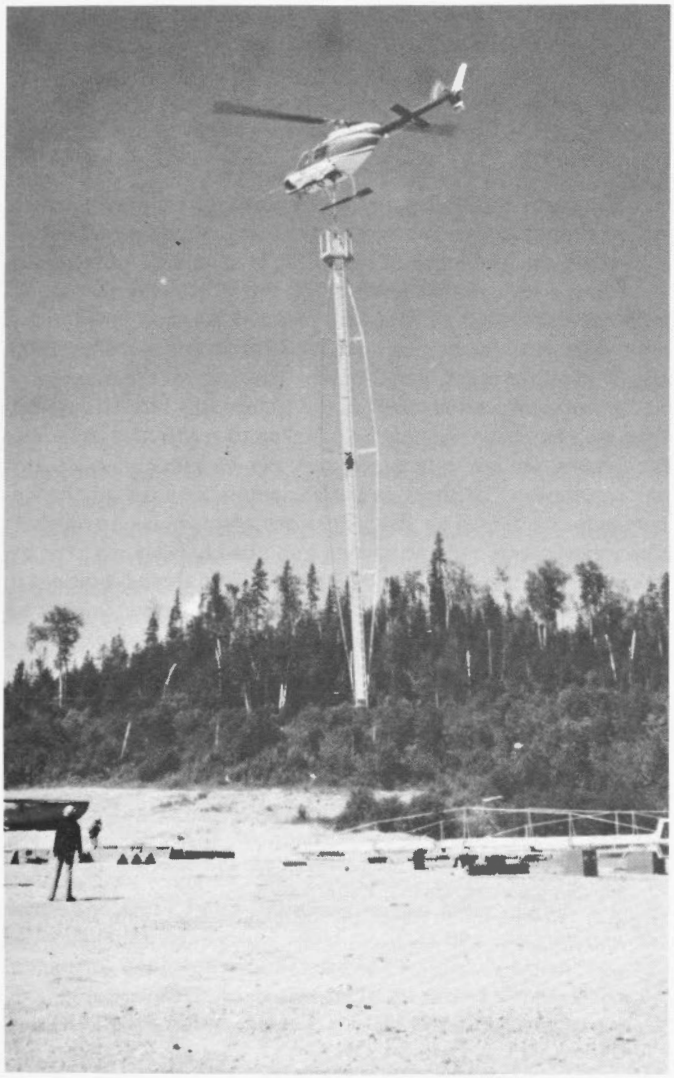

Figure 4. Transporting a geodetic tower by helicopter to a remote site.

Figure 5. Typical station in a precise gravity network.

Theoretical calculations have been carried out by the Earth Physics Branch on the expected elastic depression of the crust due to the reservoir load. The theory is now being extended to include pore pressure diffusion by workers at the University of Alberta where there is a traditional interest in the problem of induced seismicity. The monitoring of seismicity and electrical conductivity is continuing and the horizontal, vertical and gravity measurements are to be repeated at a later date.

Seismicity of the Charlevoix region

Attention has been directed in recent years to an area 130 km northeast of Quebec City where there is a concentration of microseismic activity (Leblanc *et al.*, 1973; Leblanc and Buchbinder, in press) and a history of large earthquakes occurring roughly every 60 to 90 years (there was a magnitude 7 earthquake in 1925). Since 1972 various kinds of geophysical control have been established by the Earth Physics Branch to supplement the existing vertical and horizontal control provided by the Geodetic Survey of Canada. Thus at the present time the geophysical control in the area consists of the following (Fig. 6): (1) first order levelling along the north and south shores of the St. Lawrence River (levelled 1926 and 1965), (2) a precise gravity network consisting of 15 stations and 22 connections (established 1974), (3) a triangulation network consisting of 12 points and 26 connections spanning the St. Lawrence River (established 1965), (4) two permanent tide gauges at St. Joseph de la Rive and St. Jean Port Joli, (5) a permanent seismic observatory at La Pocatière on the south shore and (6) a tilt, strain, seismic and magnetotelluric observatory located on the northshore near La Malbaie.

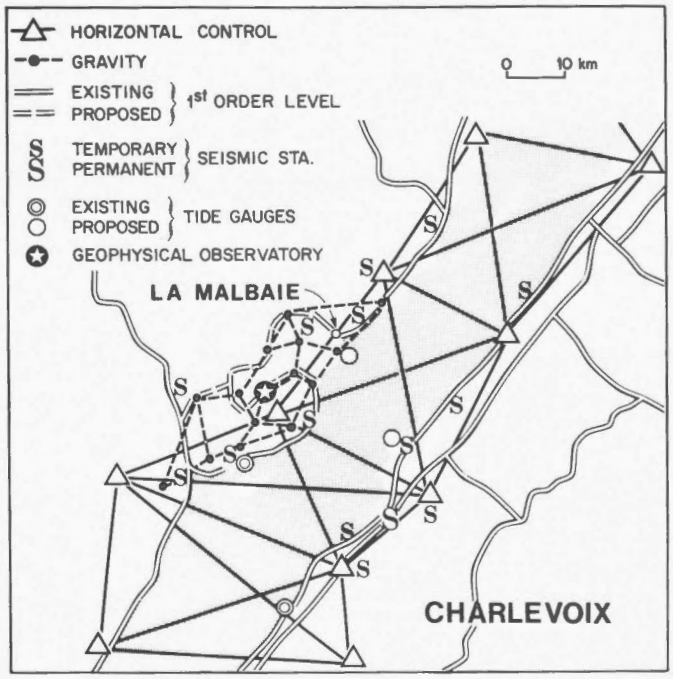

Figure 6. Geophysical and geodetic control in the seismically active Charlevoix region, Province of Quebec.

Precise gravity control was introduced so that the levelling and gravity together would allow any crustal deformations associated with seismic events to be properly modelled. The combination of gravity and levelling is necessary because a deforma-

tion of the crust is likely to distort both the surface of the ground and the reference geoidal surface (Whitcomb, 1976). The Geodetic Survey has planned a field program of relevelling of the first order line along the north shore and will provide additional first order control over most of the gravity network. The precise gravity network differs from that at Manic 3 only in that the ties were made by road. Since there were many unpaved roads in the area, the gravimeters had to be carried in a box which was springmounted inside a station wagon. As at Manic 3 95% confidence limits of about 50 nm/s^2 (5 μgal) have been achieved for the relative station values in the network.

The triangulation network established in 1965-66 was observed using Wild T3 theodolites and MRA3 Tellurometers and consequently the precision of the network is not as high as the more recent network at Manic 3. There are plans to re-observe this network more accurately in the near future.

An underground vault was constructed at the observatory during the summer of 1974 for the purpose of continuously monitoring crustal strains and tilt in this seismically active area. The installation consists of a vault housing two concrete piers 10 metres apart poured directly on the bedrock located 2 metres below ground level. The entire vault is buried beneath a 5-metre high mound of earth to provide thermal insulation. Access to one end of the vault is gained by a vertical pipe connecting the vault to the recorder building at the surface. The vault, which is oriented perpendicular to the St. Lawrence River, houses, in addition to a vertical short period seismometer, two different types of strainmeter in parallel: a Benioff-type quartz rod strainmeter and a Cambridge University wire strainmeter (Fig. 7). Three ANAC, mercury level, tiltmeters have been installed to measure the tilt parallel and perpendicular to the strainmeters. All instruments are operated at high sensitivity and good earth tide records have been obtained. Non-seismic events have been observed to occur on all components of strain and tilt prior to some small earthquakes in the region. These are presently being investigated as possible "precursory" events. In addition to the instruments in the vault a magnetotelluric station and a continuously recording gravimeter are operated on the surface. A special order levelling range and a borehole for monitoring water levels are also to be installed at the observatory shortly.

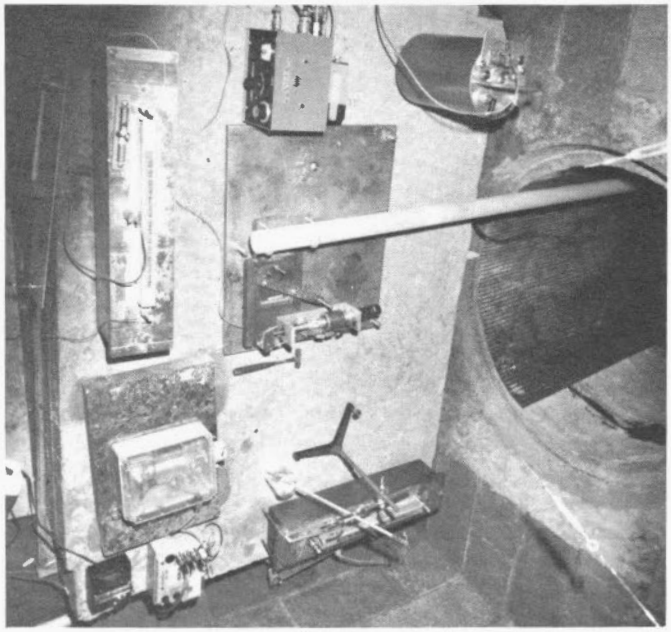

Figure 7. Strainmeters, tiltmeters and a seismometer in the underground vault at the Charlevoix observatory.

Summary

The purpose of this paper was to describe the way in which various geophysical measurements are being combined in Canada to study the deformation of the crust. It should be pointed out that there is no national program of crustal stability studies, as such. But the Canadian approach recently has been to try to involve as many different government agencies as possible in certain specific problem areas. A noticeable deficiency at the moment is the lack of coordinated effort in the tectonically interesting west coast area but steps are now being taken to rectify this situation. The general feeling is that progress can be made without any major technical advances in instrumentation; most of the instruments mentioned in this paper are commercially available. Also a fairly large volume of data had already been collected by government agencies for other purposes. Given these conditions it is often only necessary to identify areas of geophysical interest to ensure that a wide spectrum of data becomes available.

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Prof. G. P. Woollard:

Thank you very much Dr. Lambert. Our next speaker is Dr. T. Simkin who will present a paper entitled **"Historic Volcanism and Eruption in Latin America".**

Dr. T. Simkin:

Volcanic eruptions have on at least six separate occasions claimed the lives of 10,000 or more people. The most recent of these major catastrophies was in 1902 and we might well ask why there has been none since. The answer is not (a) that volcanic activity has declined — we find no such evidence in the volcanological literature (b) that human populations have declined — the world population has nearly tripled since 1902 or (c) that we have learned to predict and control volcanoes — the best monitored volcanoes continue to surprise their monitors. The answer I think is (d) that we have been very lucky. Although most parts of the world are better equipped now than in 1902 to deal with a major eruption the main reason we have had no recent eruptions claiming tens of thousands of lives is that most violent eruptions have taken place in thinly populated regions.

In the hope that the next disastrous eruption does not take place in Latin America, this paper will first review the history of volcanism there (with comparisons to other major volcanic regions), review volcanic hazards and discuss methods for monitoring dangerous volcanoes and finally close with a few comments on how PAIGH can assist in the effort to prevent future volcanic disasters.

Historical volcanism in Latin America

The many volcanoes of Latin America are concentrated in 6 linear regions or belts as shown in Fig. 1. These belts contain 106 volcanoes that have erupted in historic time and Sapper (1927) found Nicaragua to contain the most explosive group of volcanoes in the world. For several years at the Smithsonian Institution we have been compiling data on recent volcanism and Table I presents some preliminary data allowing for more current comparisons of volcanic belts than the data available to Sapper 50 years ago. Here the 6 belts of Fig. 1 are summarized and 6 additional volcanic belts from the other side of the Pacific Ocean are included for comparison. Offshore island volcanoes of Mexico, Ecuador and Chile are not included in this compilation because of their oceanic nature and relatively small hazard. Each line of Table I will be discussed individually.

1. The length of each volcano belt is given in kilometres. Since all belts are narrow and linear, their length can be used to give better comparisons between belts (lines 4, 9, and 12).

2. The total number of volcanoes in each belt includes those in our file that have no historically recorded eruption, but are thought (for a variety of reasons) to have been active in the past few thousand years. The true number of such volcanoes is certainly higher than shown here, but volcanoes thought to have been dead have sometimes erupted with disastrous results and it is therefore useful to include this large figure in our tabulation.

Figure 1. Volcanic belts of Latin America.

3. The number of volcanoes with historic eruptions, however, is a more easily compiled and probably more standardized figure for comparison between belts (4).

4. This comparison shows that the volcanoes of Mexico are relatively far apart while those of Central America are closely spaced. The spacing of Latin American volcanoes shows both range and average quite comparable to the other belts.

5. The earliest recorded eruption is about 1500 AD in most Latin American belts, but these like the earliest historic eruptions elsewhere in the world tended to be only the more dramatic eruptions.

6-8. Inspection of these data — the total number of eruptions in our data file, those since 1800, and those in this century only — shows what a small proportion of eruptions were reported in the first few centuries of volcanic history. The apparent increase in eruptive frequency during the last few centuries is due largely if not totally to better reporting from a more widely dispersed population.

9. As a comparison measurement this line shows the number of eruptions since 1800, by which time worldwide reporting was reasonably good, averaged per 100 km of belt length. Although the high frequency of eruptions in Central America is well known, the equally high frequency in Colombia and Ecuador may surprise some readers.

10. The slow build-up of pressure within a long-dormant volcano often results in especially explosive eruptions after long periods of repose. And the human toll of such an eruption is often high because most humans tend to ignore the dangers of a volcano

TABLE I

Comparison of Volcanic Belts in Latin America with Other Major World Volcanic Belts

	A Mexico	B Guatemala — Panama	C Colombia — Ecuador	D Peru — N. Chile	E Chile (Cent. and S.)	F Lesser Antilles	Kamchatka — Kuriles	Japan	Java	Sumatra	Lesser Sunda	New Zealand
Volcano Belt												
1. Length (km)	856	1156	829	966	1100	573	1730	1719	928	1526	884	221
2. Volcanoes (total)	10	55	21	20	28	14	82	49	36	26	27	7
3. Volcanoes (historically active)	7	36	17	12	26	8	60	41	23	13	19	5
4. Volcanoes (historically active per 100 km)	.8	3.1	2.0	1.2	2.4	1.4	3.5	2.4	2.5	.8	2.1	2.3
Eruptions												
5. Earliest recorded eruption (AD)	1347	1469	1532	1438	1558	1680	1690	0684	1000	1510	1512	1826
6. Total eruptions in file	79	353	264	70	146	37	429	665	499	124	128	157
7. Eruptions since 1900	25	147	78	25	61	15	280	264	211	70	79	115
8. Eruptions since 1800	39	265	188	57	126	27	383	377	439	121	122	157
9. Eruptions since 1800 per 100 km	4	23	23	6	11	5	22	22	47	8	14	71
Repose History												
10. Volcanoes inactive last 100 years	3	14	3	2	7	3	13	11	3	1	0	0
11. All volcanoes with 100 year reposes	6	23	9	4	11	4	29	30	13	2	5	0
12. Line 11 (above) as % of active volcanoes	86	64	53	33	42	50	48	73	56	15	26	60
Human Interaction												
13. Fatal eruptions	1	9	7	1	7	3	4	31	41	1	7	5
14. Population density (thousands/100 km^2)	59	52	39	5	37	190	1	280	527	44	76	18
15. Population growth (per 1000 per year)	33	31	34	31	20	25	10	11	29	29	29	14
16. References per active volcanoes	7	3	2	2	1	13	2	5	2	1	1	22

that has not erupted within the memory of their grandparents. Therefore it is useful to tabulate the number of volcanoes that have not erupted within the last 100 years (but have in earlier historic time).

11-12. Additional historically active volcanoes have repose periods exceeding 100 years and they have been added to line 10 to give an indication of the number of potentially very explosive "sleeping giants" in each volcanic belt. This number, line 11, is shown in line 12 as a proportion of the total number of historically active volcanoes in each belt. This shows that Mexican volcanoes for example have unusually long repose periods.

13. The number of fatal eruptions in our file is no doubt less than the true number, but it is nonetheless clear that only a small proportion of volcanic eruptions are accompanied by human fatalities.

14-15. These population data are not from our volcano file but have been compiled from the 1970 Encyclopedia Britannica and other sources. Population densities attempt to cover the surrounding regions immediately affected by each volcanic belt and they show in general the expected close relationship between eruption fatalities and high population density. Population growth data have been included as a reminder that areas of relatively high growth rate are rapidly increasing their population density.

16. A very rough indication of the relative volume of scientific study published for each volcanic belt can be gained from these figures. They show the number of references (divided by number of active volcanoes) devoted to each region in my personal file of 10,000 geologic references. While this file is far from encyclopedic it emphasizes both volcanologic literature and studies in Latin America. Therefore it is probably a fair reflection of the relatively small number of studies of South American volcanic belts.

Volcanic hazards

The most dramatic hazards are pyroclastic flows hot glowing avalanches of gas and ash that can sweep down volcanic slopes at speeds exceeding 100 km/hour. Famous examples include the 79 AD eruption of Vesuvius that destroyed Pompeii, and the 1902 tragedy on the island of Martinique when 30,000 citizens of St. Pierre were killed within a few minutes. Nearly all Latin American volcanoes have produced such flows in the past, but the most devastating seem to be those that follow a particularly long period of repose. In 1968 Costa Rica's Volcan Arenal appeared on no lists of active volcanoes because it had not erupted in historic time (more than 400 years), but it erupted violently in July of that year and pyroclastic flows claimed 81 lives. While small flows of this type may travel several kilometres from the base of the volcano similar massive ashflow deposits have been geologically traced over hundreds of kilometres. The processes involved in these massive eruptions are not well known because no eruption of this scale has taken place in historic time, but the traces of such eruptions are obvious in the recent geologic record in the Andes and elsewhere.

At least equally dangerous are the volcanic mudfloes commonly associated with eruptions in orogenic regions. Most Latin American volcanoes consist largely of the fragmental deposits of past explosive eruptions, and these loose mixtures of debris are easily turned into a wet, mobile slurry by heavy rains (like those accompanying many eruptions). Moving down steep slopes, these mudflows pick up more debris and, most importantly, great momentum that carries them far beyond the foot of the volcano. Ice-covered volcanoes are particularly vulnerable as an eruption can melt the ice and snow and rapidly flood the flanks with large volumes of water. The 1877 eruption of Cotopaxi in Ecuador turned the broad fertile Latacunga Valley into "a great mud lake in wild turbulence" (Wolf, 1878) with the mudflow moving at speeds of 10 m/sec and causing great destruction as far as 100 km from the volcano.

The immediate danger from volcanic ashfall is usually limited to a few kilometres from the volcanic vent, but its broader effects can be great. Fine ash and gas from a 1783 eruption in Iceland so damaged crop growth that over half the livestock in the country later died. The resulting famine killed an estimated 10,000 people or one-fifth of the nation's population. The 1815 eruption of Tomboro in the East Indies was probably the most explosive eruption of historic time. Its fine volcanic ash was distributed around the globe in the upper atmosphere where much of it remained for many months forming a natural filter for incoming solar radiation and lowering global temperatures an average of 2°C during the following year. This significant global cooling caused massive crop failures as well as severe heating problems in 1816.

Although many people immediately associate lava flows with volcanic eruptions, only 23% of the 949 historic Latin American eruptions in our file included lava flows. Furthermore the lavas from these volcanoes are normally so viscous that they flow at speeds no greater than a few metres per hour. Thus lava flows pose little danger to human life, but property damage can of course be large.

Finally mention should be made of tsunamis, the giant sea waves that killed tens of thousands in the famous 1883 eruption of Krakatoa. The events that produce tsunamis are unusual in any volcanoes and fortunately only a very few Latin American volcanoes are located on a large body of water.

Hazard evaluation

The many ways in which man evaluates the hazards of a potentially dangerous volcano, can be likened to the many ways in which a medical doctor examines a troubled patient (Decker, 1971). The problem must be diagnosed from external symptoms in most cases and the methods of investigation are similar. Unfortunately, however, there are very few "cures" and the best that can usually be expected is an understanding of what is likely to happen so that preparations can be made at the right time and place.

As in medicine basic research is essential to this understanding and to long-term solutions. Laboratory experiments at high temperature and pressure are necessary to understand the conditions deep inside an active volcano. An excellent summary and example of this approach to volcanoes can be found in the recent book by Yoder (1976). As important as laboratory and theoretical studies are, careful field investigation of ancient volcano interiors exposed at the earth's surface by erosion and faulting offer our best look at the underlying physical relationships of active volcanoes. Many governments and industries recognizing the essential link between basic research and practical problems such as volcanic hazards and volcanogenic mineral deposits give support to the research labs and universities capable of doing this work.

This far-sighted approach, however, may be of little immediate help when a nearby volcano begins to show threatening signs. Like any medical patient the endangered population wants excellent professional advice, preferably from experts familiar

both with the best current scientific literature on the subject and with the particular idiosyncrasies of the patient/volcano itself. This requires the support of well-trained professional volcanologists dedicated to the study of the local volcanoes and it may also mean importing specialists when the need arises.

The history of a new patient is the first information sought by an examining physician (even, it sometimes seems, when the patient is bleeding to death). The need for historical information is just as important for volcanoes. No two volcanoes are the same, and the historic record often provides our best guide to what might be expected in the future. Obviously a volcano that has regularly erupted every 10-20 years deserves special attention after 30 years of quiet. Some volcanoes have a history of flank eruptions following a summit eruption within a few months and such information can be very useful even after a summit eruption has begun. Furthermore, many volcanoes are now known to be more likely to erupt at a particular day in the 14-day tidal cycle than on other days — tidal forces even though small are apparently sufficient to trigger an eruption in a pressurized volcanic chamber that may have been ready to erupt for weeks. Mauk and Johnson (1973) found, in a global study, that historic South American eruptions were closely in phase with the 14-day tides.

Many volcanoes like patients with poor memories have such a short historical record that it is little help to an investigator. As emphasized earlier many volcanoes lie quiet for hundreds of years before violent eruptions and man's descriptive record of much of this planet is simply too short. For such volcanoes a history useful in predicting future behavior comes mainly from geologic mapping. This work — analagous to the physician's physical examination of the patient for scars and other traces of former medical problems — requires time and effort. A good modern example of this approach is the U.S. Geological Survey team of D. R. Crandell, D. R. Mullineaux and co-workers who have been working on a large number of volcanoes by paying special attention to the record of geologically recent behavior and interpreting it in terms of contemporary hazard. They have for example provided helpful criteria for recognizing (and differentiating between) pyroclastic flow deposits, mudflow deposits and glacial debris (Crandell and Mullineaux, 1975). By mapping and radiocarbon dating of these deposits they have pieced together the last four thousand years of eruptive history for Mount St. Helens, a dangerous volcano in the state of Washington that had formerly been known only for a few eruptions witnessed during the first half of the 19th century (Crandell, Mullineaux and Rubin, 1975). From such studies this group has compiled volcanic hazard maps that show areas of "low", "moderate", and "high" risk from mudflows and ashfall (e.g. Crandell, 1973). Hazard maps are enormously valuable to local authorities, helping them to prepare contingency evacuation plans and to educate the inhabitants of these hazard zones. Rough but useful maps can be produced quickly by trained geologists particularly if detailed topographic maps are available. Threatening premonitory signs on Cotopaxi in late 1975 (Simkin, 1976) brought an AID-sponsored USGS team to Ecuador and they produced a hazard map for Cotopaxi, scene of the devastating mud flow described earlier in this paper, in one month of hard work. The volcano cooperated by postponing its eruption so the map is already in use by Ecuadorian authorities and will undoubtedly save lives when the eruption does take place.

The volcanologist is less dependent on the thermometer than is his physician counterpart, but he is at least as concerned by unusual increases in temperature. This may be recognized by increased vapor emission, anomalous melting of snow, warm streams, or remote detection of increased infrared radiation. Warming of Lake Taal, in the Philippines, gave some warning of the devastating 1965 eruption there (Moore, Nakamura, and Alcarez, 1966) and Birnie's (1973) hand-held infrared radiometer mapping of Santiaguito in Guatemala located a previously unrecognized thermal anomaly that was the site of an eruption several months later. There are, however, many examples of increased thermal activity on volcanoes that have then refused to erupt.

The volcanologist's stethoscope is the seismograph and monitoring of earthquake swarms has been one of the best techniques for investigating the inner workings of volcanoes. Volcanic earthquakes are often too small to be located by the world-wide seismic network, but they are sometimes felt by residents and have historically provided the most vivid alarm system for impending eruptions. Well-monitored volcanoes have permanent sensitive seismographs (Kilauea and Mauna Loa on Hawaii have at least 25) and the development of the modern, portable seismograph means that most volcanoes can now be monitored without great expense. A simple plot of number of events per day if standardized can warn of increasing activity and careful study of the seismograph "signatures" for each event (see Minakami, 1974) can refine this approach considerably. Harmonic tremor is a sure sign of moving magma and its appearance on Hawaiian seismographs often coincide with the start of an eruption, but in New Zealand it has provided warning from 10 hours to 7 days before an eruption (Decker, 1973). Multiple seismographs can provide valuable information on depth of focus and migration of earthquakes, but timing synchronization problems and seismic velocity uncertainties often make this impractical for portable units on remote volcanoes. Using a variety of seismic techniques Tokarev (1976) successfully predicted the time and place of the great 1975 eruption of Plosky Tolbachik in Kamchatka. There are, however, some eruptions without premonitory seismicity (e.g. the 1971 eruption of St. Vincent's Soufrière volcano in the Lesser Antilles) and many volcanic earthquake swarms without a subsequent eruption (e.g. the much-publicized events at Guadeloupe's La Soufrière in 1976). Therefore the volcanologist's stethescope should not be used alone.

Chemical analysis of a patient's waste products provides valuable data for both physician and volcanologist. The water and gas brought to a volcano's surface in hot springs, fumaroles, and solfataric fields challenges the chemist in collection and interpretation, but may yield the most promising indicators of a forthcoming eruption. In what might be called the "urine analysis of an active volcano", Chirkov (1976) monitored the radon content of hot spring water from Karymsky volcano in Kamchatka. Radon apparently released by microfracturing of rock in the volcano's interior, increased dramatically in content for months before the 1970 eruption and then dropped to the low proportion that was noted after the previous eruption (in 1967). Increased volcanic flatulence has been reported before some eruptions and recent analytical work on fumarolic gases indicates systematic chemical changes that may be premonitory. For example, Giggenbach's (1976) work on White Island, New Zealand indicates that increases in the S/Cl ratio of fumarolic gas may warn by weeks or months of a forthcoming eruption.

Any of the above premonitory phenomena might help explain the unusual animal behavior often noted before an erup-

tion. In 1955 dogs were seen sniffing and digging the ground at the very site a few days later of a fissure eruption on Hawaii's East Rift Zone. Anderson (1973) has compiled other such reports and recent use of animal behavior by the Chinese in their earthquake prediction work has revived interest in the different sensitivities of animals as sensors of geophysical events.

The inadequacy of the human senses in volcanic prediction is illustrated by Neumann Van Padang (1963) who tells of an Indonesian surveyor on Anak Krakatau in 1939. He climbed to the summit and looked around as he set up his surveying instrument. It must be admitted that he had no dog with him, but he smelled no unusual smells, felt no tremors, heard no unusual sounds and saw no unusual sights. He soon noticed, however, that the magnetic needle on his compass was swinging wildly and he quickly made haste down to his boat from which he had an excellent view of the eruption as he pulled away from the island. Moving magma is non-magnetic yet a good conductor and therefore can produce large local magnetic and electrical anomalies. The Japanese have done some intensive work on these phenomena (e.g. Rikitake *et al.*, 1963) and the 1971 eruption of Kilauea, Hawaii was preceded by magnetic noise (Keller, Jackson, and Rapolla, 1972), but only a very few active volcanoes are being monitored for magnetic or electrical premonitory indicators.

The last, but no means least monitoring technique to be discussed in this listing is the deformation experienced by an active volcano as magma moves near the surface and swells the edifice. To stretch our medical analogy, this might be compared to a pregnancy (but with an uncertain gestation period!). The classic work of Eaton (1959) showed that the surface of Kilauea tilded upwards by tens of microradians over several months prior to the 1959 eruption. A microradian of tilt is a 1 mm elevation change over a 1 km baseline and sensitive measuring devices are obviously needed to detect such changes. The value of this monitoring technique has been so well demonstrated, on Hawaii and elsewhere that a variety of tilt meters and geodimeter (horizontal inflation measurement) techniques have been developed (see Kinoshita, Swanson, and Jackson, 1974). I describe here only the geodetic leveling, or "dry tilt" technique because of its simplicity and the fact that the necessary equipment already exists in any country with geodetic surveying capability. Permanent benchmarks are established at the 4 ends of a 40 m cross on the lower flanks of the volcano, the level is set up at the centre of the cross 20 m from each benchmark and the elevation differences between the benchmarks are then carefully measured using first-order leveling techniques. The benchmaks can then be releveled days or weeks later and any change in their relative elevations must indicate tilt of the volcano's surface at that point (unless there has been local movement of one or more benchmarks). Surveying precision can be checked because the four benchmarks can be solved for four different triangles all of which should yield similar values (and directions) of tilt. Surveyors from Ecuador's Instituto Geográfico Militar established such tilt stations on Cotopaxi during its threatening activity of late 1975 and their evidence that the volcano was not deforming provided a valuable counter to the increased seismicity and geothermal activity. Deformation measurements can be made quickly and as at Cotopaxi are particularly useful indicators to supplement other monitors of volcanic behavior. When these other monitors suggest threatening behavior, however, it is very helpful to have "dry tilt" benchmarks already established and leveled. Then one quick releveling will often be enough to show whether the volcano is indeed inflating.

Conclusion

Volcanoes pose serious hazards to many parts of Latin America. Some basis for assessing the regional frequency or likelihood of eruptions can be found in the first part of this paper, the hazards are summarized in the second part and the third describes various ways in which we can deal with these hazards. Eruptions cannot be prevented by man and efforts to control them have met with only limited success. However, there is much that can be done to evaluate what to expect from a volcano and when to expect it. This is the information that can save many lives and in many cases this information depends more on awareness and communication than on expensive equipment. PAIGH can make valuable contributions to this effort in several ways. The PAIGH history subsection could help in gathering the ancient eruption descriptions and dates that are so useful in assessing future behavior. Seismologists can help by alerting geologists to any unusual seismicity near volcanoes and by periodic monitoring, with portable seismographs of potentially dangerous volcanoes distant from permanent seismographs. Geodesists can help by periodic monitoring of inflation on hazardous volcanoes and, of course, good topographic maps and aerial photographs are essential to any modern studies on volcanoes. Geologists can prepare "risk maps" of dangerous volcanoes and make them available to government authorities. The geologist is also needed to compile information from this wide variety of sources to combine it with careful field study and to work toward an understanding of each volcano. At the Smithsonian Institution we can help with our volcano reference file and particularly with our Scientific Event Alert Network, acting as a communication centre to alert interested specialists when threatening (or worse) behavior is observed at a volcano. Other specialists can help with some of the chemical or geophysical monitoring techniques available for active volcanoes. But "to evaluate what to expect from a volcano and when to expect it" requires in the end, a good understanding of that particular volcano and this understanding, in turn usually requires the dedication and hard work of a geologist (plus the support necessary for such work).

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Prof. G. P. Woollard:

Thank you very much Dr. Simkin. Our last speaker for this morning's session is Dr. D. Harlow who will present a paper entitled **"Geophysics in the Study of Structures and Processes of Volcanoes".**

Dr. D. Harlow:

I would like to very briefly concentrate on one technological approach to a global early warning system — a volcano surveillance system. There are more than 500 active volcanoes throughout the world today and the eruptions usually come as a surprise to almost everybody despite the existence of geophysical parameters that change and can be used to at least give us a warning that many quiescent volcanoes are potentially becoming eruptive.

With the advent of the LANDSAT satellite it became possible for the first time to install instruments at remote sites and relay the data back to a central recording site via satellite. With this system a ground recording site can be set up which transmits the data to the satellite which in turn relays the data to receiving sites on the ground. The technology that has been developed for this radio relaying link is very good and very reliable being normally 95% or more and often as high as 98% efficient.

Mainly of interest to this group are the instruments that we have installed on volcanoes in Central America. The geophysical parameters that we have concentrated on recording are groundtilt and the frequency and distribution of small earthquakes, because they appear to be the most reliable indicators of an impending eruption. These appear logical choices if you imagine a volcano in response to the shallow instrusion of magma slowly and minutely inflating like a balloon, but at the same time the stress due to the intruding magma produces a sharp increase in microearthquakes. The two instruments that we installed on the volcanoes are biaxial tiltmeters and multilevel seismic event counters. The advantage of the tiltmeter is that it is small, portable and can be easily installed on volcanoes in remote sites. The installation on the site involves placing it at least six metres deep in either bedrock or volcanic ash. The tiltmeter has the sensitivity of 1 microradian (a microradian is 1 millimetre elevation change in 1 kilometre). Our biggest worry before this project started was finding sites with the required stability. As it turned out the best sites we had were in volcanic ash and the reason for this is that, despite the high rainfall, the ash provides excellent drainage and therefore apparent high stability. The heart of the tiltmeter used for our experiment in Central America is a level bubble formerly used in inertial guidance systems for ballistic missiles. We are not even sure that the manufacturers specifications have been released but we do know it performs to our requirements.

Some of the most recent results from the tiltmeter come from Puego volcano in Guatemala. This volcano began inflating very slowly in early May of 1975 and on the 28th there was a small eruption of Puego volcano followed by a tilt event. Since that time the degree of tilt has gradually been increasing. This has been somewhat of a surprise as normally an eruption should act as a release and from experience in Hawaii the volcano should rapidly deflate. The conclusion drawn from our experience in Latin America is that we saw a small event, but have not yet seen the main eruption.

The multilevel seismic event counter is designed to count seismic disturbances on four different levels giving us not only the numbers of sizes of disturbances but a sort of a classification by size. The event counter, the transmitter, the antennae, the seismometer and the batteries are all housed in a package which is convenient for transport and installation. The power requirements are small so that the batteries are sufficient to operate the system for years.

The event counters have not, however, worked very well in counting or getting an indication of harmonic tremor which is a sort of continuous seismic noise apparently generated by movement of magma in the volcano. Thus we are not as pleased with the results from the event counters as we are with those from tiltmeters. In fairness, I must emphasize that the event counter itself is a complicated instrument package which must reduce a complex set of seismic signals to a form suitable for transmission via satellite. In order to improve this process we are attemping to design new data processing hardware using micro-processors which in effect amounts to developing a specialized minicomputer. We hope this will lead to a much more simple design that will more effectively tell us about the distribution and intensity of seismic activity at sites of potential volcanic activity.

As classical volcanic observatories are expensive and as it is often decades between eruptions, we hope this efficient data collection system will provide us the opportunity to deploy a large number of instruments at sites of potential volcanic activity. Given this capability to identify quickly volcanoes showing signs of being restless, we are in an excellent position to move in rapidly with other techniques and thereby vastly increase the data on volcanoes needed to develop sufficient understanding of the mechanism of a volcanic eruption to predict its occurrence.

Prof. G. P. Woollard:

Thank you Dr. Harlow and that concludes the morning session. Our chairman this afternoon will be Mr. R. Geller.

FOURTH SESSION
Tuesday, September 28

QUATRIÈME SÉANCE
La mardi 28 septembre

CUARTA SESIÓN
Martes, 28 de septiembre

OBJECTIVES AND METHODOLOGY OF SELECTED NORTH AMERICAN PROGRAMS

LES OBJECTIFS ET LA MÉTHODOLOGIE DE CERTAINS PROGRAMMES NORD-AMÉRICAINS

OBJETIVOS Y METODOLOGIA DE PROGRAMAS NORTEAMERICANOS SELECCIONADOS

Chairman/Président/Presidente
Mr. R. Geller

Speakers/Conférenciers/Expositores

DR. A. G. DARNLEY
MR. R. H. PEMBERTON
MR. R. LINDSETH
DR. R. BALLARD

Mr. R. Geller:

To continue our presentations concerning the Objectives and Methodology of Selected North American Geophysical Programs, Dr. A. G. Darnley will speak concerning **"Research in Exploration Geoscience in Government".**

Dr. A. G. Darnley:

This paper is concerned with the reasons why research into mineral exploration needs to be conducted within government, the type of geoscience research that is required and how it can be organized with reference to the type of work being performed by or for the Geological Survey of Canada in Canada and also in Brazil. There is no question that the world has a need for additional mineral resources. The need for finding new mineral deposits is greater now than ever before because of the ever-increasing demands created by rising expectations of an increasing population. Because mineral resources are limited and are a wasting asset governments must be concerned with the management of their resources irrespective of the type of political structure existing within any country. Although many of the ensuing comments generally apply to all types of mineral exploration this paper is primarily concerned with exploration related to metalliferous resources and illustrated by reference to geophysical methods of exploration.

The need for exploration research in government

Most people recognize that government must exercise some measure of control over natural resources within its boundaries. To do this government requires reliable information. The first bit of information required concerns the present and future availability of natural resources. The identity, quantity and quality of resources need to be established as a basis for long term economic planning, regional development, import and export policies, industrial policies, etc. It is necessary to know not only about resources which have already been discovered, but also about the probability of further discoveries. How much exploration is currently taking place? How efficient is the exploration activity? Can anything be done to improve the efficiency of the exploration process? In order to establish what is useful and significant information related to mineral exploration a government must have its own cadre of experts with the required knowledge and experience. At the lowest possible level of involvement, where government depends almost entirely on outside expertise, it must nevertheless ensure that competent outside experts are being hired and that they are performing in a satisfactory manner. In practice, in order to influence events and not merely be a passive recipient of complex technical reports, a government must have a sufficient number of scientific and technical experts with a level of knowledge and experience at least equal to that of outside consultants or contractors. This level of expertise cannot be maintained unless the individuals concerned are closely associated with active scientific work. Active scientific work must include an element of research.

Mineral exploration is a very expensive activity. The average expenditure for discovering a new metalliferous deposit is now estimated to be in the region of $25,000,000 although there is a very wide variance. This is for expenditures up to the point where a deposit has been proved, but before any expenditures have been made for development. There is little reason to doubt that discovery costs in all parts of the world will continue to rise. At the same time the availability of capital to finance the discoveries will diminish due to accelerating demands for large amounts of capital for the other essentials of civilization such as fertilizers, water supply, housing and transportation. Competition for the available funds will be more intense and decisions on priorities will be an increasingly political matter. In these circumstances it will fall upon government to ensure that exploration activities are pursued as efficiently as possible, that the best methods are clearly established for all commonly occurring circumstances and that all resource information becomes publicly available within a reasonable time period. Whereas an industrial enterprise must give priority to short term results a government organization must take a longer term view. To do this it must employ individuals with the necessary breadth of knowledge who are aware of scientific and technical trends and developments. Awareness of future trends can only come about as a result of involvement with current research.

In most fields of knowledge it is usually possible to obtain the services of specialized consultants. However it is an unfortunate fact of life that in many scientific and technical problem areas where judgment in addition to knowledge is required, it is difficult to obtain a unanimous opinion. In such cases there must be a referee who takes responsibility for making a decision. This is best done by a technical person who has an appreciation of all factors involved. In other words, when consultants differ, it may take someone in government to make a decision.

In geoscience more than in most other forms of scientific activity, the painstaking collection of much detailed and at first seemingly unrelated information is a necessary and time consuming preliminary step before any predictions are possible. It is most important that this basic information is gathered systematically and that it is readily available. Systematic data collection may be considered as a passive form of research, but it is as vital for efficient mineral exploration as it is for basic geological science.

While basic geoscience data have been considered a suitable responsibility for government in many countries the acquisition of systematic data relating to mineral exploration has been much more erratic. This is certainly the case in most developed countries where the initiatives for mineral exploration have rested primarily with private industry. The information gained in the course of exploration has been considered to be of a proprietary nature because it has been gathered at private expense. This situation has led to a large amount of duplication in data gathering for mineral exploration purposes, much of it of uncertain quality and unavailable for comparative purposes. By making research into exploration a concern of government in the same way that research into basic geoscience has been a concern of government exploration information will progressively become a subject for more informed open scientific discussion. The provision of adequate resources through efficient mineral exploration is too important to our society to be handicapped by barriers in the data collection process.

The type of research which needs to be done

The purpose of a government organization undertaking research into exploration geoscience should be to increase the efficiency of the exploration process for all organizations undertaking

exploration. In order to achieve this purpose the exploration research carried out by government must be practically applied to the problems of the country and intermediate to the type of research undertaken by universities and the routine exploration procedures followed by organizations primarily concerned with mineral exploration. It must be stressed that successful exploration is a multidisciplinary activity with equal contributions from geology, geophysics and geochemistry. Within each of these disciplines it is important that a multiparameter approach is taken. The occurrrence of a mineral deposit is rarely so obvious that a single parameter is capable of positively identifying its presence. Within a university knowledge is usually accumulated and taught on a discipline and specialized basis with emphasis on theoretical principles. Such specialization is necessary for training in fundamentals and for the pursuit of advanced research into natural phenomena. The university approach to research is usually strong on theory and rather weak with respect to comparative evaluation and coordination, while the approach of industry is usually empirical and not motivated towards scientific investigations more thorough than necessary to achieve immediate objectives. A government institution concerned with exploration geoscience research must therefore bridge the gap between theory and practice by testing, comparing and evaluating the latest techniques and theories in practical situations and endeavouring to obtain a scientifically satisfactory explanation for all data it gathers. It is particularly important for institutions in countries where subjects such as exploration geophysics have not hitherto received much attention to evaluate existing techniques and knowledge in the light of the particular geological and environmental situation which applies in that particular country.

In order to perform useful research in relation to mineral exploration it is necessary to know the effectiveness of existing available methods within the country. It is usually assumed that if a mine has been found as a result of a particular exploration program good methods suitable for widespread application elsewhere have been used. This may be an incorrect assumption. Possibly if the methods had been more skillfully used or equipment was functioning to design specifications, several mines would have been found. Alternatively, if an exploration program has been conducted in a particular area and nothing has been found, this may be so because there is nothing to be found or because the methods employed are unsuited to the area where they have been used. Even on occasions when exploration methods are properly and successfully applied much information relating to the exploration process which might be useful on a later occasion in the same or other areas is frequently discarded and not made available to other users who might benefit. The short life of many exploration companies often militates against the preservation of information on the methods they have used and the positive or negative results they have obtained. For all these reasons it is necessary for an institution concerned with exploration research to be aware of the methods that are currently being used within a country, the way in which they are being used and at the same time to make an independent assessment of their effectiveness in a number of different geological situations where the discovery of mineralization may be either easy or difficult. Knowledge of the effectiveness of presently used methods is an essential first step before deciding on the most important lines of research for the future.

The identification of the most fruitful lines of research and development is particularly important because the available funds and manpower are always inadequate to perform more than a small percentage of possible lines of research. It is much easier to perform research which is of academic interest only than to perform research directed towards a specific practical objective. It is always easier to refine and develop some already familiar technique than it is to initiate action in a new field. Exploration must be viewed as a whole, as an integrated system, and its weakest links identified. It is because mineral exploration is or should be an organized sequence of activities that an institution concerned with exploration geophysics for example should not be set up in isolation from such activities in disciplines such as economic geology and geochemistry. The types of question which should be asked are as follows: Is it worth attempting to develop advanced electrical techniques which might indicate whether subsurface mineralization is principally iron or copper sulphide when geochemical techniques already exist which can provide evidence as to probable composition? How much effort should be devoted to the perfection of digital recording and digital compilation of airborne surveys for the purpose of simplifying compilation procedures? Until such time as there is an automated aircraft flight-path plotting system with the necessary degree of accuracy much of the advantage of digital recording of airborne data is lost because many man-hours must be spent by technicians in tracing the aircraft's position from photographs. How important is it to obtain a device for giving a relatively imprecise but immediate measure of metal content in a rock outcrop as compared with providing much more precise measurements of metal content in a base laboratory? Problems such as these are intended to show that decisions as to the most needed types of research can best be determined by an organization in close contact with current exploration situations.

The organization of exploration research

As with any type of research organization the success and usefulness of a group devoted to mineral exploration research will be largely detemined by the quality and suitability of the research personnel employed. Given that exploration research is applied research, personnel must have a strong interest in the problems of mineral exploration and experience in mineral exploration in addition to academic training in a relevant specialization. They must be sufficiently individualistic to be creative without being so individualistic as to be unwilling to participate in team activities or divert their attention to urgent problems requiring an immediate solution. It is assumed that an adequate level of technical facilities can be made available and that there will be sufficient support staff so that scientists can be primarily engaged with science. At the same time research staff must expect to participate actively in field work and directly participate in the real-life problems experienced by field operators and technicians. Only by understanding the realities of equipment used under difficult field conditions will realistic methods be devised and practical solutions obtained for the inevitable problems.

A balanced research and development program should contain both long and short range elements with the deliberate intention of using contact with current exploration problems and trouble-shooting with respect to these as a means of tempering the idealistic intentions of long range studies. It is possible to build an organization structure either around scientific disciplines or according to anticipated missions or problems. In either case it is important to recognize that an individual scientist can seldom

develop his specialization in isolation. He or she requires the support of colleagues who understand and can critically discuss the specialization. Thus a viable research effort requires a minimum number of scientists in each specialization and each group would normally require a minimum of two or three scientists and two to four technical support staff. This minimum size of cell is necessary in order to obtain mutual stimulation and also provide continuity in the event of absences or losses. For a small sized organization the only practical organizational structure is to manage scientists by discipline in order to ensure that there are viable specialist groups. As an organization grows in size it becomes possible and desirable to subdivide specialist groups between different missions on a continuing basis. The optimum size for a mission-oriented research group will vary according to the complexity of its mission. It must be large enough to permit the diversity of specialists and support staff necessary for the mission, but not so large as to contain more individuals than can be well known to the leader of the group. It is also important that the scope of the mission should not be too narrowly defined or too short term. There is a "running-in" period before any group of individuals, especially from diverse specializations, can become an effective team and once established this investment in team-building should not be dissipated too readily. It would not seem to be warranted to establish major mission-oriented organization groups around any task for which the expected duration is less than five years.

Exploration geophysics research performed by the Geological Survey of Canada

This paper thus far has been mainly of a philosophical nature. As an example of the types of geophyscial research relevant to exploration which are being conducted by a government organization recent and current work of the Resource Geophysics and Geochemistry Division, Geological Survey of Canada is used. There are other organizations of similar type elsewhere in the world performing broadly similar functions and some of them are more closely tailored to the specific problems of exploration research, but the Geological Survey of Canada is most familiar to the writer. The Resource Geophysics and Geochemistry Division is only one out of six divisions of the Geological Survey engaged in scientific research. The other divisions are concerned with regional mapping and economic geology, petroleum geology, marine geology, and surficial and engineering geology. There is another part of the Federal Department of Energy, Mines and Resources, the Earth Physics Branch which has a responsibility for solid-earth geophysics.

The objectives of the Resource Geophysics and Geochemistry Division are within the overall objectives of the Geological Survey and are to provide the geophysical and geochemical information necessary for ascertaining Canada's solid energy and mineral resources and facilitating their exploration and development. This involves the acquisition, interpretation and use of geophysical and geochemical data, the development, testing and calibration of relevant instrumentation and the integration of such data with available geological information. The division developed from an aeromagnetic survey unit which was set up in 1947 and grew with the addition of successive specializations. It now consists of five sections (four geophysical and one geochemical) providing specialist field services and four sections providing specialized support to these services. The sections are listed on the left-hand side of Fig. 1. The total number of staff involved is 102, consisting of 40 scientists, 42 technicians and 20 other support staff. As pointed out earlier in this paper an organization which is administered according to scientific or technical specialization tends to funnel its growth along these same lines. Since most practical exploration problems require a combination of methods to obtain a solution, this specialist orientation which serves well for development of individual techniques is not ideal for an organization with a responsibility to exploration research where the emphasis must be on evaluation and integration of methods as well as on their development.

In order to provide a problem or customer-oriented approach the organization structure of the division has been recently re-aligned so that it coincide with the principal missions of the Geological Survey. These are Resource Identification and Evaluation, Regional Geophysics, Terrain Geophysics and Overseas Aid (via the Canadian International Development Agency). The matrix structure which has been created is shown in Fig. 1. This figure shows the principal involvements of the various specializations within the division at the present time. All specializations are nominally available to contribute to the requirements of each of the programs. The section head for each specialization is the senior adviser in this field and has respon-

	Resource I & E	Regional Geophysics	Terrain Geophysics	CIDA
Electrical Methods	+		++	–
Geochemistry	++			–
Magnetic Methods		++		–
Radiation Methods	++			–
Seismic Methods		+	++	
Analytical and Nuclear Instrumentation	++			–
Contract Survey		++		+
Digital Compilation	–	++		–
Experimental Airborne Operations	+	+		

++ Major activity
+ Intermediate activity
– Minor activity

Figure 1. Resource Geophysics and Geochemistry Division, Geological Survey of Canada. The organization is based on a matrix formed of scientific and technical specializations along one axis and mission-oriented programs along the other axis.

sibility for the quality of work produced by the scientists and technicians in his section. It is his responsibility to allocate them to meet the requirements of the program heads who control budgets. The Resource Identification and Evaluation program is the one which is directly concerned with mineral exploration research.

The flow of research and development within the division is summarized by Fig. 2. At any time there are a number of ideas undergoing preliminary research; some of these are done in-house and others are being performed by means of research agreements with outside organizations. The initial stage of research is the lowest cost stage, but it is also the stage at which there is the greatest uncertainty about its usefulness. Examples of topics which are presently under investigation include: the best means of utilizing the full gamma-ray spectrum for airborne survey; the relationship between self-potential and geochemical anomalies and the mechanism of element migration; methods of employing geophysical and geochemical data for better resource estimation; the usefulness of helium isotope ratios for radioactive mineral exploration.

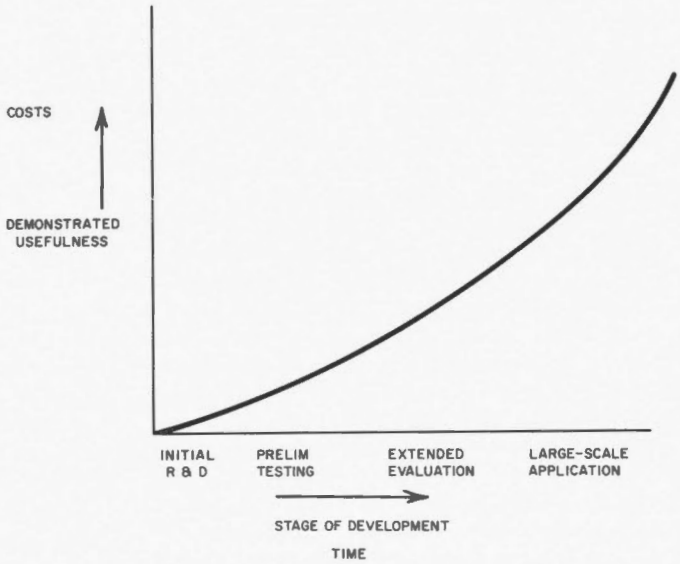


Figure 2. The flow of research and development at the Resource Geophysics and Geochemistry Division, Geological Survey of Canada.

Methods which on the basis of the preliminary research appear to have promising possibilities go through a more exten-

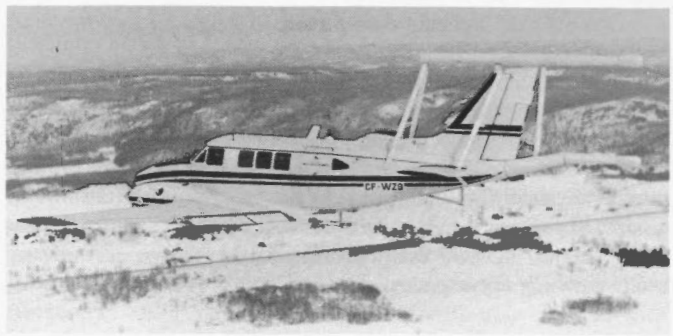


Figure 3. The Geological Survey of Canada's Beech Queenair aircraft with magnetic gradiometer attached. The two sensors each consist of a self-orienting rubidium-vapour magnetometer at the end of a 3-metre boom.

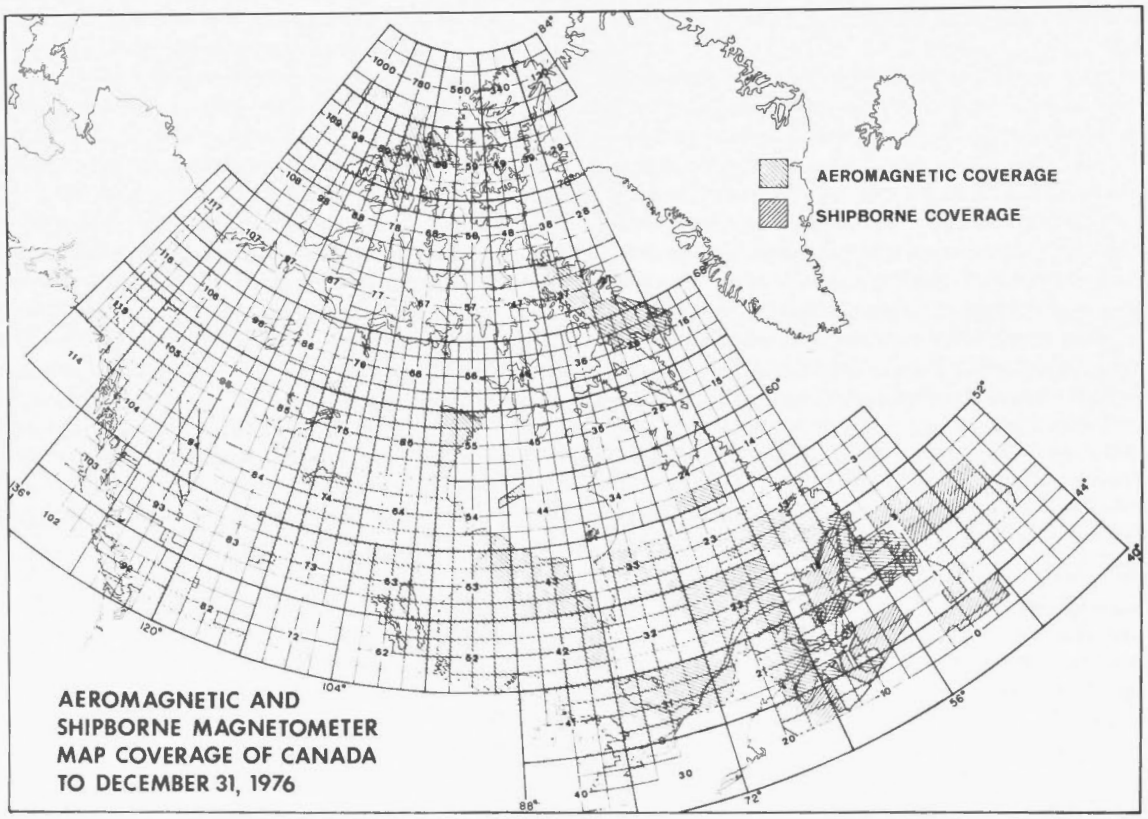


Figure 4. Aeromagnetic (and shipborne magnetometer) coverage of Canada gathered and compiled to the specifications of the Geological Survey of Canada.

sive evaluation usually involving field work in order to test methods and/or interpretations. Good examples of this systematic approach have been provided by the work done during the past decade with respect to the development of airborne gamma-ray spectrometry into a routine although complex survey operation and similarly the development of a dual sensor airborne magnetic gradiometer (Fig. 3). In each case small scale field trials have been succeded by more extended field operations. In earlier years, during the 1950's, systematic development occurred with respect to what are now considered standard sensitivity aeromagnetic surveys leading to the Federal-Provincial Aeromagnetic Survey Program, which is now on the way to covering 70% of the area of Canada (Fig. 4). In the case of high sensitivity airborne gamma-ray spectrometry this operation has like the standard Aeromagnetic Program now been placed in the hands of private contractors who follow specifications developed through the method development work undertaken by the Geological Survey of Canada. Fig. 5 shows the aircraft the Geological Survey has used and continues to use for the development of gamma-ray spectrometry and related techniques and Fig. 6 shows the area now covered by high sensitivity gamma-ray spectrometry surveys. The fact that it has become accepted practice in

Figure 5. Short Skyvan aircraft used by the Geological Survey of Canada, primarily for the development of high sensitivity airborne gamma-ray spectrometry.

Canada for extensive routine surveys to be handled by commercial contractors does not mean that this is the only way such work can be done. However, the requirements for efficient, economical and rapid production are rather different from the requirements for a research organization. There is little doubt in the writer's

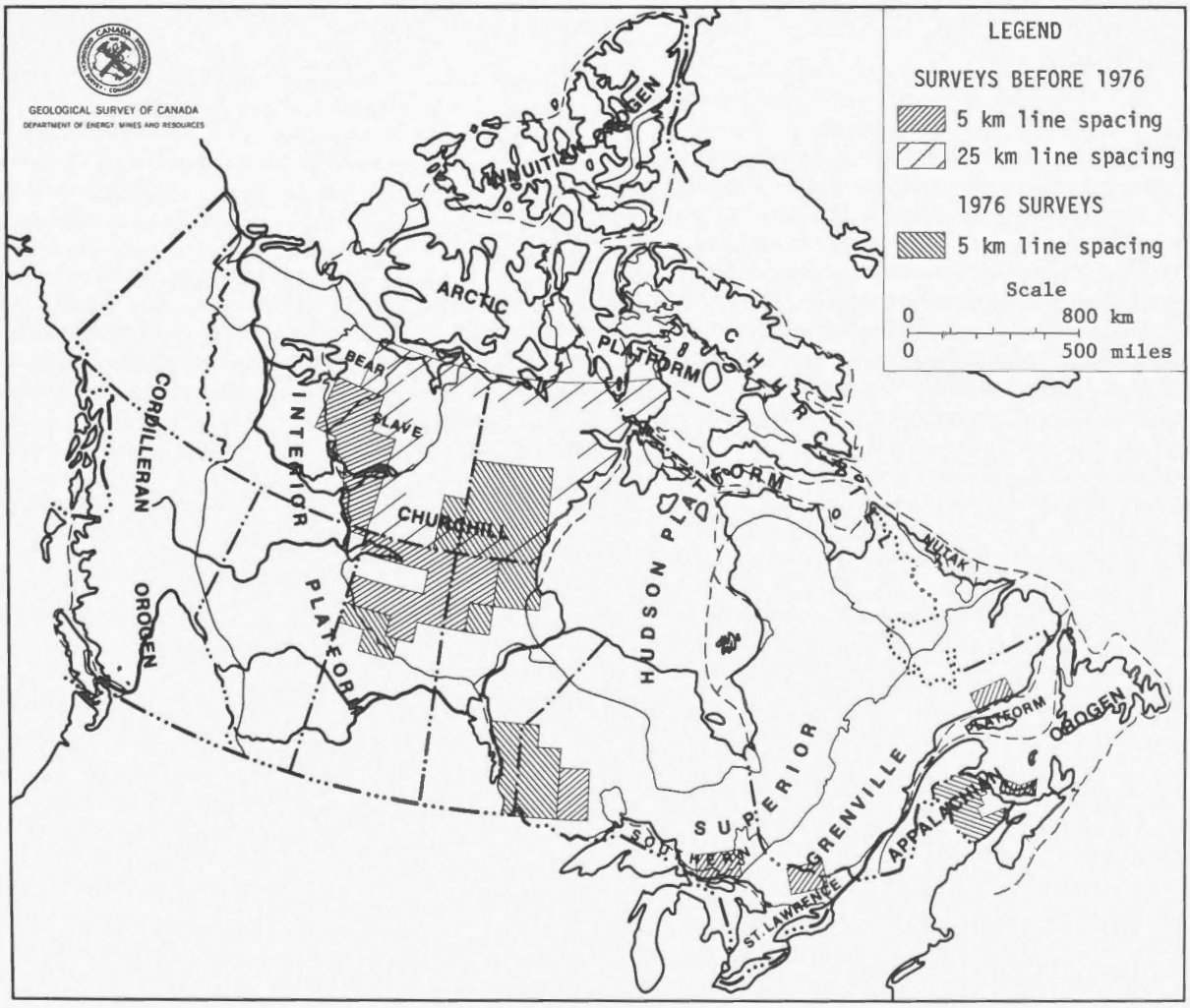


Figure 6. Airborne radiometric coverage of Canada gathered and compiled to the specifications of the Geological Survey of Canada.

mind that such tasks, although they must be closely coordinated so that the benefits of research are incorporated into large scale production, should be managed separately.

As an example of the type of research work that is relevant to a country at a less advanced stage of industrial development than Canada a major project in Brazil can be cited which involves the Geological Survey os Canada in an advisory role. The Projecto Geofisico Brazil-Canada which is funded in part through the Inter American Development Bank has been planned under the technical supervision of the Resource Geophysics and Geochemistry Division. The Project involves phased mineral exploration over an area of 375,000 km² located between 5°S and 16°S and 48°W to 51°W with the Brazilian capital of Brasilia at the southeast corner. Preliminary geological mapping was already available for this area, produced mainly from air photo interpretation with limited ground verification. From experience in other tropical regions combined with knowledge of previous experience in Brazil it was apparent that a combined magnetic and radiometric airborne survey would best serve to define areas of greatest exploration interest in a region of tropical weathering and poor outcrop and extensive areas of Quaternary sand cover. This initial airborne coverage has been done in two phases, initially at 2 km spacing over the whole area with subsequent in-fill over areas of greatest interest amounting to 25% of the total area. Since there was some doubt as to the efficacy of the electromagnetic and regional geochemical methods in this climatic and geological region five pilot study areas each of 3,000 km² were selected at different places within the overall project area. Airborne electromagnetic equipment from Canada was test flown over a series of lines within three of these study areas and stream sediment geochemistry was undertaken in all of them. Subsequently, ground geophysical work by teams of scientists and technicians from Canadian geophysical service companies has been undertaken for the purposes of verifying airborne anomalies and providing training to Brazilian scientists. The test surveys which were undertaken over ground with some indications of mineralization served to demonstrate the degree of usefulness of existing types of geophysical equipment under the local conditions. Final verification of the significance of the results will only be obtained when drilling has been undertaken. This step by step scientific approach is the only valid way in which to test the suitability of existing methods under new conditions and to recognize their strengths and weaknesses. Knowledge of the latter is the first step towards finding the means of overcoming or by-passing these weaknesses. This should be the first objective of exploration research. The importance of a combination of sound basic knowledge of each technique with a willingness to experiment, test and confirm interpretations under field conditions cannot be too highly stressed. Without the means of investigating the effectiveness of exploration research and development much effort will be wasted and much of the motivation and challenge for the scientists concerned will be lost.

In the past it has been rather common practice in the mineral exploration business not to divulge the real or supposed secrets of how any particular success was achieved. Details of the methods used and philosophies followed have frequently been treated as trade secrets.

In a world where any real or imagined shortage of an essential raw material is increasingly likely to create the most serious political consequences it is no longer reasonable that the best and latest development in exploration technology should not be public knowledge. For this reason in particular it is necessary that governments be involved in research into exploration geoscience.

Mr. R. Geller:

Thank you very much Dr. Darnley. I think there is particular interest here in applied techniques and an appreciation of the value of freely available data. Our next speaker is Mr. R. Pemberton who will present a paper entitled **"Exploration Geophysics Programs in the Mineral Industry".**

Mr. R. Pemberton:

How important is the minerals industry to Canada? In 1975 its output was valued at $13.4 billion or 8.7% of Canada's GNP. Canada exports 60% of her minerals production which accounts for one-third of our exports. Considering the fact that in 1975 Canada had a $5 billion trade deficit, you would think our various levels of government would do what it can to support such a major contributor to the average Canadian's economic well-being.

Until recently the exploration industry in Canada was the envy of the mining world. We had excellent rapport between industry and government. The roles of these parties were "distinctive but interdependent". The government thought or acted as if it thought the role of the private sector was essential. In at least some parts of the country there now seems to be some effort to change these roles, especially for the government to assume the role of industry.

The Canadian federal and provincial departments of mines and geological surveys probably are the best in the world. The success of the Canadian mineral industry is in no small measure due to the results of their producing, collecting, compiling, analyzing and reporting on geophysical, geochemical and geological data. The fact that they put this information in a readable and usable form and make it available free or at low cost to individual prospectors and to small and large companies alike has made it possible for imaginative explorationists to conceive good and productive exploration program.

The mineral industry has a key role to play in Canada's future as it has had in the past. In order to play this role the industry must be able to operate in an equitable and stable economic climate. This is of vital importance to the industry in view of the long lead times associated with all its activities.

Recent legislation has added considerably to the normal level of uncertainty of the industry and thus to the detriment of the industry and ultimately to the detriment of Canada's well-being.

Mining is essentially an industry of uncertainty where there are many losers and some winners and where even the successful are subject to a considerable fluctuation in fortune. In particular, exploration — the first phase of all development — calls for investment and perseverance against all odds. In this instance, certain individuals and companies are prepared to risk their capital in the hope of future rewards. Some succeed, but the vast majority fail.

We all recognize that ultimately mineral deposits belong to the province of the country. However, let us also recognize that a deposit is essentially useless until developed and leave the development to the most efficient and experienced organization — the mining firm — and have a fair division of the rewards resulting from the expenditures. That is, allow the mining firm to

make a reasonable profit after all its expenditures have been taken into account and allow the government a fair return in the form of taxation of profits. In this way, mining firms will be encouraged to reinvest their profits and the results will be a steady growth in tax revenues, employment levels and economic well-being.

I assume that most of you are aware of the various geophysical methods used by industry in mining exploration in Canada and how we organize our exploration activities. Of first importance in our base-metal programs is the airborne electromagnetics flown in conjunction with the magnetometer. In the 50's and 60's many mining companies flew their own E.M. systems but with the exception of a few like INCO most E.M. work is conducted by contractors. The 1974 oil crisis sparked a renewed search for uranium and during the past two years for more line miles of airborne radioactivity have been flown in Canada than has E.M. for base-metals. Ground follow-up of target airborne anomalies involves generally ground electromagnetics and magnetics to pin-point the conductor more precisely prior to possible drilling. Because we are now looking at ever increasing depths much attention has been given to the development of deeper penetrating E.M. systems such as pulse E.M. and multifrequency systems.

The organization of exploration activities by a mining company is generally on a decentralized basis with regional offices being established in areas of exploration interest. My company, Noranda Exploration for instance, has permanent exploration offices in more than 11 places in Canada ranging from Vancouver in British Columbia to Gander in Newfoundland. Exploration activities are conducted by permanent staffs of geologists, geophysicists and technicians out of all these centres. Because geophysical methods have been commonly used in Canada now for over 25 years in exploration our geologists for the most part are now quite familiar and at ease with techniques being used. Indeed our good exploration people are geologists, geophysicists and geochemists all rolled into one.

Industry has been highly successful not only in finding the mines but also in research which developed the instruments and methods used to find the mines. Take the geophysical methods we have been using. The original fluxgate magnetometer was developed by Gulf Oil; the proton magnetometer by Varian Research and the high-sensitivity magnetometers by Varian, Pure Oil, Texas Instruments and Compagnie Générale de Géophysique. In E.M., INCO, McPhar, Hunting, Ronka, ABEM, Newmont, Mullard, Selco and Barringer have all carried out important instrumental developments. American, Canadian, British and French companies have developed very sophisticated radioactive detectors; Worden and LaCoste and Romberg the gravity meters; Geometrics, Scintrex and McPhar the ground magnetometers; Crone, Scintrex, McPhar, INCO, Ronka, Apex the ground electromagnetometers; Scintrex, Huntec, McPhar, Elliot the Induced Polarization systems. Recent new developments include the Crone-Newmont Pulse E.M., the Hudson Bay-Geoterrex air E.M. system, the Alpha Nuclear solid state radon detector and the Scintrex laser induced uranium fluorimeter.

Certainly industry sponsored research in mining geophysics has paid off handsomely. Many major mining companies have their own in-house research facilities. Noranda for instance has its own Noranda Research Centre in Montreal where more than 170 skilled people work on the practical application of science and technology to the needs of the company in the fields of instrumen-

TABLE I

Airborne E.M. Systems

Fixed wing
1. Input — pulse E.M.
2. Single frequency — in-phase and quadrature
3. Dual frequency — quadrature
4. Three frequency — in-phase and quadrature
5. V.L.F. — receivers
6. E-phase and radiophase

Helicopter
1. Single frequency — in-phase and quadrature
2. Turair
3. V.L.F.
4. E-phase and radiophase

TABLE II

Airborne Magnetometers

1. Proton magnetometers >.1 gamma
2. Fluxgate magnetometers > 1 gamma
3. High sensitivity >.001 gamma
4. Cryogenic – 0.0002 gamma

TABLE III

Recent E.M. Developments

1. Ground pulse E.M.
2. Airborne 3-frequency in-phase and quadrature
3. V.L.F. — ground resistivity meter
4. Fourteen frequency E.M. inductive system for permafrost resistivity mapping.

TABLE IV

Advantages of ground pulse E.M.

1. High resolution
2. Deep penetration in high conductivity areas
3. Insensitivity to topography
4. Wide frequency spectrum
5. Geometrical information on strike and dip of conductor obtained by moving receiver around
6. Can work close in to power lines

TABLE V

Airborne Radioactivity

- Multichannel analyzers with large crystal volumes (400-3,000 cubic inches)
- Produce net Tl 208, Bi 214, and K–40 + total count + ratios.
- Compton correction factors now employed, can produce large errors in net counts.
- Possible solution — record full spectrum and correct compton on per spectrum basis.

TABLE VI

Ground Radioactivity

1. Total count scintillometer
2. Integral counter — variable threshold — four channel
3. Differential — four channel analyzers — useful for radiochemical P.P.M. analyses of outcrop.
4. Emmanometer — for radon/thoron gases in soil gas or water (either ionization chamber or zinc sulphide scintillator and pulse counter types)
5. Track etch — radon gas alpha counters
6. Solid state — radon — alpha counters

TABLE VII

Recent I.P. Developments

1. Combined time and frequency domain transmitters
2. Three layer I.P. and σ response curves
3. Phase angle frequency domain measurements for removal of inductive coupling effects
4. Magnetic I.P. in conductive areas
5. I.P. discrimination analyses
   (i) Zonge multi-frequency system
   (ii) University of Utah
   (iii) Russian non-linear voltage effect

TABLE VIII

Uncommon Geophysical Applications

1. Drill-hole I.P.-E.M. and radioactivity
2. Magnetic I.P.
3. Mercury soil gas
4. Neutron activation analyses
5. Ground pulse E.M.
6. Radioactivity spectrum analyses
7. Magnetotelluric surveys
8. Emmanometry for soil gas and water
9. Radiohm — V.L.F. resistivity mapping
10. Track etch radon technique
11. Multielement radio frequency emmission spectrometer

TABLE IX

Drill Hole I.P. Logging

- Used for logging barren holes that are "near misses"

Two types of I.P. logging

1. Detection logging
   To locate depth below surface and distance from drill hole of polarizable material.
2. Directional logging
   To determine direction or particular quadrant in which polarizable material is located.

tation, physical extractive and mechanical metallurgy, solid state, physical and analytical chemistry, process engineering, electrochemistry and corrosion, techno-economics and so forth.

Rather than undertake ourselves extensive basic and applied research in mining geophysics our general policy in this area is to support outside research and development programs which need financial backing to bring them to the point of producing a useful and needed new instrument or methodology which we ourselves will be able to employ in our exploration efforts. The following is a short list of some of the programs we have supported during the recent past.

1. A uranium in water analyzer employing laser induced fluorimetric analysis techniques. This program was originated by Scintrex and supported by two other mining companies in addition to ourselves.
2. An x-ray fluorescent analyzer for underground assaying undertaken by Mineral Exploration Research Institute in Montreal.
3. Alpha Nuclear Corporation's development of a solid-state radon gas analyzer.
4. University of Toronto's research on pulse electromagnetic methods.
5. University of Utah's research on induced polarization discrimination analyses.
6. Geological Survey of Canada's drill hole geophysical instrumentation test and evaluation program.
7. Extensive testing and evaluation of the Crone Pulse E.M. and Apex multi-frequency E.M. systems.

I might point out that our support is given with few if any strings attached. That is to say, we do not request exclusive rights to the ultimate use of the instruments. Our interest is to see their development for the general use of the mining community as a whole.

In Canada our mining geophysical frontier is the search for ore at ever increasing depths under extremely variable cover or over burden conditions. To increase our odds of finding deep targets at minimum expense is our challenge.

Mining geophysics is not like petroleum geophysics in many ways.

Our targets are more varied and our methods more numerous. It's difficult for anyone to have a good overview of mining geophysics in general. It's difficult for any of us to keep abreast of the numerous developments in numerous methods in mining geophysics. As I am no different than the next man I'm subject to the same type of tunnel-vision as he. For what its worth, however, I hope the aperture of my "particular" tunnel view is somewhat wider than some others.

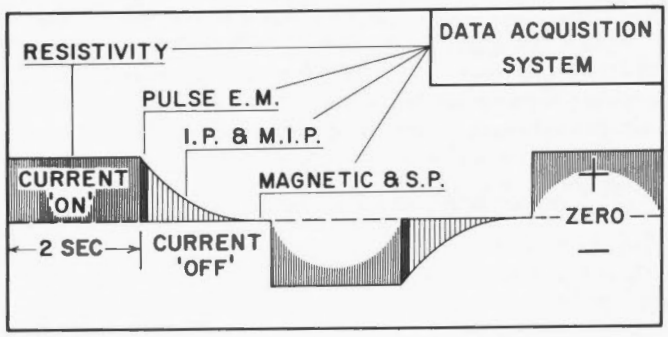


Figure 1. A possible strategy for the operation of a multi-instrumented electrical and magnetic exploration package.

The accompanying tables show the current status of airborne techniques used in mining. Those dealing with ground geophysical techniques refer to new techniques only, which are or will gain increasing acceptance. Down hole logging is still in its infancy in mining circles although we are just now beginning to catch up a wee bit to our petroleum brethren who have been sophisticated in this area for decades.

Finding ore is as much an "art" as it is a "science".

To a fair degree our initial successes in finding ore with geophysics mislead us in our natural pursuit to find more ore. Texas Gulf's Kidd Creek deposit in Ontario surprised many of us — an airborne E.M. conductor with no coincident magnetic anomaly for example.

We have been perhaps too selective in our choice of airborne E.M. anomalies for ground follow-up. We have given top priority to only the better conductors of limited strike length. Indeed we have found many massive sulphides this way but how many undrilled targets of lesser conductivity or of longer strike length are undiscovered orebodies? After all, INCO's Thompson orebody is associated with a conductor 5 miles long. At the other end of the spectrum, Cupra, Marbridge, or Selco's South Bay Mines are essentially only one line conductors.

High conductivity as calculated by our "free-air" response diagrams which we now know can mislead us since the true conductivity of a bedrock conductor can be very drastically changed by the current flow in the surrounding host rock and overburden cover.

So in many ways we are back to square one again, the wheel having gone full circle.

An anomaly is anomalous and that's about it in many cases. If it is favourably located geologically and structurally drill it. Do not be too concerned about its relative conductivity or depth as calculated by our response diagrams. They can as I said be wrong and therefore downright misleading in certain geological environments.

There are lots of geophysical methods available to those looking for mineral deposits. We should use them, interpret their results carefully and move on to the next stage and test them. We should not gather data for data's sake alone. Too many of us spend too much time massaging and messaging data because we are either too timid to commit our interpretations to the final step of the drill or because too many of us forget that the name of the game and the purpose of the whole exercise is *"to find an ore deposit"*.

Mr. R. Geller:

Thank you very much Mr. Pemberton. Our next speaker is Mr. R. Lindseth who will present a paper entitled **"Geophysics in the Petroleum Industry".**

Mr. R. O. Lindseth:

The science of solid earth geophysics which is the concern of many delegates here today might be termed macro-geophysics, since it concerns the physical properties of the earth as a whole.

If so the science of petroleum geophysics would surely be termed microgeophysics as it is concerned with the investigation of ever finer detail within the thin sedimentary skin on the earth's surface.

To a large degree the interest in this detail is determined not by science but by economics. Current prices for oil and gas in North America make worthwhile targets of say 10 metres thickness at a depth of three kilometres. The economic drilling depth is about 8 km, but the interest of the geophysicist usually extends to basement or about 10 km whichever is shallower.

The only exploration tool which can hope to supply the required detail is the reflection seismic method and for that reason it is clearly the preferred method.

The other common geophysical tools, magnetics, gravity and seismic refraction are used much less frequently for petroleum work and then only as reconnaissance tools or to help clarify ambiguous reflection results such as the probable nature of a deep seated uplift.

As might be expected the interest in reflection seismic work carries through to research, and many more improvements and innovations are made each year to the reflection method than to any other.

In spite of this, the fundamental concept of the reflection seismic method has not changed since its introduction some 60 years ago. It is still concerned with measuring the time it takes for a small signal to travel from a near-surface source to some reflecting horizon and echo back to a surface detector.

Although the basic concept has not changed, field technique and data handling have changed considerably and it now appears that even the basic property measured, reflection time, may become of secondary importance to reflection amplitudes.

Two major improvements have been responsible for or have led to practically all of the other advances.

The first of these was reproducible recording and the second digital processing, but many of the benefits of the second arise out of the first.

Reproducible recording is a major advance providing the ability to modify the field recorded signal by filtering and compensating for distortion. But the most important result is that it makes possible the multi-coverage stacking process. This simple procedure by which several repetitive observations of the same point are summed and averaged brings the power of statistical methods to data recording. It is the only method other than multichannel filtering by which the ratio of signal to noise within the same frequency can be improved substantially.

Digital processing has supplied the capability for a multitude of techniques in both signal processing and data handling. It is usually associated with filtering techniques, including inverse filter processes, but probably of equal importance is the power of the digital machine in purely data handling operations to correct, sort, shift and otherwise manipulate the immense and ever increasing amounts of seismic field data.

Not the least of the reasons for increased amounts of data is the increasing interest in water covered areas. Some of the greatest potential for new discoveries lies offshore and the seismic acquisition process can be made much faster and more efficient when it is moved to the marine environments.

A few problems of marine operation are non-existent or of less importance on land. Many of these are related to energy sources and the search continues for a non-destructive high penetration broad band pulse which can be reproduced economically.

One recent development is an evacuated glass sphere for a signal source. Such spheres have great strength under water and can resist great pressure. When shattered at depth the sphere implodes and the inrushing water creates a sharp pulse that has no secondary oscillation.

Another recent development is the use of a horizontal array of air guns which can be fired in sequence and timed to the rate of travel of the vessel so that each gun is fired at the precise moment it passes over the signal source point. This creates an input signal with a strong vertical component extending over some period of time which can suppress multiple wave guide oscillations in the water.

A review of all recent developments is impossible here within the time available, but excellent progress reviews are published at frequent intervals in Geophysics, the journal published by the Society of Exploration of Geophysicists.

Modern field data is practically unusable in its raw state. It must be processed through a digital computer before it can be interpreted. Perhaps the importance of this is demonstrated by the rapid growth of this phase of the industry.

In 1960 there was little or no digital processing, but in 1975 some $330 million was spent world wide in this activity. It is also probably worth noting that of the total $138 million was spent in the United States, about $24 million in Canada (in a period of extremely low exploration activity), and $30 million in all of Latin America. These are key indicators of the probably future amount of future petroleum to be discovered some years hence.

During the brief time of its existence digital computing has gone through at least three generations of equipment and philosophy.

Some of the most popular machines used for the original development no longer even exist. EMR, SDS and the Sigma series of machines are no longer manufactured. Minicomputers have appeared on the scene and have quickly become more powerful than many of the previously "large" machines. Now the trend appears to be back to very large and powerful machines capable of handling the very large amounts of data and the very lengthy computing routines that are used to improve the data.

Digital computing combined with digital recorders capable of measuring amplitudes over a range of 120 db (1,000,000 to 1) appear to offer hope of attacking the search for stratigraphic traps. To date petroleum exploration has been directed almost entirely to the structural trap since the seismic method is extremely well adapted to determining the shape of the subsurface section. What it is not well suited for is the location of stratigraphic traps, reservoirs in which the petroleum is trapped in lenticular pods or lenses caused by lateral changes in porosity of the rock, old sand bars covered with shale or simply large wedges of sand. Some of the largest oil fields have their oil trapped in such situations. The enormous Bolivar Coastal fields of Venezuela are simple sand wedges sealed up dip. The Boscan field of Venezuela is an example of a similar type. The production in Chile is largely from their sands which pinch out. Brazil's new offshore production comes from sands in old submarine fans. In most cases such production is found more by accident than by design. Drilling is more likely than not based on some structural effect that may or may not be associated with the trap. The greater portion of the world's known oil is produced from structural traps, but this is at least partially because such features are easier to find with the seismic method.

Recent work has been directed towards developing techniques for stratigraphic exploration. Other work seeks to use the amplitude of returning energy to indicate changes which may be significant.

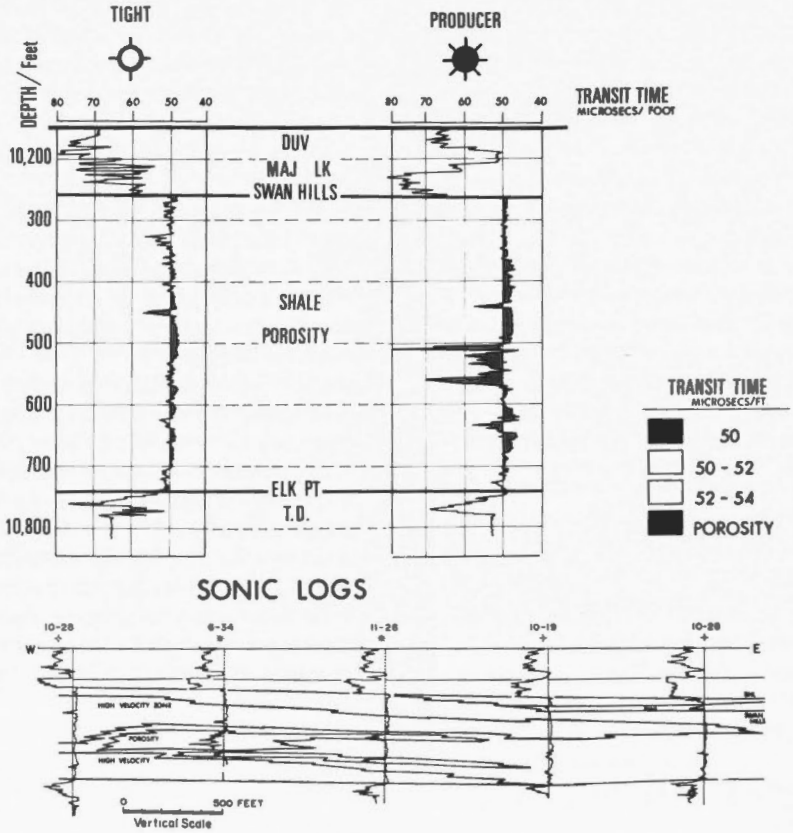


Figure 1. Rosevear generalized log section — Beaverhill Lake.

An example of the problem is illustrated in Fig. 1. Carbonate sections frequently have primary or secondary developments of porosity within the section which are purely lateral changes with no structural indication at all. The example is a reef bank, the front of which falls off into the basin. Frequently porosity develops just back of the reef edge as indicated by the reduced velocity measured on the sonic logs.

Conventional seismic data across such a condition is presented in Fig. 2. The reef lies in the narrow band between two reflections below 1.8 seconds. Some change is noted in the section, but it is difficult to interpret.

The seismic reflection amplitudes recorded with modern instruments can be digitally processed to compute a pseudo-sonic log. A conventional sonic log which measures the velocity in the section with great detail is obtained by lowering a sonic measuring tool down a borehole to measure the velocity continuously as it traverses the sections. However, it requires a borehole to be drilled deep into the ground. The pseudo-sonic log is obtained from the surface of the ground without the need to first drill a deep hole. The results of this process in Fig. 3, have been contoured to map units of constant velocity. The darkest color maps the highest velocity, associated with the densest material having the

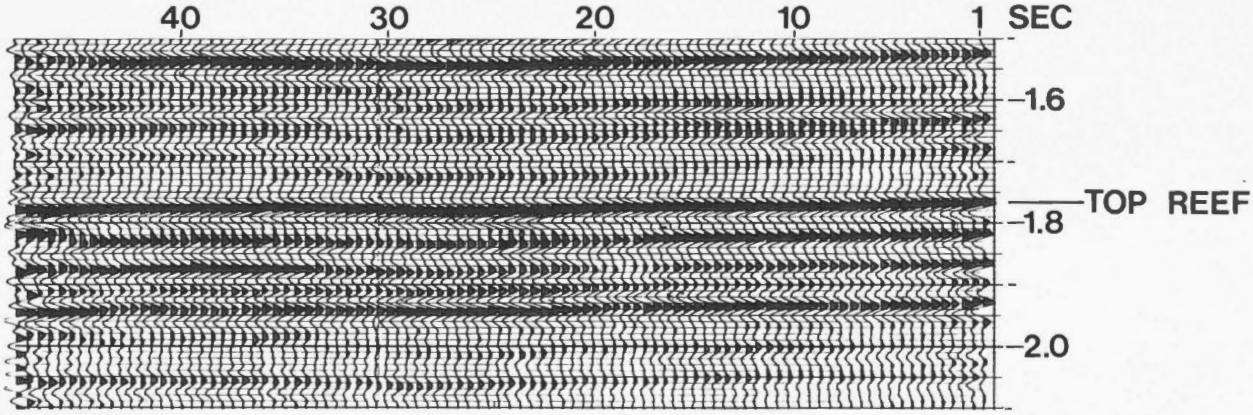


Figure 2. Conventional seismic data across a lateral porosity change — in this case a reef bank.

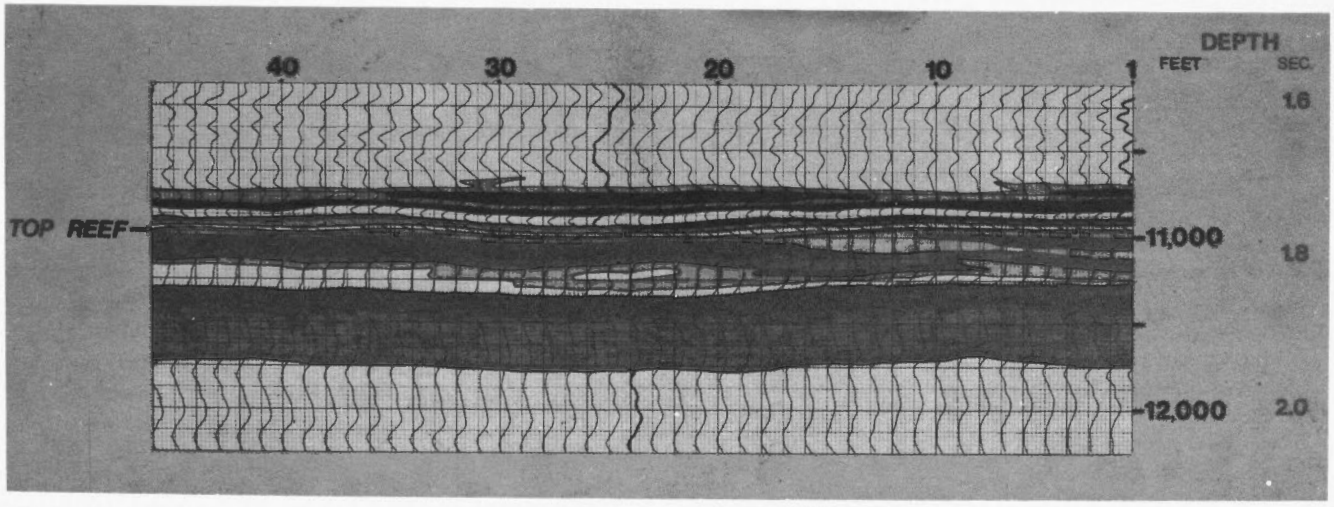


Figure 3. Cross section computed from seismic data shown in Figure 2. The lighter colours indicate the zones with the highest porosity.

lowest porosity. The lighter colors indicate lower velocity material and the lowest velocity colored white is porosity within the reef. Note that the pattern resulting from this type of analysis is almost identical to the section measured by borehole sonic logs, but it was not necessary to drill boreholes to get the sonic information.

A common stratigraphic problem is to map the unconformity which exists at a buried erosional surface. In the particular area represented by the seismic section in Fig. 4 the unconformity is usually mapped as the strong reflection near 1.43 seonds. In fact, this reflector is known to arise from a low velocity sand draped over the unconformity. It generally conforms to a smooth surface which lies over but does not actually map the unconformity surface. The true contact with the unconformity lies deeper in the section, near 1.46 seconds.

The inversion results, Fig. 5, once contoured and colored as described earlier, simplify the interpretation and make possible a detailed mapping of the eroded surface. Thin remnants of exposed high velocity material have been incised by drainage channels. It is shown to lie over a thin lower velocity unit, probably shale. Near shotpoints 40 and 50 channels have cut through the higher velocity material into the lower velocity base material. To the left of shotpoint 60 the total upper section has been eroded away.

One of the most dramatic and useful examples of the process is the ability to map the detail of thin bedded sands. Such

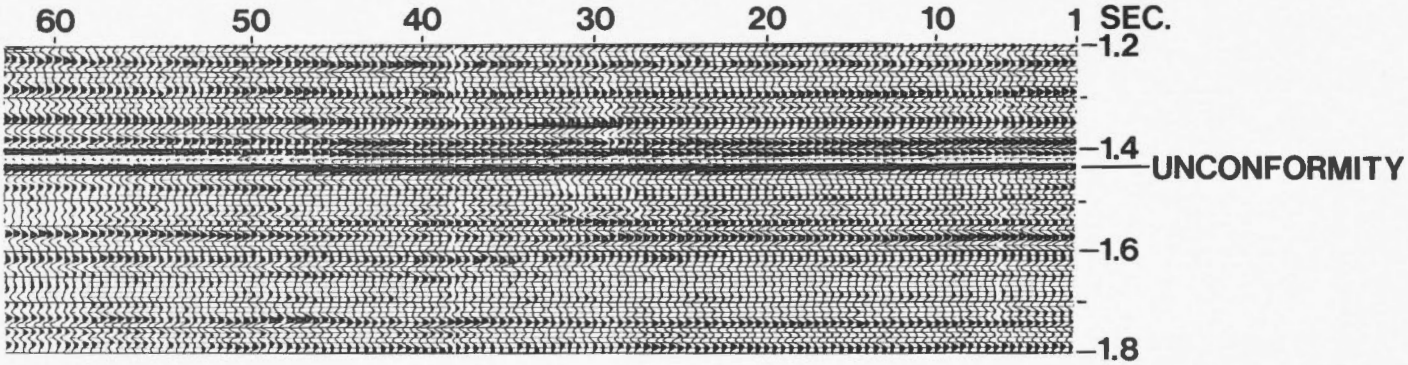


Figure 4. Seismic data over an unconformity.

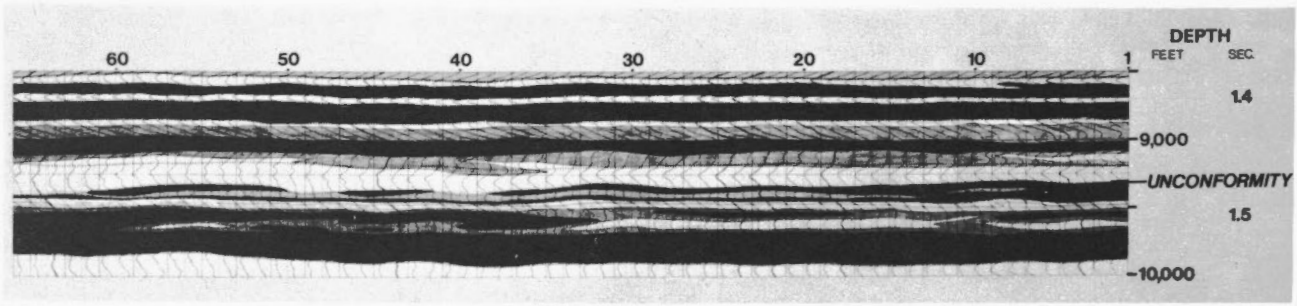


Figure 5. Cross section computed from seismic records shown in Figure 4. The darker shaded colors indicate regions of higher seismic velocity.

features form the basis for much economic production throughout the world and form much of the potential reservoirs offshore. The interval to be examined is that lying between 1.1 and 1.2 seconds on the seismic section. Fig. 6 the seismic section, while considered to be good seismic data representative of the area shows very little stratigraphic detail. This is relatively shallow data and fortunately it is in the shallow sections that the broadest frequency band and hence the greatest detail can be obtained for its special processing.

The results of processing the previous data through inversion, Fig. 7, illustrates two distinct stratigraphic groupings within the interval of slightly more than 100 milliseconds of seismic data. The upper is a relatively thick zone containing a rather dirty sand between the two dotted lines which rarely produces. But scattered within the zone are intermittent clean coarse sands which are frequently productive. These sands are outlined by the high velocity contours having the darkest color on the section. The lenticular sand units are often no more than 25 feet thick and a few

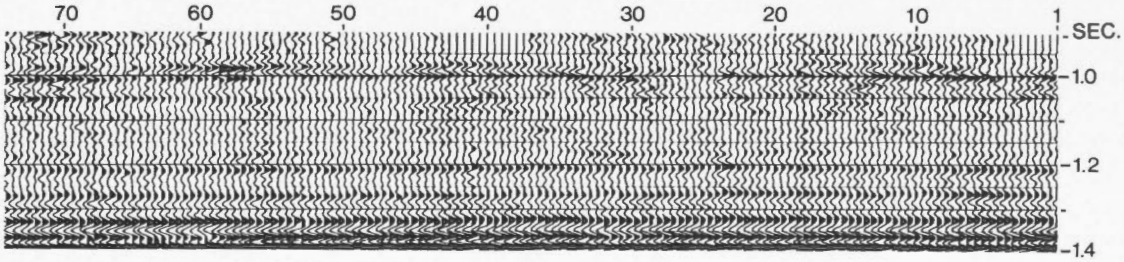


Figure 6. Seismic data over thin bedded sands.

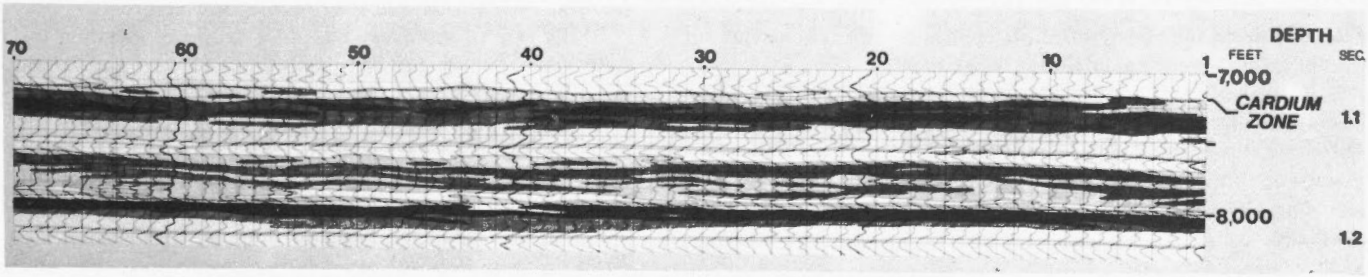


Figure 7. Cross section from seismic records shown in Figure 6. The darker shaded regions represent regions of higher seismic velocity.

hundred feet long. This zone overlies a second grouping which is mostly shale but which contains occasional streaks of sand. This zone is not of economic interest but it has been chosen to demonstrate the degree of detail that lies within the seismic data. The velocity contours outline a series of prograding sands typical of a receding shoreline. Note the clinoform bedding which carries individual sand units from the top to the base of the zone. These are thin dirty sands which lie within the shale matrix yet they are mapped clearly and in considerable detail.

At this point I would like to change the tenor of this talk from the assigned topic in order to rebut a proposal made earlier and to discuss the philosophy of petroleum research and exploration. In many ways petroleum exploration is similar to research and in fact due to the extremely rapid advances in technology, it is sometimes difficult to determine the line which divides research from exploration technique.

It has been proposed that all earth science activities, including research and exploration, be consolidated into one government agency. It is claimed that under state planning duplication would be eliminated resulting in more efficient use of talent and equipment. Another is that the elimination of secrecy concerning data gathering and research by private companies would eliminate duplication and hasten progress by releasing the results of advances sooner. It is suggested that the proposed consolidation would make the country a leader in technology and self-sufficient with control over its resources.

I submit to you that these assumptions and the other related claims are not correct and in fact ample experience and history has shown them to be wrong.

Historically, research and exploration have always responded best to the multiple overlapping approach by many workers having different opinions, techniques and methods of attacking the problem. It is also by far the most efficient. As in a horse race one contender will reach the goal ahead of all others. While this may disappoint the losers they are then free to devote their talents to the next problem.

No single person or organization can be right every time. History is replete with records of searching blind alleys for solutions which do not exist. Oil industry legends are based on major oilfields that were discovered by a newcomer with a new idea after one or more other firms had declared the area to be barren.

No single organization can have all the talent and no organization can nor will try all of the methods which might be used to solve a given problem. The single agency approach works particular hardship on the professional who disagrees with the policies laid down by the organization. He has no other choice but to accept or find some other line of work.

Exploration has always been very sensitive to new developments in technology and successful exploration demands the best and the latest. Throughout the world it has worked best under the multifaceted massive attack resulting from the combined efforts of many companies applying their resources and talent under competitive pressures. Canada is no exception to this.

Fig. 8 represents the finding or success rate of a single seismic exploration crew. It is obtained by dividing the total new oil found each year, adjusted for the log between exploration and drilling and for the total reserves eventually attributed to a discovery, by the number of operating exploration crews.

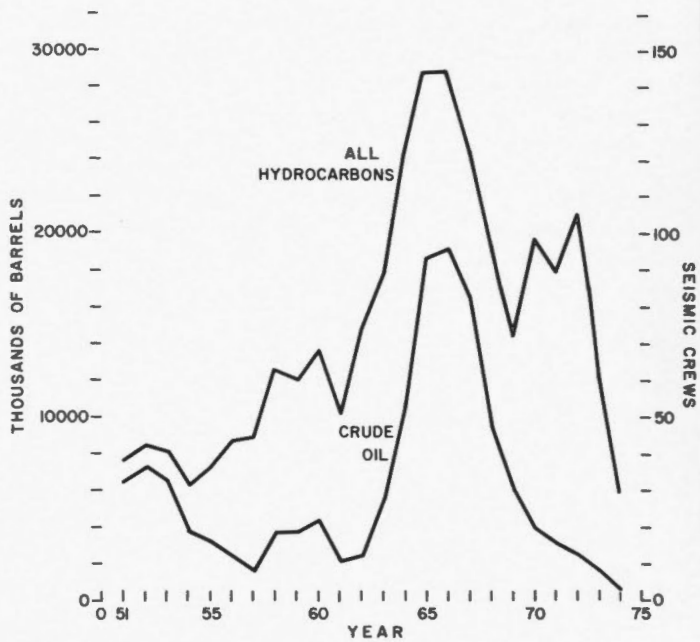


Figure 8. Discovery rate per seismic crew year by year of discovery. Information supplied by Canadian Petroleum Association and the Society of Exploration Geophysicists.

Prior to 1948 there was no appreciable exploration industry in Canada and little production. Discovery of the Leduc field initiated a rush of exploration and by 1951 the number of exploration crews reached a peak. However, with the relatively limited powers of resolution of the methods of the time, the discovery rate was not particularly high and once the initial easy discoveries were made the rate dropped. It revived briefly in the early 1950's with the introduction of the analogue recorder which made reproducible recording possible.

The discovery rate increased again for a few years and then dropped. One of the dilemmas facing the explorationist is that the more successful he is at finding oil in a given area the less there is remaining and the harder it is to find. He needs all the technology he can get.

The next change came in the early 1960's when the stacking method became popular. Digital processing compounded the improvement and as a result, the finding rate grew enourmously. Much more oil was found on the average by each seismic crew in the mid 1960's than had ever been found before.

The rate of discovery has since dropped, awaiting the next step in technology and the exploration of the more remote untested areas.

The recent discovery rate for gas has remained fairly high due to the development of techniques which favor the detection of gas filled reservoirs.

Now, through all this time the total number of seismic crews operating has generally decreased (Fig. 9). This has not been the result of any devious plan, but a response to demand and capacity.

It is demonstrated very well in Fig. 10 that in this period private industry was able to use a diminishing number of crews, because of greater efficiency and favorable success ratios, to find in each year in Canada a greater amount of oil than was con-

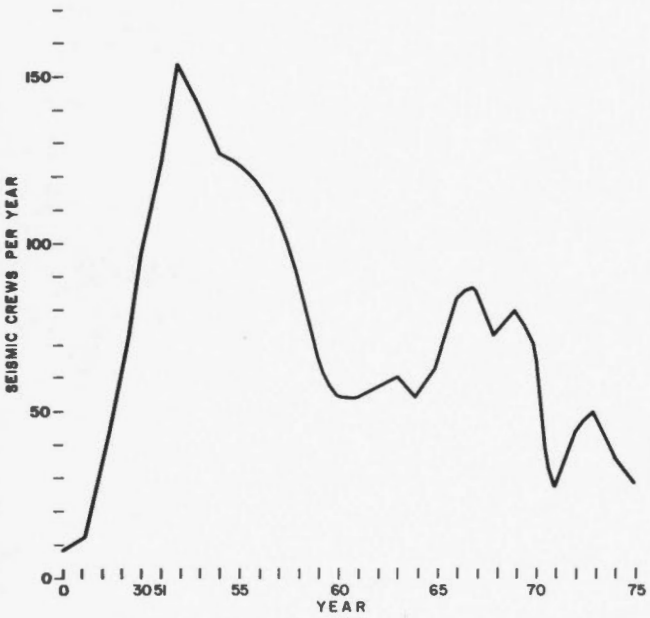


Figure 9. Seismic crews operating in Canada by year. Information supplied by the Society of Exploration Geophysicists.

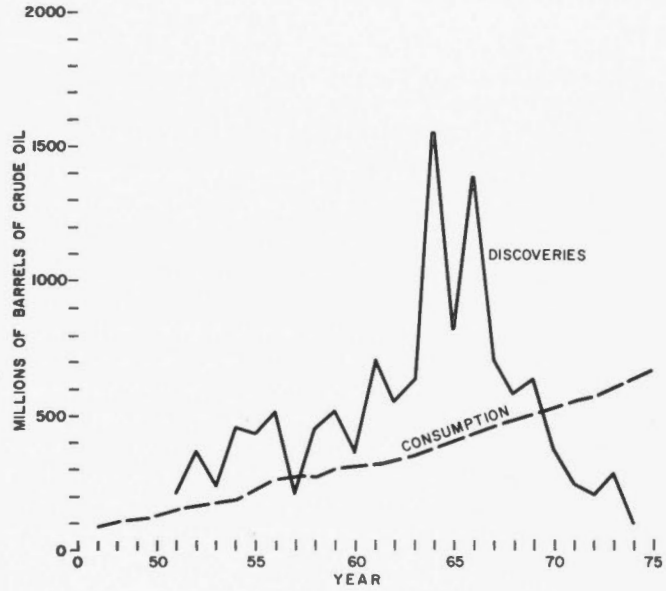


Figure 10. Crude oil discoveries in Canada and the rate of consumption. Information supplied by Canadian Petroleum Association.

sumed and which added a comfortable margin to the known reserves.

The system failed in 1970 but for a non-technical reason. About this time government intervened in the process by abrogating contracts, increasing royalties and taxes and imposing elements of state planning and controls. The result was to destroy the incentive for exploration. Exploration fell and Canada is now no longer self sufficient in petroleum.

Some of the measures instituted by government may have been well intentioned in the belief that they would increase the percentage of Canadian investment and create a strong national technology. In fact the result has been the opposite.

Prior to 1948 there was no exploration technology in Canada. The initial exploration was done almost entirely with imported technology and scientists who brought to this country the best available knowledge. But in the short space of 10 to 15 years exploration was carried out almost entirely by Canadian staff. Canadians filled exploration positions rapidly as soon as they became trained and able. The imported experts either returned home or settled down to become very welcome and highly appreciated new Canadians. All this was a natural process done without government intervention nor strong nationalist pressures. And through this time in spite of diminishing number of seismic crews the total number of earth scientists and professionals increased. This is because it takes about two professionals, geologists and/or geophysicists to maintain each thousand barrels per day of production. As production increased so did the need for trained professionals.

Also the large amount of imported foreign technology had produced an osmotic effect so that by the late 1960's Canada had capabilities in petroleum exploration research and development second only to those of the United States. In fields, such as reef technology and cold weather operations for example Canadian expertise led the world.

Unfortunately, the results of the government intervention have destroyed much of the impetus to continue this progress. The greatly reduced activity has caused many Canadian explorationists to leave the country. Research activities have also diminished causing the relative level of competence and excellence to fall.

The status of petroleum exploration technology in the world today is at a level such that it is probably possible for any country having a reasonable sedimentary section to become self sufficient in petroleum provided it is willing to provide sufficient incentive to attract the quality of talent in the numbers required to reach the production goal. On the other hand, it is not likely that any country can do it alone. A massive attack using the multifaceted approach must be applied in order to catch up to the demand.

The problem was well explained in a recent article in the Scientific American and is also related to the critical mass concept defined earlier in this symposium by Dr. Kausel. Technology and demands increase exponentially. In those areas with advanced technology, developments proceed today along the steep upward branch of the curve. In the less well developed areas development remains on the flat branch of the exponential curve. Thus even though the rate of increase of the curve may be at a higher percentage than the developed country, the difference in actual change is such that the numerical gap continues to grow wider.

The only solution is to raise the lower branch by a vertical shift which usually can be done only by importing sufficient technology to reach the critical mass which creates a viable national industry. This need not be purchased and in fact it is doubtful if it could be purchased by a have not nation in the amounts and diversity required, but it can be brought in by incentive. The method has worked well in every country in which it has been used.

I close with one thought.

Try to imagine any way in which any country such as Canada, Venezuela, Ecuador, or most of the OPEC countries, in which outside technology and the multi-organization free enterprise approach was used to develop the original production base, could have achieved the standards it now enjoys or could be any

better off today by having tried to use only its own resources, by having relied on a single agency to develop all of the exploration skills and by mounting the associated exploration effort required to reach the current level of production.

Mr. R. Geller:

Thank you very much Mr. Lindseth. Our next speaker is Dr. R. Ballard who will present a paper entitled **"Marine Geophysics in the Caribbean".**

Dr. R. D. Ballard:

Geologists and geophysicists at several institutions within the United States and Jamaica are presently involved in a detailed investigation of the Cayman Trough (Fig. 1). The region of intense study is along the Mid-Cayman Rise in the central portion of the Trough. The rise runs north-south across the width of the trough south of Grand Cayman Island and extends for a distance of 150 km, connecting the east-west trending Oriente and Swan fracture zones (Fig. 2). The Mid-Cayman Rise is situated along the western Caribbean plate boundary and is believed to be a zone of plate divergence between the American and Caribbean plates (Fig. 3). It is further thought that this divergent boundary has led to the formation of new oceanic crust which is now located between the semi-continental masses making up the Cayman Ridge and Nicaraguan Rise.

During the early months of this year two separate field programs were conducted in the Cayman Trough to study this boundary. One of the cruises involved the use of a ship attached to the U.S. Naval Oceanographic Office. This vessel conducted a

Figure 1. Arrow pointed to Cayman Trough on Atlantic Ocean Floor map© 1968 by National Geographic Society. Based on bathymetric studies by B. C. Heezen and Marie Tharp.

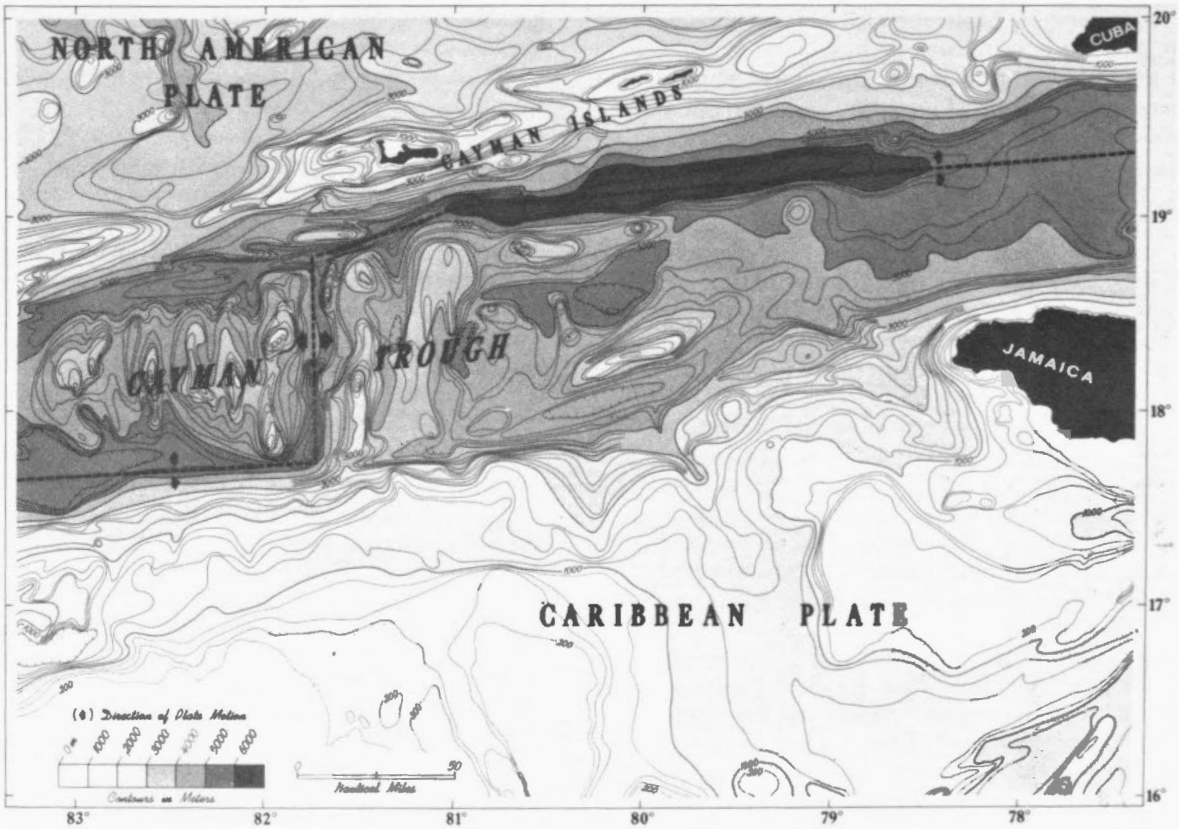


Figure 2. Contour map of the Cayman Trough shows spreading centre running across the floor of the Trough; 6,000-foot fault scarps are located on either side of the spreading centre. Map after Holcombe *et al.* 1973.

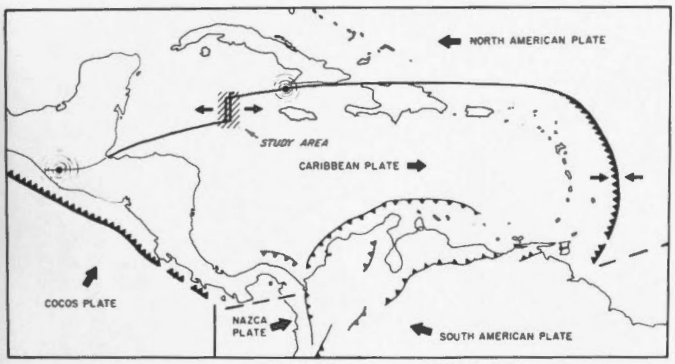


Figure 3. Tectonic plate map of the Caribbean shows Cayman Trough study area. Arrows show direction of plate motion. Circles with radiating lines indicate recent large earthquake locations. Figure after Jordan, 1975.

closely spaced geophysical survey of the rise collecting topographic, magnetic, and gravity profiles. A multi-narrow beam hull-mounted sonar system having 60 separate narrow beams tied to an inertia navigation system was utilized. Based upon topographic information obtained with this system a map of the rise was constructed aboard ship with an approximate scale of 1:130,000 and contour interval of 50 fathoms. In addition, specific areas along the rise were enlarged to a scale of 1:30,000 at a contour interval of 5 fathoms.

These maps revealed that the rift valley of the rise does not extend as a single straight valley connecting the two flanking transform faults as previously reported but instead consists of a series of shorter valley segments aligned in an *en echelon* pattern. In addition to this pattern the flanking crestal region contains structural trends which reflect a left-lateral shear system containing numerous fault scarps many of which with slopes in excess of 2,000 metres. The gravity and magnetic fields within the rise are greatly affected by this rough terrain. This topographic effect coupled with the nearness of the rise to the equator, the overall north-south trends of the crustal structures and the existence of *en echelon* spreading centres has not led to the formation of typical magnetic lineation patterns associated with most spreading centres.

In January and February 1976 a combined surface ship and submersible field program was carried out within the rift valley of the rise and on its flanking fault scarps. The research vessel *KNORR* from the Woods Hole Oceanographic Institution concentrated its effort in the rift valley. After a preliminary bathymetric survey a series of acoustical navigation transponders were dropped from the surface. This network was then surveyed-in to provide a precision reference frame for subsequent investigations. The work within the rift valley centred around a variety of instrument lowerings including camera runs, dredge stations, heat flow measurements and micro-earthquake studies using surface deployed sonobuoys.

Numerous camera runs and dredge hauls across and down the rift valley axis delineated a narrow zone of magma injection characterized by a linear belt of volcanic rock. The bottom photographs revealed a wide variety of volcanic features including large bulbous lava pillows, pahoehoe sheet floes and steep-sided flow fronts (Fig. 4). Cutting across the volcanic terrain are several open fissures having vertical fault planes (Fig. 5). Samples recovered from this central zone of volcanism ranged from weathered to fresh basalts. In several instances the fresh basalts popped and cracked on the deck of the ship following their recovery. Their freshness was further evidenced by a fresh glassy pillow surface. Heat flow measurements made across the width of the rift valley were highest near the present volcanic centre although the overall values were below those of most spreading centres. Micro-earthquake activity in the Mid-Cayman Rise was also below that of most spreading centres but two large quakes were recorded. Shortly after the surface ship program commenced our sonobuoy array picked up the major quake that occurred in Guatemala west along the Swan fracture zone lineation (Fig. 3). Following this quake micro-earthquake activity in the rise increased fourfold until another large quake occurred east along the Oriente fracture zone lineation south of Cuba (Fig. 3).

While the *KNORR* conducted its various programs in the rift valley working to depths of 5-6,000 metres the research submersible *ALVIN*, also from the Woods Hole Oceanographic Institution, carried out a series of 15 dive traverses up the steep fault scarps flanking the rift valley. During the initial survey of the

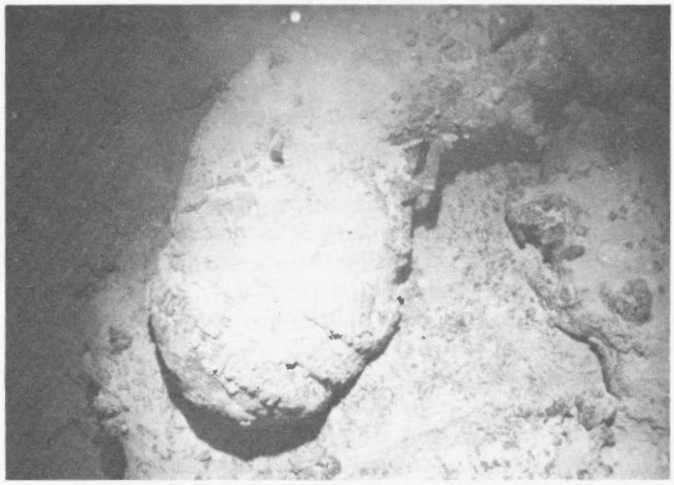


Figure 4. Photo taken by camera towed by *R/V KNORR* in spreading centre shows pillow lava formations in the Cayman Trough similar to those found on the Mid-Atlantic Ridge. (Courtesy of Woods Hole Oceanographic Institution.)

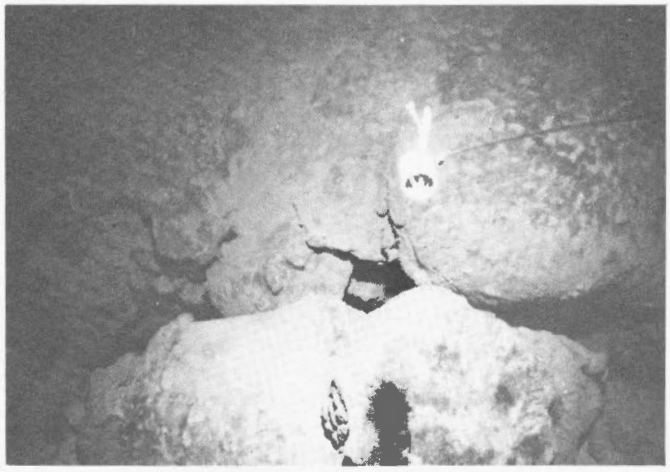


Figure 5. Fissure in floor of Cayman Trough is similar to those found on Mid-Atlantic Ridge spreading centre and indicates that this is a typical geological characteristic of spreading centres. Winged device is a compass mounted on the towed camera rig (Courtesy of Woods Hole Oceanographic Institution).

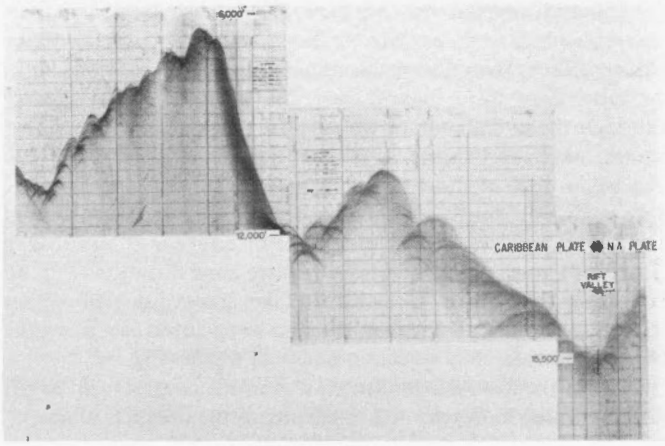


Figure 6. Composite of echo-sounding profiles made from the *R/V KNORR* at the beginning of the Cayman Trough expedition shows contour of fault scarp on one side of spreading centre. *ALVIN* made explorations to the 12,000 foot level, and the deeper diving *TRIESTE II* is scheduled to explore the rift valley early next year (Courtesy of Woods Hole Oceanographic Institution).

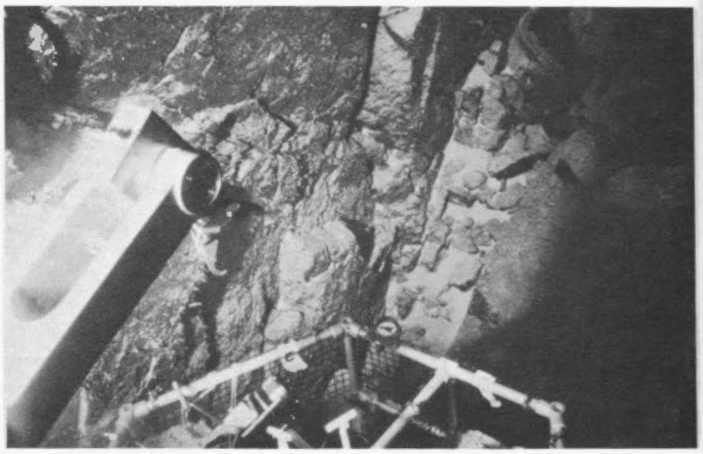


Figure 7. Near-vertical face of 6,000 foot scarp in the Cayman Trough presented scientists with a window into the earth's interior. Photo taken from submersible *ALVIN* shows sub's mechanical arm and sample try (Courtesy of Woods Hole Oceanographic Institution).

rise by the *KNORR* two steep fault scarps were located on either side of the valley, both of which were approximately 2,000 metres in relief (Fig. 6).

Prior to the diving operations networks of acoustical transponders were placed at the base of these scarps. Using these reference beacons it was possible to track the submersible within a three-dimensional frame of reference and obtain fixes every minute to an accuracy of 10-20 metres in the x and y planes and less than 5 metres in the z plane.

Two scientists and a pilot participated in each of the 15 traverses. Using the navigation system it was possible to begin a traverse where a previous one had ended. In that way a continuous traverse was made up the face of each scarp. During a traverse the submersible stopped at regular intervals to collect samples from the various rock layers exposed (Fig. 7). Photographs were taken every 10 seconds which provided a near-continuous documentation of the outcrop surface. The photographs complemented the visual observations which were recorded by the two scientists within the submersible's pressure sphere. Approximately 80 sample stations were made. Preliminary analysis of these samples reveals a wide range of rock types varying from weathered basalt at the top of the section through meta-basite to meta-gabbro with varying degrees of cataclastic alteration to fresh gabbros deeper into the section. The majority of the samples obtained were of gabbroic composition which suggests that both fault scarps expose the upper portions of the oceanic layer, layer 3. At the base of the western scarp three traverses were made on which ultra-mafic rocks were recovered including serpentinezed peridotite and dunite. Two-thousand metres of fault relief is not a sufficient amount of vertical displacement to have cut through both layers 2 and 3 and into the upper mantle particularly since pillow basalts were obtained at the top of this scarp. It does appear, therefore, that this ultra-mafic material represents an intercrustal accumulation.

At the present time the data collected during these two cruises is undergoing intense analysis. The rock samples have only recently been off-loaded from the ships that participated in the field program and are now being distributed to a large number of investigators in the U.S., Canada and Jamaica.

Plans are now being made for three additional cruises to the Mid-Cayman Rise in 1977 and 1978. The first will be a re-visit by the submersible *ALVIN* following a major diving program in the Galapagos Rift spreading centre. The Cayman dives are scheduled in early 1977 and will concentrate on obtaining a closer sample spacing along certain parts of the section obtained in 1976. This effort will be followed in the summer of 1977 when the U.S. Navy bathyscaph *TRIESTE II* will conduct a series of dives in the rift valley where the *KNORR* operations were previously made. The *TRIESTE II* will concentrate on the recent zone of volcanic activity. Emphasis will be placed upon locating the vents or volcanic source areas, sampling the various flows, determining the relationship between constructional volcanic processes and the previously obtained precision topography and measuring the field relationships of the tensional fissure and fault scarps known to exist within the rift valley. An attempt will also be made to investigate a large volcano situated along the valley axis which has an open crater at its summit. Since the *TRIESTE II* traverses will start and end near the steep fault scarps which border the valley it is hoped that samples may be recovered which come from deeper in the section that those obtained by *ALVIN*. *ALVIN* was limited to 3,500 metres while *TRIESTE II* will be able to reach 6,000 metres.

The third program being formulated for early 1978 centres around the use of a multi-channel seismic profiling system developed at Woods Hole. During the summer of 1975 the author used for the first time a 6-channel seismic system aboard the *R/V ATLANTIS II* to study Georges Bank off the New England coast. This system proved successful in having good resolution to 4-5 seconds into the bottom. The system is now being up-graded to a 12-channel unit for use in the Cayman Trough. The emphasis of this program will be to investigate the structure of the Cayman Ridge and Nicaraguan Rise as they relate to the tectonic history of the western Caribbean plate boundary and in particular to the recent tensional history of the Mid-Cayman Rise.

Mr. R. Geller:

Thank you very much Dr. Ballard. That closes the session for today. I would like to thank the speakers for their cooperation with the clock.

FIFTH SESSION
Wednesday, September 29

CINQUIÈME SÉANCE
Le mercredi 29 septembre

QUINTA SESIÓN
Miércoles, 29 de septiembre

INFORMATION SYSTEMS IN GEOPHYSICS

SYSTÈMES INFORMATISÉS EN GÉOPHYSIQUE

SISTEMAS DE INFORMACION EN GEOFISICA

Chairman/Président/Presidente
ING. R. SALGUEIRO

Speakers/Conférenciers/Expositores

MR. R. K. McCONNELL
PROF. G. P. WOOLLARD
MR. R. GELLER
DR. L. WILCOX
MR. K. SVENDSEN
MR. W. CALLAHAN
DR. G. LACHAPELLE

Ing. R. Salgueiro:

En las cuatro sesiones previas hemos tenido oportunidad de escuchar expresiones relacionadas con la información, la construcción de bases y bancos de datos geofísicos, y la conservación de los mismos.

En igual forma hemos escuchado impresiones sobre las enormes inversiones que se están realizando cada año en los programas de prospección de minerales y petróleo, los estudios teóricos especializados y la investigación muy particularmente en la América Latina. Esta sesión tiene el objetivo de dedicar las exposiciones a mostrar una imágen del trabajo que se ha ejecutado durante los últimos cuatro años, de tal manera que solicito como Presidente de esta Mesa la máxima participación de los colegas, particularmente latinoamericanos, con el objeto de poder hacer aclaraciones, comentarios y probablemente algunas consultas inherentes a los temas que sean tratados. Voy a invitar, en primer término al Sr. R. K. McConnell para que ocupe la tribuna con el objeto de poder exponer su trabajo sobre **"la Base de Datos Gravimétricos Nacional del Canadá".**

Mr. R. K. McConnell:

The launching of a systematic gravity mapping program in Canada (Gibb and Thomas, this volume) coincided conveniently with the introduction of the first large scale digital computers. Although employed initially as a data reduction tool (Tanner and Buck, 1964), the rapid development of computer technology soon led to the use of computers for storage and retrieval of gravity data (Buck and Tanner, 1972). The present structure of the National Gravity Data Base and the design of its accompanying data reduction and management software has evolved in response to the requirement of Canadian government, industry and university geophysical research programs for gravity and related data in computer processable or digital map form. In addition the National Gravity Data Base has been designed to process and distribute station descriptions and digital information relating to the National Gravity Net which forms the basis of gravity standards in Canada (McConnell and Tanner, 1974). A further factor influencing the design of the data base has been the requirement to provide to the International Gravimetric Bureau a scientific and technical service for the management of data and station descriptions related to the International Gravity Standardization Net 1971 (IGSN71) (Morelli *et al.*, 1974) and to the SILAG Working Group of PAIGH for a similar service relating to the Latin American Gravity Standardization Net (LAGSN).

Data base organization

In this report the term "data base" will be used in its most general sense, that is a collection of information. The National Gravity Data Base consists of six files (Fig. 1), two of which (Instrument Data and Control Station Data) reside on random access devices and are directly accessible by the applications software systems (Fig. 2). The three remaining digital files (Anomaly Data, Network Observation Data and Altimetry Data) due to their large size reside in binary form on magnetic tape. Applications software programs which require data from these files must first search the file sequentially and prepare a sub-file upon which subsequent operations are performed.

The Station Description File is maintained in the form of hard copy reproduced by photo offset or Xerox printing.

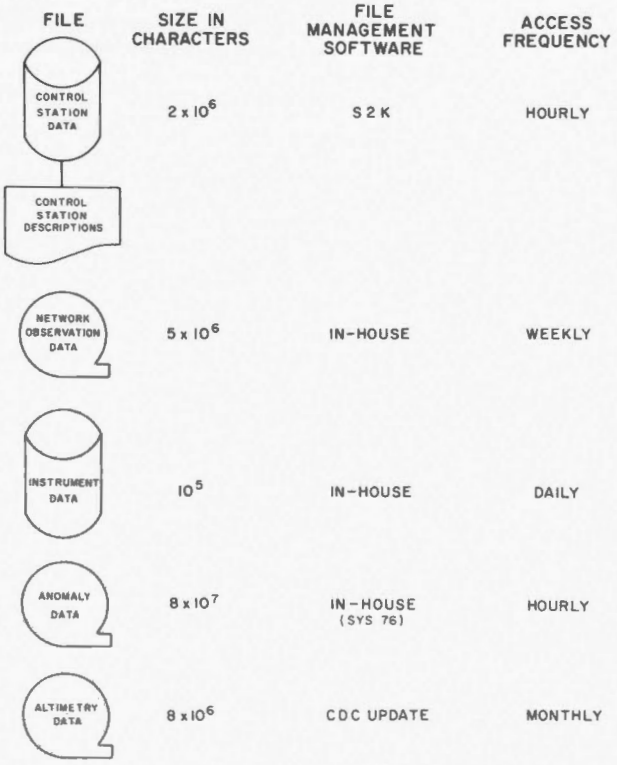


Figure 1. The five digital and one manuscript files which comprise the National Gravity Data Base.

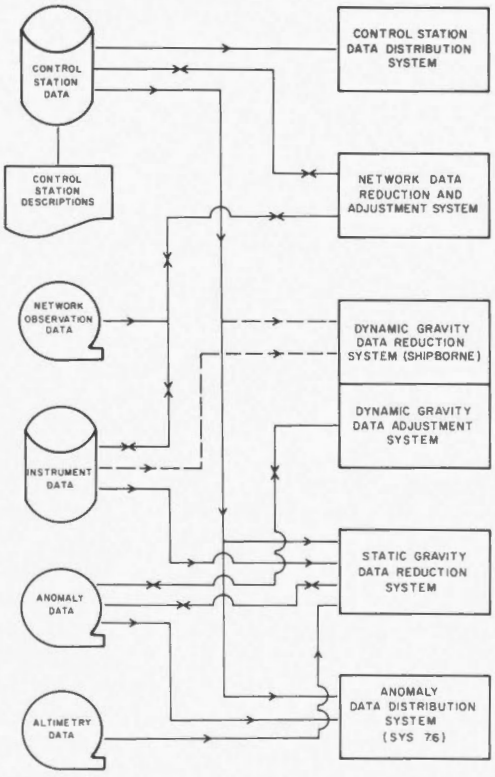


Figure 2. Interaction between the data base and its associated applications software.

Data base content and access

1. Control Station Data File

The file presently consists of 6,650 records containing the coordinates, elevations, gravity values and other information (Fig. 3) for control stations in the National Gravity Net, IGSN71, LAGSN and a few local networks outside Canada. Due to its high usage (several thousand accesses per year) and the requirement for interactive access and updating the file is operated through a commercial data base management system known as System 2000 (S2K).

```
RECORD STATUS (ACTIVE OR DELETED)
STATION STATUS (OBSOLETE, DESTROYED, RESTRICTED, NO DESCRIPTION)
EPB ASSIGNED STATION NUMBER AND YEAR
IGSN71 STATION NUMBER AND SITE LETTER (IGSN71 STATIONS ONLY)
STATION NAME
COUNTRY AND PROVINCE/STATE (MNEMONIC CODE)
NATIONAL NET GRAVITY VALUE AND ERROR ESTIMATE (IGSN71 DATUM)
IGSN71 GRAVITY VALUE AND ERROR ESTIMATE (IGSN71 STATIONS ONLY)
ADJUSTMENT NUMBER
EPB ASSIGNED PROJECT NUMBER AND YEAR
SOURCE AGENCY CODE
STATION CLASS CODE
LATITUDE (WITHOUT SIGN)
LONGITUDE (WITHOUT SIGN)
CO-ORDINATE ACCURACY AND SOURCE FACTORS
QUADRANT AND DEGREE SQUARE
ELEVATION
ELEVATION ACCURACY, DATUM AND SOURCE FACTORS
TERRAIN CORRECTION
TERRAIN CORRECTION ACCURACY FACTOR
NUMBER OF EXTERNAL TIES (TO STATIONS WITH DIFFERENT IGSN71 NUMERIC CODES)
NUMBER OF INTERNAL TIES (TO STATIONS WITH THE SAME IGSN71 NUMERIC CODE)
DESCRIPTION OF THE STATION LOCATION
DATE OF RECORD CREATION OR MOST RECENT UPDATE
```

Figure 3. Control Station Data File record contents.

Basic data for new stations are added to the file through the Network Reduction and Adjustment System (Fig. 4). Initially, only approximate gravity values are entered. After adjustment of new network observations the final gravity values, error estimates, times tied and adjustment number are merged into the file. Subsequent corrections are done in either batch or interactive mode depending on the volume of data involved.

The Control Station Data File is also accessed directly by the Static Gravity Data Reduction System (Fig. 5), through which all anomaly survey data observed with static type gravimeters is processed.

Control station data for internal or external users are made available in the form of listings, magnetic tape or disk files through the Control Station Data Distribution System (Fig. 2). Since the complete data record for any station is rarely required the system has a report generating capability which permits the selection of fields for construction of the output record. Examples of the retrieval commands available in this system are given in Fig. 6.

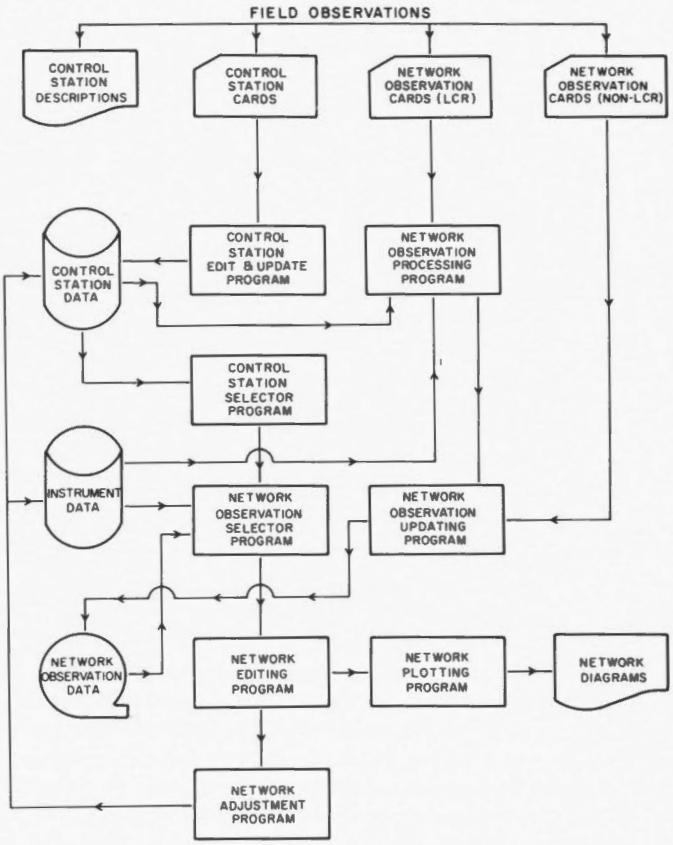


Figure 4. Network Data Reduction and Adjustment System.

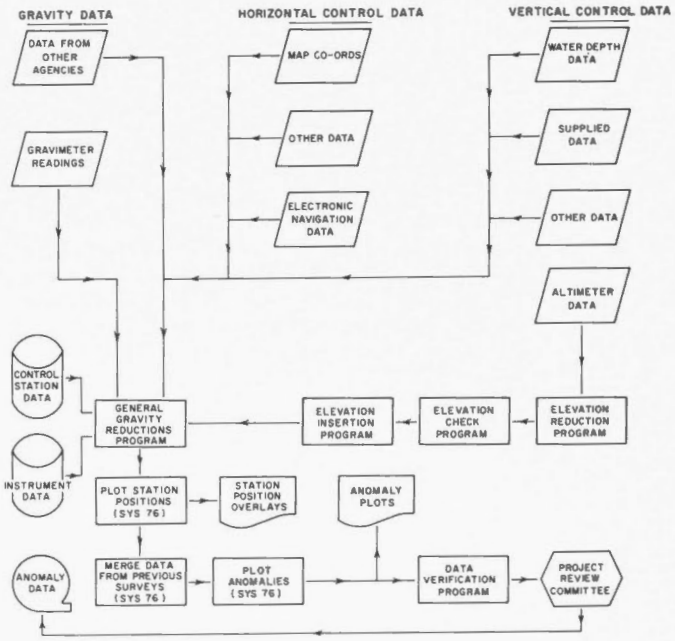


Figure 5. Static Gravity Data Reduction System.

COMMAND	FUNCTION
POLYG	SPECIFY VERTICES FOR POLYGONAL AREA
DEGSQ	SPECIFY LIST OF DEGREE SQUARES
COUNTRY	SPECIFY COUNTRY OR COUNTRY PROVINCE CODE
NAME	SPECIFY LIST AND STATION NAMES
IGSNSEQ	SPECIFY SEQUENCE OF IGSN STATION NUMBERS
EPBSEQ	SPECIFY SEQUENCE OF EPB STATION NUMBERS
DELETES	INCLUDE DELETED STATIONS IN OUTPUT
STATUS	SPECIFY INCLUSION OF DESTROYED, OBSOLETE, RESTRICTED OR UNDESCRIBED STATIONS
FORTRAN	USE SPECIAL SELECTION SUBROUTINE
OUTPUT	SPECIFY OUTPUT DEVICES
SORT	SPECIFY ORDER OF DATA ON OUTPUT
REPORT	SPECIFY FORMAT AND CONTENT OF OUTPUT RECORD

Figure 6. Examples of Control Station Distribution System retrieval commands.

2. *Control Station Description File*

The file contains about 5,000 descriptions of national and international control stations. Master descriptions (Fig. 7) are presently reproduced by Xerox printing. Conversion to photo offset printing is now underway which will significantly improve the quality of reproduction of the photography.

Requests for descriptions are processed through the Control Station Distribution System which prepares, in addition to the output listing sorted to the user's specifications, an ordered list of station numbers to aid in the manual retrieval of the corresponding descriptions. Examples of the retrieval commands available in this system are given in Fig. 2.

To minimize the updating and reprinting of station descriptions the information most subject to change (coordinates, elevation and gravity value) is recorded only on the Control Station Data File and therefore appears only on the listing accompanying each description retrieval.

3. *Network Observation Data File*

This binary tape file contains the raw field data and computed gravity differences (Fig. 8) for some 56,000 direct measurements between control stations. About half of these data pertain to the National Gravity Net and the remainder to the IGSN, LAGSN and a few other networks.

New observations are added to the file after processing and editing in the Network Reduction and Adjustment System (Fig. 4). This system also retrieves and prepares the sub-file required for a re-adjustment of a given network. After each adjustment any errors found are corrected in the master file. Observations deleted in an adjustment are flagged on the master file and retained for possible later examination.

NUMERO DE ESTACION: 9750-70
STATION NUMBER

PAIS: VENEZUELA
COUNTRY

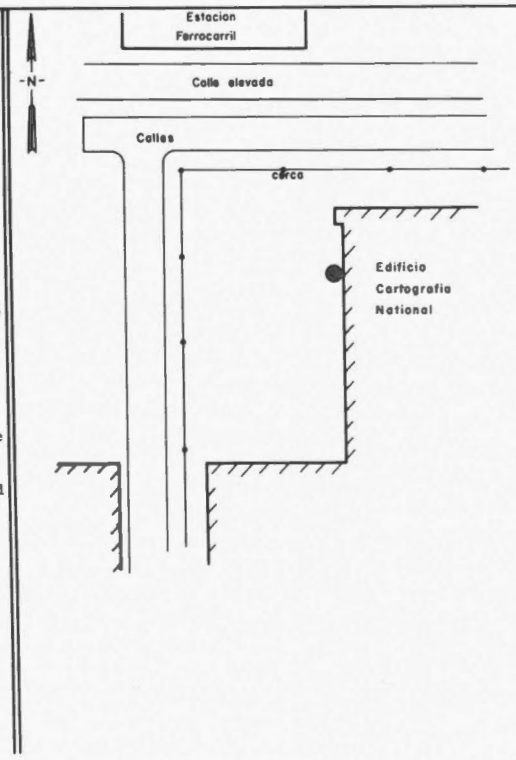
NOMBRE DE ESTACION: CARACAS
STATION NAME

PROVINCIA O ESTADO / PROVINCE OR STATE: DISTRITO FEDERAL
ESTABLECIDO POR / ESTABLISHED BY: DCN
FECHA DE LA ULTIMA REVISION / DATE OF LAST REVISION: 1970
OTRA DESIGNACION / OTHER DESIGNATION:

La estación está en la oficina de Cartografía Nacional, Quinta Santa Inés, en el lado W del edificio, 0.1 m. de la pared y 4.1 m. al S de la esquina NW, a nivel del suelo, junto al disco de bronce con el letrero "Cartografía Nacional Estación de Gravedad Santa Inés".

----0----

The station is at the Cartografia Nacional Office, Quinta Santa Inés at the W side of the building, 0.1 m. from the wall and 4.1 m. S of the NW corner, at ground level by the bronze disc inscribed "Cartografía Nacional Estación de Gravedad Santa Inés".



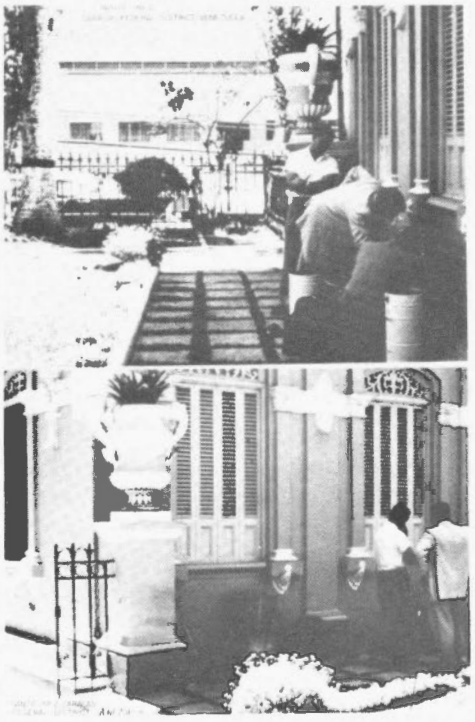


Figure 7. Sample control station description from Latin American Gravity Standardization Net.

```
RECORD TYPE CODE (RAW DIAL RDG, PRECOMPUTED ΔR, PRECOMPUTED ΔG, ETC.)
RECORD STATUS CODE (ACTIVE OR DELECTED)
OBSERVATION WEIGHT (TRIAL VALUE)
EPB NUMBER OF FIRST CONTROL STATION
TIME OF READING AT FIRST CONTROL STATION (YEAR, MONTH, DAY, HOUR, MINUTE)(GMT)
IGSN71 SITE LETTER OF FIRST CONTROL STATION
EPB NUMBER OF SECOND CONTROL STATION
GRAVIMETER READING AT SECOND CONTROL STATION
TIME OF READING AT SECOND CONTROL STATION
IGSN71 SITE LETTER FOR SECOND CONTROL STATION
GRAVIMETER IDENTIFICATION
DIAL FACTOR TABLE NUMBER (LCR GRAVIMETER)
TRANSPORTATION TYPE CODE
CORRECTED READING DIFFERENCE BETWEEN FIRST AND SECOND CONTROL STATION
EPB FIELD BOOK AND PAGE NUMBER
EPB PROJECT NUMBER
SOURCE AGENCY CODE
```

Figure 8. Network Observation Data File record contents.

4. *Instrument Data File*

This file contains the scale correction factors derived from accepted calibration standards, the dial factor tables for LaCoste and Romberg gravimeters (supplied by the manufacturer) and temperature and/or pressure correction factors where applicable (Fig. 9). The file contains information for 200 gravimeters and resides on a direct access device. It is accessible by the Network Data Reduction and Adjustment System (Fig. 4) and the Static Gravity Data Reduction System (Fig. 5).

```
NOTE:     EACH ENTRY IN THE FILE CONSISTS OF A VARIABLE
          NUMBER OF RECORDS COMPRISING THE INFORMATION
          PRETAINING TO A PARTICULAR GRAVIMETER.

GRAVIMETER TYPE
GRAVIMETER SERIAL NUMBER
DATA SPAN FOR DIAL FACTOR TABLE #1 (LCR ONLY)
DIAL FACTOR TABLE #1
CIRCULAR ERROR CORRECTION FUNCTION FOR TABLE #1
DATA SPANS AND CORRESPONDING SCALE CORRECTION FACTORS APPLICABLE TO TABLE #1
DATA SPAN FOR DIAL FACTOR TABLE #2
DIAL FACTOR TABLE #2
CIRCULAR ERROR CORRECTION FUNCTION FOR TABLE #2
DATA SPANS AND CORRESPONDING SCALE CORRECTION FACTORS APPLICABLE TO TABLE #2
                              .
                              .
                              .
                              .
                             ETC
DATA SPANS AND CORRESPONDING SCALE CORRECTION FACTORS (NON-LCR)
DATA SPANS AND CORRESPONDING TEMPERATURE CORRECTION FACTORS (NON-LCR)
DATA SPANS AND CORRESPONDING PRESSURE CORRECTION FACTORS (NON-LCR)
```

Figure 9. Instrument Data File contents.

5. *Anomaly Data File*

This is a binary file on magnetic tape which contains (Fig. 10) the observed and/or reduced parameters obtained from federal government gravity surveys or those contributed by universities and exploration companies in Canada. Presently some 375,000 observations are on file. Although this is a frequently accessed file, it cannot be economically operated through commercially available data base management systems due to its large size. Therefore a specialized retrieval system including a plotting capability has been developed in-house. This is referred to as the Anomaly Data Distribution System (Fig. 2) or simply SYS76.

New data are added to this file after reduction and editing in the Static Gravity Data Reduction (Fig. 5) or the Dynamic Gravity Data Adjustment System (Fig. 11) and after scrutiny by the project review committee. The functions of this committee are discussed later under the heading of quality control.

All editing and assessment of anomaly data including data from outside sources are carried out by field personnel. Field officers are assigned project areas and are responsible not only for processing new data but also for the editing, assessment and, where necessary, re-reduction of all previously existing data in that area.

Requests from internal or external users of the Anomaly Data File are processed through SYS76. Output may be in the form of listings, plots or digital files on cards, magnetic tape or

```
RECORD STATUS CODE (ACTIVE OR DELETED)
SECURITY CODE
RECORD TYPE CODE (RAW DIAL RDG, PRECOMPUTED OBSERVED G, ETC)
SURVEY TYPE CODE
EPB ASSIGNED STATION NUMBER AND YEAR
TIME OF OBSERVATION (YEAR, MONTH, DAY, HOUR, MINUTE) (GMT)
GRAVIMETER IDENTIFICATION
GRAVIMETER HEIGHT (IF OBSERVATION NOT AT GROUND LEVEL)
GRAVIMETER TEMPERATURE (NON LCR ONLY)
RAW GRAVIMETER DIAL READING (STATIC GRAVIMETER ONLY)
LATITUDE (WITHOUT SIGN)
LONGITUDE (WITHOUT SIGN)
CO-ORDINATE ACCURACY, SOURCE QUADRANT FACTORS
ELEVATION
ELEVATION ACCURACY, SOURCE AND DATUM FACTORS
WATER DEPTH
DEPTH ACCURACY, SOURCE AND TYPE FACTORS
ICE THICKNESS
ICE THICKNESS ACCURACY AND SOURCE FACTORS
TERRAIN CORRECTION
TERRAIN CORRECTION ACCURACY AND SOURCE FACTORS
EOTVOS CORRECTION (DYNAMIC GRAVITY DATA ONLY)
UNADJUSTED OBSERVED G (DYNAMIC GRAVITY DATA ONLY)
ADJUSTED OBSERVED G
OBSERVED GRAVITY ACCURACY FACTOR
FREE AIR ANOMALY
FREE AIR ACCURACY FACTOR
BOUGUER ANOMALY
BOUGUER ANOMALY ACCURACY FACTOR
ADJUSTMENT NUMBER (DYNAMIC GRAVITY DATA ONLY)
FIELD BOOK NUMBER AND PAGE
SOURCE AGENCY CODE
EPB ASSIGNED PROJECT NUMBER AND YEAR
DATE OF RECORD CREATION OR MOST RECENT UPDATE
```

Figure 10. Anomaly Data File record contents.

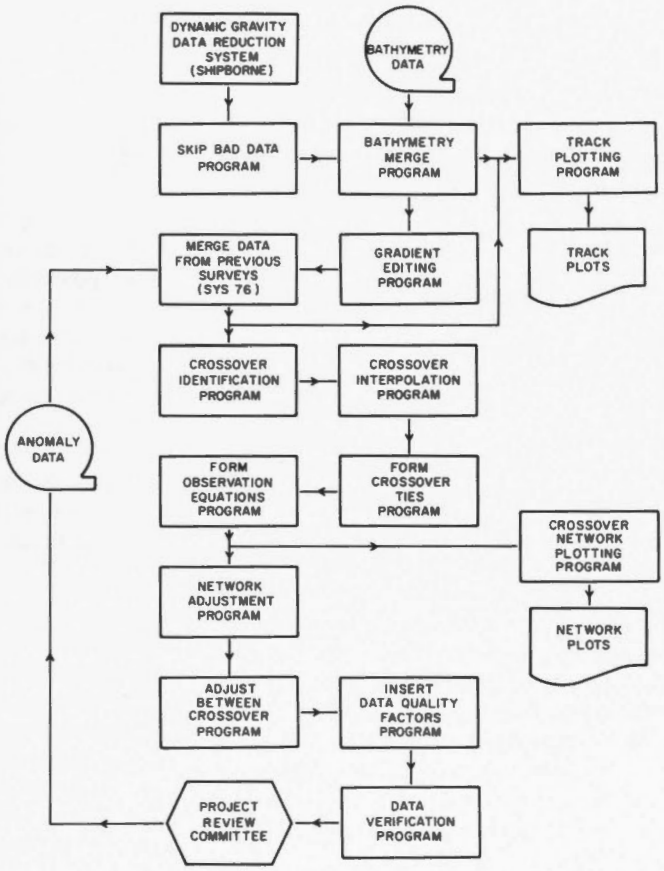


Figure 11. Dynamic Gravity Data Adjustment System.

disk. A special output format containing the raw field readings is available to field officers who may wish to reprocess older surveys. As with the Control Station Data Distribution System a report generating capability is available for the construction of output records containing only the desired data fields. Examples of the retrieval commands associated with SYS76 are given in Fig. 12.

COMMAND	FUNCTION
INPUT	SPECIFY DEVICE NAMES ON WHICH INPUT APPEARS
OUTPUT	SPECIFY DEVICE NAMES ON WHICH OUTPUT APPEARS
AREA	SPECIFY LAT-LONG BOUNDARIES
MAP	SPECIFY NATIONAL TOPOGRAPHIC SYSTEM MAP #
POLYG	SPECIFY VERTICES OF POLYGONAL AREA
SELECT	SPECIFY FIELD AND RANGE OF VALUES
DISCARD	SPECIFY FIELD AND RANGE OF VALUES
SUBROUTINE	USE SPECIAL SELECTION SUBROUTINE
SORT	SPECIFY ORDER OF DATA ON OUTPUT DEVICES
CONVERT	APPLY DATUM AND SCALE CORRECTION TO SPECIFIED DATA SET
DENSITY	RECOMPUTE ANOMALIES USING SPECIFIED DENSITIES FOR ROCK, ICE, WATER
PLOT	SPECIFY SCALE, PROJECTION, DATA, PRINT DIRECTION
REPORT	SPECIFY FORMAT AND CONTENT OF OUTPUT RECORD

Figure 12. Examples of Anomaly Data Distribution System (SYS76) commands.

6. *Altimetry Data File*

This file contains the raw altimetry and associated data (Fig. 13) acquired during the course of gravity anomaly surveys in hinterland areas. It consists of some 100,000 observations stored in binary form on magnetic tape. Retrieval and updating are accomplished through the use of a file management package known as CDC Update which is available on the CDC 6,000 Series computers. With the considerable improvement in vertical control networks in Canada over the past 10 years it is possible to improve the accuracy of older gravity anomaly surveys by recomputing the original altimetry with new vertical control. The addition of an interactive capability to the present altimetry reduction software (Fig. 5) is now being considered to speed up the recomputation of old altimetry data.

RECORD TYPE CODE (FLAG FOR START OR END OF TRAVERSE)
EPB GRAVITY STATION NUMBER AND YEAR
ELEVATION CONTROL POINT STATION NUMBER AND YEAR (IF NOT A GRAVITY STATION)
CONTROL POINT ELEVATION
ALTIMETER SERIAL NUMBERS
TIME OF OBSERVATION (MONTH, DAY, HOUR, MINUTE) (GMT)
READING OF ALTIMETER #1
READING OF ALTIMETER #2
WET BULB TEMPERATURE
DRY BULB TEMPERATURE
HEIGHT OF GRAVITY STATION ABOVE OR BELOW ALTIMETERS
HEIGHT OF ALTIMETERS ABOVE OR BELOW CONTROL POINT ELEVATION

Figure 13. Altimetry Data File record contents.

Quality control

Although all data processing systems associated with the data base have a large number of built-in checks the most important factor in the quality procedure is the intuition and judgement of the data processing staff, most of whom have extensive field experience. Due to the large volume of data entering or being reprocessed in the Anomaly Data File an additional check is performed by a project review committee, made up of the field project manager, data base manager and one or more field officers. The function of this committee is not to challenge the decisions of the field officer but simply to verify that all steps in the complex data assessment procedure have been carried out. It also provides a specific point in time when the responsibility for the integrity of a given data set and all its associated documentation passes from the field officer to the data base manager. In general, a given project will be considered twice by the committee. The first meeting will involve an in-depth examination of the data processing procedures and the project documentation. Any deficiencies discovered by the committee are noted in the project review report. These are rectified by the field officer before the final review.

Data security

The overall security of the data base and associated documentation is the responsibility of the data base manager. Since the Anomaly Data File contains data with release restric-

tions each record in this file contains a security code which can be assigned or changed only by the data base manager who is responsible for the integrity of the security coding system.

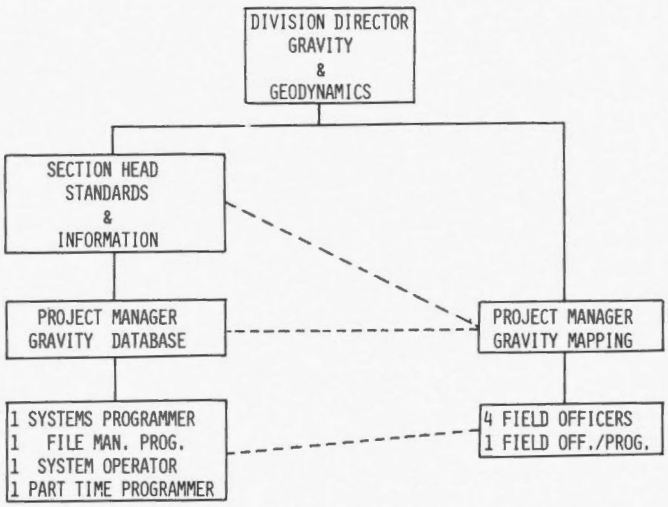


Figure 14. Organization and staffing of Gravity Data Base.

Staffing and organization

The staff of the Gravity and Geodynamics Division, involved in the management of the National Gravity Data Base, is shown in Fig. 14. Policy direction is provided by the division director. The overall design of the data base and its associated applications software systems and the coordination of the data processing activities of the field officers and data base staff is the responsibility of the Head, Standards and Information Section. The data base manager supervises the operation of the data base and the development of data distribution systems and provides the interface for all external users of the data base.

External usage of the National Gravity Data Base

Of the six files which comprise the National Gravity Data Base only three are commonly used by the public. Two of these, the Control Station Data and Control Station Description Files, are accessible without restriction. The third, the Anomaly Data File, contains some proprietary data from external agencies which has release restrictions. Data are made available at retrieval cost plus 100%.

References

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McConnell, R. K. and J. G. Tanner, 1974. Gravity standards in Canada. Proc. 1973 CSEG National Convention edited by A. E. Wren and R. B. Cruz, 235-237.

Morelli, C., C. Gantar, T. Honkasalo, R. K. McConnell, B. Szabo, J. G. Tanner, U. Uotila and C. T. Whalen, 1974. *The International Gravity Standardization Net 1971 (IGSN71).* Spec. Pub. No. 4 of Int. Assoc. of Geod.

Tanner, J. G. and R. J. Buck, 1964. A computer-oriented system for the reduction of gravity data. Pub. Dom. Obs., **31**, 53-65.

Ing. R. Salgueiro:

Muchas gracias, Sr. McConnell. Probablemente uno de los temas más nuevos e interesantes ha sido presentado por el Sr. McConnell.

Es uno de los trabajos más nuevos que existe actualmente, un sistema integrado en el sistema de computación y esa es la idea que debe estar orientada en la América Latina particularmente para construir la base de datos.

Creo sinceramente que la exposición hecha por el Sr. McConnell nos sirve para ponernos en contacto con la labor de este organismo, y nos permite intercambiar ideas que seguramente serán de gran utilidad en nuestros futuros trabajos.

Tenemos una experiencia definida en lo que respecta al trabajo del sistema de información de gravedad, que iría posteriormente a integrarse a otros sistemas para formar el sistema integrado de geociencias. Todo esto es una ilustración práctica que debemos aprovecharla en un máximo para, en esta ocasión, en esta reunión, para ver el enfoque y la filosofía del sistema de gravedad que ha sido construido aquí en Canadá.

El siguiente trabajo estará a cargo del Prof. G. P. Woollard y el Sr. Román Geller de los Estados Unidos. El tema que va a ser tratado por estos dos distinguidos cientificos es **"La Cartografia Gravimétrica en la América del Sur".**

Prof. G. P. Woollard:

If I follow the pattern established yesterday in reviewing the Canadian gravity program I would have to go back to the French expedition of around 1700 when the period of a pendulum was compared between France and Peru. This approach, however, would involve a lengthy exposition of a number of what I regard as great field expeditions; an approach which time does not permit. Suffice it to acknowledge the great efforts of Lavine and Mateo in Argentina (pendulums) and the pioneering work of the "grand old man of gravity" in Latin America, Professor Baglietto of Argentina.

If I may digress for a moment I would like to pick up on the discussion of yesterday with respect to government-industry relationships. As with geophysical exploration, the conduct of scientific research depends very much on the goodwill and cooperation of the government to achieve its objectives. All too often in the history of my activities in Latin America the job has been made more difficult by the lack of cooperation of government agencies because of apparent conflicts with mandates, changes of laws and what have you. All the advantage lies with government agencies and it is easy for an agency to put individuals and companies through a "meat-grinder" by using the undoubted power of government to frustrate what I regard to be legitimate and honest attempts to carry out original work. In the process, individual initiative and creativity are all too often stifled or destroyed to the great loss of everyone including the government. I personally find the current trend of government toward increasing control over and interference in the affairs of non-government institutions misdirected and not at all beneficial

to the continued healthy development of our societies. Pollution is a natural fact of life as is evolution. Let us not inhibit the development of the spirit of man through the unnatural and arbitrary intervention of government. Let us also remember that human effort and creativity is probably the greatest source of energy in our society. So much for philosophy.

Within Latin America we now have an excellent primary gravity standard that can be used as a reference for all gravity surveys in this vast area. An excellent calibration line exists throughout the length of Latin America and most if not all the national nets are tied in some fashion to the Latin American Gravity Standardization Net developed under the coordination of the SILAG working group.

We run into problems when we speak of the completeness of national coverage in the mapping sense because of the enormous difficulties in operating in the region. It is no easy matter to run a gravity line through the jungle or across the Andes. Therefore we will have to accept that national coverage in the sense we speak of in North America will be incomplete. Large gaps exist and will exist for some time to come.

In terms of current programs I am pleased to see the number of national catalogues and maps that have been issued. Uruguay, Ecuador, Chile, Bolivia, Belize, Guatemala, Trinidad and the Dominican Republic to name a few have all made gravity data available. Columbia, Argentina, Brazil, Peru, Nicaragua, Salvadore and others have made data available but gaps still exist in areas covered by jungle. Brazil is a special problem because of the enormous area. However, I would point out that a large amount of data exists in the files of Petrobras, the national oil company. I believe Brazil could make a significant contribution to science by getting Petrobras to cooperate with university and government agencies to get at least some of these data into the public domain. I might point out that a similar situation exists with national oil companies of other countries in Latin America. I feel there must be some mechanism that will respect the legitimate aims of these companies and yet at the same time make at least regional coverage available to the scientific community.

There are a number of areas for which I know or suspect there is little or no coverage available. I see no point in singling out individual countries at this point because this would fail to recognize the real problems that exist. We will, however, have to find ways of providing more assistance to countries in the gap areas.

I also think that some mention should be made of offshore regions. Oil companies and university groups have carried out a number of operations offshore of various countries in Latin America and a respectable data base is being built up. Along the Pacific margin there is reasonable coverage in a narrow band over what is believed to be a major zone of subduction. Along the Atlantic coast a number of lines has been observed offshore of Venezuela, Brazil and Argentina. I believe we should attempt to include these data on our proposed gravity maps of Latin America.

This concludes any general remarks that I would like to make. I now turn you over to Mr. R. Geller who is much more familiar with the details of national coverage.

Mr. R. Geller:

Concerning the comments by Prof. Woollard on general gravity coverage in Latin America, perhaps I can comment on some of the gap areas. Paraguay for example is an area for which a small amount of data are available. Several gravity traverses have been observed but only a small portion of the data can be reduced at this point because the overall geodetic control scheme in mapping has not been sufficiently extended throughout Paraguay to enable the computation of anomalies. We have good vertical control but lack horizontal control at this point. However, the Paraguayans have assumed responsibility and are making a serious attempt to pursue a gravity program. I might also mention the data in the Tierra del Fuego area that have been observed but have yet to be reduced and tabulated.

I think Prof. Woollard indicated that in Chile all the data have been published in tabular form. I believe the southern section has not been reduced but I understand that again the intention exists to publish the remaining sector of the observed data in Chile.

There is a small amount of data available I believe in Guyana but for Surinam and French Guiana there is really very little. There have been reference bases established to which future and perhaps existing surveys could be tied and referred to as common standards.

In the Antilles, beginning with Jamaica, I believe the British Overseas Surveys completed most of the coverage and have produced a publication and a chart. There is perhaps one gap at the top of Blue Mountain back of Kingston and I suggest someone check the value on the top of the mountain — it would be fun.

There are a few stations in the Cayman Islands. I worked in Cuba for about six months in 1960 and completed coverage of the western end of the island. I understand that the coverage has since been extended and a report published on the Cuban gravity investigations. Dr. Carl Bowen of Woods Hole published, in conjunction with a geological analysis of Espanola, a reconnaissance chart of Haiti.

In the Dominican Republic I believe the University of Santo Domingo again early in the 1950's completed quite a bit of coverage and the data have been used as the basis for a thesis at the University of Utah.

In the Antilles, the British Overseas Surveys have observed gravity over certain of the islands and have published the results in down the tail of the chain in Trinidad. There are also some data available from exploration efforts by the British.

I think that about covers the gap areas that might not have been discussed. There are various stations on isolated islands (Swan Island) and generally wherever it was possible to take a gravity meter somebody has been there. Easter Island was surveyed to an extent and tied to the mainland. We have not visited the Falkland Islands. I think that about covers it.

Ing. R. Salgueiro:

Queremos agradecer al Prof. Woollard y al Sr. Roman Geller por haber dado una exposición generalizada y poner al día nuestro conocimiento acerca de los trabajos que se están realizando en la materia en América Latina.

Ofrezco la palabra al delegado por Brasil.

Sr. R. de Godoy:

Creo que es necesario enfatisar la importancia que tienen la cantidad y calidad del personal que interviene en un proyecto.

Solicito por ello que se tenga como importante criterio de selección, los antecedentes que califican a quien interviene en un proyecto.

Ing. R. Salgueiro:

A continuación vamos a tener la oportunidad de escuchar al Sr. L. Wilcox de los Estados Unidos que se va a ocupar de ilustrarnos acerca de los sistemas automáticos de biblioteca y servicios del Departamento de Mapas de los Estados Unidos, con una ilustración correspondiente al **"Mapa Gravimétrico de Anomalías de Bouguer de América del Sur".**

Dr. L. Wilcox:

I wish to cover two different subjects in this presentation: (1) The DoD Gravity Library, and (2) the regional gravity and elevation maps that we have prepared for South America.

In the first part of this talk I will discuss those aspects of the DoD Gravity Library (DODGL) which I believe will be of most interest to you. I plan to emphasize the gravity data collection, products and servicing activities. I will also mention our gravity data holdings, one of our gravity data formats, and our data processing activities. However, I do not plan to go into much detail about the data processing part. I think it would be better if you wish to obtain more details on DODGL data formats, storage, retrievals and processing you consult a document that is published by the Defense Mapping Agency Aerospace Center (DMAAC) entitled "Holdings, Storage, and Retrieval of DoD Gravity Library Data". Copies of this publication may be obtained by written request to DMAAC or to the Inter-American Geodetic Survey (IAGS).

The DoD Gravity Library has several assigned responsibilities — first, we are responsible for the management, maintenance and operation of a gravity library. This gravity library includes a number of automated data files. We are responsible for the collection of all existing and newly surveyed gravity data. We acquire gravity data through the informal exchange agreements we have established with scientific organizations, governmental agencies, universities, private oil and geophysical companies and individual scientists. Within the Americas we work closely in this effort with the Inter-American Geodetic Survey. We are also responsible for the reduction and evaluation of all the gravity data stored in our automated data files. Since we accept gravity data from a wide variety of sources and in various forms and stages of reduction, the reduction and evaluation responsibility turns out to be one of our biggest tasks. Finally, we are responsible for providing gravity products and services. Specifically, in exchange for gravity data contributed to the DoD Gravity Library any organization or individual is given access to our gravity data products and services. Within the Americas arrangements for gravity data exchange and services may be made through the Inter-American Geodetic Survey.

Gravity data provided to the DoD Gravity Library in exchange for products and services can be in any form and at any stage in the reduction process. Many of our contributors provide raw data in the form of field survey notes, gravity charts or data listings. Data received in raw form are completely processed, reduced and evaluated by the DoD Gravity Library. Then the donor is given finished gravity products such as computer listings, data cards or magnetic tape and data plots.

The DoD Gravity Library has provided at least some of these services to several American countries which have exchange agreements with the Inter-American Geodetic Survey. Some of these countries are Bolivia, Brazil, Chile, Columbia, Ecuador, Honduras, Nicaragua, Panama and Peru.

Gravity data are also contributed to the DoD Gravity Library in many other forms such as finished gravity anomaly maps, published or unpublished documents or reports, sketches and descriptions of gravity measurement site locations, principal facts for gravity surveys and/or geologic or geophysical interpretations of completed gravity surveys. We also get data in the form of automated listings, punchcards and magnetic tapes. Those who contribute gravity data in these more finished forms also have access to DoD Gravity Library products and services.

Upon a contributor's request gravity data contributed to the DoD Gravity Library are marked, "proprietary". This marking limits use of the data to the Department of Defense and no other government agency, private or educational organization or individual is given access to such data without the contributor's expressed written permission; in other words we treat such data as being confidential. If no such restriction is requested by donors of gravity data the data are placed on an open file and are furnished to users upon their request.

Largely through the success of our gravity data collection and exchange activities the DoD Gravity Library has become the most complete depository of gravity data which is known to exist. The DoD Gravity Library now has on file more than 11 million unique gravity measurements. These provide very extensive gravity data coverage. Data for approximately 6 million gravity stations are now stored on magnetic tape which is processed by a UNIVAC 1108 computer system. This automated file known as the Gravity Point Anomaly or GPA file serves as a focal point for the automated storage and retrieval of gravity data within the DoD Gravity Library. The remaining 5 million stations, which provide gravity data coverage in excess of our gravity data requirements, are maintained in a non-automated contingency backlog file. A program for conversion of the GPA file from magnetic tape to disk storage is now under way.

Information recorded on the Gravity Point Anomaly file for each gravity measurement includes the position of the measurement site in terms of its latitude and longitude, the elevation of the measurements site and, when the measurement site has an unusual location such as surface of an ice-cap or inland lake, a supplementary elevation such as ice thickness or depth of lake is also recorded. A code is used to indicate the nature of the measurement site location, whether that be land surface, ocean surface, ice-cap surface, lake bottom or whatever. This code also determines the formula which we use for anomaly computations.

Observed gravity as recorded on the GPA file is referenced to the International Gravity Standardization Network of 1971 (IGSN71). Normal gravity is not recorded but it is computed where needed using the gravity formula for the Geodetic Reference System of 1967. The free-air and Bouguer anomalies and their estimated accuracies are recorded on the GPA file. When a terrain correction is available a code is used to indicate this fact although the terrain correction value itself is not now being recorded. The source code is a four digit number which is keyed to the Author-Index file. The Author-Index file is another automated file which provides a cross-index to the document or source from which the gravity data has been extracted. The base reference code is a four digit number which is keyed to the automated Gravity Base Station file which gives the principal facts for the base reference station to which each measurement is referred. Descriptions of the exact location of many of these stations are also available. Any point gravity data provided by the DoD Gravity Library in accordance with exchange agreements

will be contained in the GPA file which we have just described in general terms.

We have already mentioned three of the automated data files maintained by the DoD Gravity Library: the Gravity Point Anomaly, Author-Index and Gravity Base Station files. There are some others as well. Our Mean Gravity Anomaly files contain mean gravity values for approximately 30,000 1° x 1° areas. There are also some values for surface elements of other sizes. These mean anomaly values are predicted by various conventional, statistical, and geophysical methods. The Mean Elevation File contains complete world-wide coverage of 1° x 1° mean elevation values. We also have some mean elevation values for 5′ x 5′ surface elements. The Gravity Anomaly Map collection of the DoD Gravity Library has been automated to enable rapid listing and retrieval of our gravity anomaly map holdings.

In addition to the several automated files that I have discussed with you the DoD Library has the capability to generate a variety of gravity data plots and maps using automatic plotting equipment. This includes station location maps with gravity anomaly values annotated, density and distribution indexes and fully contoured gravity anomaly maps. An example of a fully contoured automated gravity anomaly map is the mean elevation map of South America which is included in our regional gravity and elevation maps of South America. We also have the capability to digitize point and line data from maps.

Among our gravity anomaly map products are a series of continental gravity anomaly maps — these are contoured representations of our 1° x 1° mean gravity values and they have been published for four continental areas: Asia, Africa, South America, and Greenland. We will talk more about our new South American maps shortly.

I would like to conclude the first part of this talk by summarizing the products and services provided by the DoD Gravity Library to individuals and organizations which contribute data to the Library. We provide point and mean gravity data for any area of interest on punchcards, magnetic tape and machine listings. We provide annotated point plots at any scale, on a choice of projections, and containing station location and gravity values. Free-air and Bouguer anomaly maps can be provided at various scales and on a variety of projections. When gravity data in raw form are contributed to the DoD Gravity Library, we provide data reduction, processing and automation services into the GPA format. Information and copies of textual documents held by the DoD Gravity Library can be provided when requested. Upon request we can provide copies of the gravity base station description information held by the DoD Gravity Library. We usually furnish appropriate base station information along with all shipments of point gravity data. Finally we can provide copies of our Quarterly Accessions List which is a listing of all unrestricted gravity documents acquired by the DoD Gravity Library during the quarter.

The DoD Gravity Library has been pleased to cooperate with the American countries in the past in gravity related matters and looks forward to continued cooperation in the future.

I would now like to turn to the second part of the talk which has to do with our new gravity and elevation maps of South America. These maps replace and supersede our 1973 publication, Bouguer Gravity Anomaly Map of South America. There are actually 4 maps in the new set (in pocket): regional structure, mean elevation, Bouguer anomaly and free-air anomaly.

In our regional structure map we have delineated the major structural and tectonic provinces in South America. Some of the boundaries are well defined structurally, others are somewhat arbitrarily drawn. What we have attempted to do is to try and indicate which provinces are interpretable from the standpoint of the regional gravity picture. We show the various divisions of the Andean Cordillera along the west coast. The central valley of Chile is structurally a graben. This valley is physiographically absent in the region between 27°S and 33°S, then appears again as the Pampa de Temarugal to the north where it is fault bounded on the west and is monoclinal on the east. There are several smaller structures at the north end of the Cordillera, e.g., the Maracaibo Basin and Falcon Basin. The two shield areas, the Guiana Shield and Brazilian Shield, occupy almost a third of the continent. Superimposed on the Brazilian Shield is a line of sedimentary basins and a major graben, the Bahia Graben. Surrounding the shield and separating it from the Cordillera is the Basin and Plains Belt running from the eastern Venezuelan Basin through the upper Amazon Basin and Beni Plains to the Chaco-Pampa Basin. The Pampean Range is a basin and range province. In Patagonia, we have two major massifs, the Chubut and the Deseado, with basins to the north and south of each one.

Our mean elevation map of South America shows the twofold physiographic division of South America quite clearly. Closely spaced contours represent the Andean Cordillera, with the Puna Block or Antiplano appearing as kind of a plateau at the top. Patagonia shows up as a table land descending gently towards the Atlantic. The shield areas are areas of low moderate elevation. The Basin and Plains belt is shown to be everywhere less than 250 metres in elevation except for the Beni Plains. One of the reasons for showing this mean elevation map is that the regional Bouguer gravity map is very highly correlated with the regional topography in the mountain area, so much so that some of the local and structural features do not show up too well.

The free-air map is much less correlated with topography and particularly on the flanks of the Cordillera we see some structures that do not appear on the Bouguer map.

The Bouguer Gravity Anomaly Map of South America is hand-contoured from our 1° x 1° mean Bouguer anomaly file. In the previous edition we used an automated compilation but it turns out that automated contouring does not represent the structure as well as we would like. It looks like hand-contouring of gravity maps is the best way to go at least for regional fields like these. The 1° x 1° values that we used here and, incidentally, in the free-air map were predicted using the gravity data holdings of the DoD Gravity Library and various conventional statistical and geophysical prediction methods. You should remember in looking at this map and at the free-air map that they are regional. They are 1° x 1° means and it is sometimes difficult to get a one for one comparison between a gravity map that is compiled from individual points and one that is compiled from 1° means. One of the reasons for this is that gravity variations whose wavelength is less than about a degree tend to be averaged out. One feature that is effectively averaged out is the west Columbia gravity high. This feature is just too narrow to appear on a mean anomaly map since it is overwhelmed by the adjacent negatives in the area.

Looking at the Bouguer map, we see a strong Bouguer negative which follows the Cordillera all the way from Patagonia up into Venezuela. The most intense negative is in the area of the Altiplano and Puna block where you get kind of a negative plateau which mirrors the positive plateau in the elevation field. You see there is not too much in the heavy gradients on the flanks of the Cordillera that can be interpreted in terms of structure. The

regional Bouguer field is just too highly correlated with topography over the Cordillera.

There are a number of striking Bouguer positives showing up. The Uruguay Shield area and Chaco-Pampas Basin are Bouguer positive areas. The Upper Amazon Basin is a big area of Bouguer positive. Even though all these areas are relatively low in elevation the Bouguer positive is still somewhat abnormal suggesting the existence of a high density crust in these areas which at least in the Chaco-Pampas Basin has been confirmed by high seismic velocities. There is a somewhat discontinuous positive that extends through the Amazon Trough to the Beni Plains and if you draw a line connecting this discontinuous positive it seems to coincide fairly well with one of the structural lineations known to exist in the region (Woollard, this volume). Other isolated positives are found over the El Baul Swell and the Sierra de Santa Marta which are strongly uplifted areas. The shield areas tend to be normally negative. The maximum negatives in the shield follow fairly well along the trend of the superimposed sedimentary basins on the Brazilian Shield. The Bahia Graben has a very strong negative associated with it.

On the free-air anomaly map of South America we find a definite positive which follows the Andean Cordillera from about the northern part of Patagonia up into Venezuela. However, this positive is less pronounced than the corresponding negative on the Bouguer map. A negative trend generally follows the central valley of Chile which is a structural graben. We also have a very pronounced negative in an area where the central valley is physiographically absent which possibly indicates that, even though there is no physiographic signature, there still might be a graben type structure here. The Pampa de Temarugal does not show up too well on the gravity map.

One of the most striking features on this free-air map is a negative trend that starts just north of Patagonia and runs up almost the entire eastern flank of the Andean Cordillera. This negative trend would correlate very well with a line of deep sedimentary basins along the east front of the Andes. In European circles such basins are sometimes called foredeeps. Flanking this negative to the east are a number of strong positives. One of these is located in the Pampean Range which is a basin and range province and this correlates well with an area of exposed basement. At the northern end of the Cordillera there are a number of small features showing up like the negative over the Maracaibo Basin, the positive over the Sierra de Santa Marta and the negative over the eastern Venezuelan Basin. The shield areas have kind of a mixed positive and negative expression although the overall value seems to be negative which would agree with the satellite representations of this part of South America. A line of negatives seems to follow fairly well the line of sedimentary basins in the Brazilian Shield. The Bahia Graben is a striking negative. Down in Patagonia the two massifs are marked very clearly by free-air positives. These do not show up in the Bouguer map at all. Relatively negative areas appear over the basin structures that lie to the north and south of the massifs.

With this introduction I have indicated some of the things to look for on the maps. We expect to be issuing these in the form of a DMAAC Technical Report in the near future which will include a structural summary of South America and some additional details of interpretation which for the sake of brevity we have omitted here.

Discussion:

Ing. J. J. Guevara:

Tomo la palabra para hacer un comentario a manera de información. El Instituto Nacional de Honduras esta trabajando en los levantamientos gravimétricos, los que ha estado realizando en cooperación con el Servicio Geodésico Interamericano. Se han obtenido una gran cantidad de datos. En un futuro tendremos que procesar las mediciones, para lo que necesitaremos los servicios de expertos en el tema.

También se ha estado realizando un programa modesto de levantamientos geológicos y esperamos tener la oportunidad de correlacionar los datos gravimétricos con los levantamientos geológicos, en lo que se refiere a la interpretación de las anomalías.

Ing. R. Salgueiro:

Quisiera hacer un comentario indicando lo siguiente: Que el trabajo presentado por el Dr. L. Wilcox, en lo que corresponde a la primera parte sobre sistemas automáticos de biblioteca, se complementa en forma brillante con la exposición del Sr. McConnell, y creo yo poder aprovechar la posibilidad de la obtención de los datos que se ofrecen por parte de estas dos organizaciones, además de la documentación correspondiente al software.

La misma se ha desarrollado ya, aunque orientada para otras computadoras. Creo que esta información documental podría perfectamente ser aplicada, previa adaptación a los sistemas de computación disponibles en cada uno de nuestros países.

Ahora lógicamente, este trabajo podría ser mucho más valioso si se encargase a un centro latinoamericano, el que realizaría la labor evitando una duplicación de esfuerzos. Una función de la Comisión de Geofísica podría ser la de conseguir el logro de este objetivo para que así se pudiese difundir esta información y poner a disponibilidad de los países miembros esta facilidad para el procesamiento de su base de datos.

Dr. L. Ocola:

I think your maps are very interesting. What information did you use for the Amazonian Basin? You can use the correlation with elevation in the Andes where we have gravity data as well as elevation but what about the basin area? Did you use the same correlations?

Dr. L. Wilcox:

No, we don't use the same correlations everywhere. We also developed and used specific correlations for the Amazon Basin. The latter is a difficult area to work in because as you say, the elevations don't vary much but, with the data that we have and the prediction techniques we were able to develop, I think that we have an excellent representation of the way the gravity field looks. I feel fairly confident that qualitatively it is very good. I am confident of the overall quality of our new maps of South America.

Dr. L. Ocola:

I have been looking at your first map and there is good correlation in the Andes but the correlation in the jungle is very doubtful. This does not reflect the actual obser-

vations. It happens in the last two months or so I got some maps for the jungle and a careful inspection shows the general trend, of course, but some key information related to the structure that you put in the first map in missing on your map.

Dr. L. Wilcox:

You're talking about the first edition. Have you looked at the new one and does it represent the area any better?

Dr. L. Ocola:

Yes, there is a little improvement, but I would like to point out that we could easily improve the control of the Amazon Basin if we carry on a program as proposed in Panama. At the time that they are observing the geodetic control in the Amazon Basins, arrange to have a gravity observer along as we did in Peru. We wanted to have some checks on your prediction so we tied our gravity program to the geodetic program. In that way we can have first-hand control on the prediction of the gravity field as the satellite geodetic control is very very good. I would also like to ask if there are any gravity data in your files which are classified.

Dr. L. Wilcox:

Yes, as I mentioned in the first part of the talk, we do receive gravity data from a number of people who request that we mark it proprietary and not distribute it outside the Department of Defense and we honour these commitments.

Dr. L. Ocola:

So these data have not been used?

Dr. L. Wilcox:

Many of the people who have supplied these data to us have told us they have no objections if we use their data to build 1° means and in these cases we have used those data in 1° mean predictions.

Mr. R. Geller:

Just a comment on the remarks made by Dr. Ocola. Many times these data are submitted in a proprietary classification to allow an in-country production to be finished. In other words we would like to wait for instance until the country itself has had the opportunity to compile its own data and produce a national product rather than release the data in pieces, particularly where they have the hopes of producing a national chart. They see their work published by other authors perhaps related to certain geologic studies and they wish they had a chance to do it themselves. So there is really no lack of confidence involved but merely a professional courtesy in some of these proprietary holdings.

Prof. G. P. Woollard:

I do not have any questions for Dr. Wilcox but I do feel that the group ought to be cognizant of some of the resolutions that we adopted in Panama. One involved the preparation of a gravity map of Latin America on roughly a two and half million scale. The compilation of this map is being delayed partly because we do have these proprietary holdings and the people within a country do not know what is being held in their own country because no one will tell them. I think the Defence Mapping Agency could help us here. Another point I wish to make is that it would be better if we would take full advantage of the help that is being offered by the Earth Physics Branch in providing these thousands of primary base station values adjusted to a common datum and scale for all of Latin America. We have also had the offer from the Defence Mapping Agency in St. Louis to take all data and adjust them to the new standard and datum. This letter is important because there is a whole raft of data that are still on the old international ellipsoid and the old gravity standard. It would be a lot better to get DMA to do this and provide the data in common format adjusted to LAGSN. With that we could attempt to use prediction techniques in areas where we have large gaps and just see how it connects up. It will at least give a structural grain across an area that otherwise would be just a big white spot on a map. The final thing I want to say is that I have gone to NSF to ask for support to get moving on this project and I have been told support will be available but thus far no one has told me how much. We have some momentum going on this project so let us not lose it.

Ing. R. Salgueiro:

Muchas gracias, George. Bien, considero que las exposiciones que han sido expuestas nos dan una idea que servirá de ayuda para las sesiones que tenemos programadas para el día de mañana y el viernes.

Ahora vamos a continuar con las exposiciones. El próximo expositor es el Sr. K. Svendsen quien va a exponer el tema **"Necesidad de información geomagnética y problemas sobre el intercambio de la información".**

Mr. K. Svendsen:

The World Data Centre system began with the International Geophysical Year (IGY) in 1957-58 and was designed to benefit the geophysical research community by making the data as widely available as possible. For the researcher or institution generating the data it was intended to provide a convenient place for deposit of the data after the primary needs had been met. It was thought to provide security for the data and to relieve the institution of the burden of making copies for the many individual investigators. In practice, at least at World Data Centre A, they may receive an equivalent amount of data in exchange. For what might be called the secondary data user it was intended to provide centralized easy accessibility to the data. It is generally accepted that the plan was highly successful. Widely appreciated by both data generator and data customer the system was continued after the IGY.

I have been associated with World Data Centre A since its inception and I thought it would be of interest and useful at this time to take a brief look at this operation to see what has been done and what should be done. The organization with which I am connected, the National Oceanic and Atmospheric Administration, operates World Data Centre A for Solar-Terrestrial Physics and World Data Centre A for Solid Earth Geophysics. The first one serves the disciplines of geomagnetic variations, ionospheric phenomena, solar and interplanetary phenomena, flare-associated events, aurora, cosmic rays, and airglow; the latter one serves seismology, tsunamis, gravity, earth tides, recent

movements of the earth's crust, paleomagnetism and archeomagnetism, volcanology, geothermics and geomagnetism (solid earth).

The degree of success has not been the same for all disciplines; indeed, for some of these disciplines organization of the data collection is only just beginning. The best performance has been in the field of geomagnetism, both in terms of data collection and data dissemination. This happens to be the discipline with which I have had the most experience, so the following remarks will refer to geomagnetism primarily, but some of what is said may also apply to other disciplines.

The IGY sparked a great spirit of international cooperation and for the next few years most institutions having magnetic programs were happy to furnish copies of their IGY data to the world data centres. There was a great deal of variation in the speed with which the data were deposited — in some cases as early as the following month, in others a few years — but the world data centre eventually received IGY data from about 75% of the operating observatories. This was considered a high degree of success. As for the data customers they were enthusiastic about this new method for obtaining data. They could write to one source and theoretically obtain copies of all the data they wanted. The number of orders received by the centres increased steadily. Recognizing success of the system the life of the world data centres was extended and the observatories continued to send their data to these repositories.

Further impetus was given to the system in 1964-65 with another special observing interval — the International Years of the Quiet Sun (IQSY). Data contributions were slightly higher during both the IGY and the IQSY, but the flow has been large and reasonably steady during the entire period from the IGY to this day. Data sales have been ever increasing.

Successful functioning of the system depends, of course, on voluntary deposits. Owners of the data have the choice of keeping the data to themselves or releasing the data for the use of other scientists. Although our agency (NOAA) did generate original data for many years, all of which was deposited in the world data centre, we now see the operation mostly from the viewpoint of the customer. Every day we receive more data requests and to satisfy these requests we hope fervently for the full cooperation of all the data generating individuals and institutions.

World Data Centre A distributes more copies of data than any of the other centres, probably partly because of the huge amount of research being carried on in North America, but it is interesting to note that this centre also has many customers from other parts of the world. We are constantly striving to improve service to the customer. We try to deliver better copies faster; we offer a range of formats. From the IGY onward most of the copies desired were in the form of microfilm. At the present time about 80% of the orders received are for microfilm copies of the analog records (magnetograms), but increasing numbers of customers are interested in machine-readable digital data. We also now offer some data in the form of microfiche. Much data are now stored in the computer awaiting immediate retrieval via an office terminal.

In 1964 our own bureau became the largest customer for data centre services. Through a contract with the National Aeronautics and Space Administration (NASA) we began a huge project of digitizing magnetograms. This turned out to be beneficial to the general customer. Not only did this produce digital data for deposit in the world data centre providing a wealth of new digital data for other scientists, but also the process brought attention to some problem areas. Of course, many errors were discovered in the data and attempts were made to correct these through contact with the originators. In some cases it appeared that the observatory instruments were actually malfunctioning; these problems were also attacked. The net result was upgrading of the data holdings. It was also found that greater standardization in recording format and in data presentation would materially assist the user. For example, comparison of observatory magnetograms was greatly facilitated when the stations recorded their results on the same universal time (UT). Accordingly, through the offices of the International Association of Geomagnetism and Aeronomy (IAGA), the data centre became active in promoting a standard recording format. Some progress was made in this area. All of these efforts benefited the thousands of data users.

Perhaps most important, it was found that the world data centre's collection was deficient in some important areas. Some strategically located observatories were not cooperating in the world data centre program. As mentioned previously the system is based on completely voluntary cooperation. The data centre's holdings consisted of whatever happened to be received. Until the time of this NASA program nothing had been done beyond resolutions by the IAGA urging the observatories to send copies of their records to the world data centres. Beginning about 1965, to fill holes in the data holdings, World Data Centre A sent requests to individual observatories asking them to begin (or resume) routine deposits. In addition, beginning in 1966, NASA financed the travel of an emissary to these stations to explain the need for their data, to request their cooperation and to seek solutions to any logistical problems that appeared to be real obstacles. At some stations assistance was given in adjustment of instruments. As might be expected this mission was not completely successful; many promises were made, but not all of them were kept. However, enough progress was made to consider the mission a success.

The latest approach to be taken by World Data Centre A has been to send a representative with portable microfilming apparatus to the observatories which are willing to disseminate their data, but unable to perform the filming themselves. This method of enhancing the world data centre collection was proposed to the IAGA in Grenoble in 1975. A resolution was approved which urged the observatories to offer their data to the data centre representative for filming. The first such trip was made to Latin America in 1975 and World Data Centre A is happy to report that they received the complete cooperation of all institutions. Another trip, this time to Africa, is planned for early next year. It is hoped that contributors will not become dependent on this system, but that other ways will be found for filming when it is time to update the collections.

What remains to be done? What can you, as potential contributors to the system do?

In preparing for the International Magnetospheric Study (IMS) in 1976-78, IAGA took a look at what remained to be accomplished in the way of standardization of format. In 1973 its Working Group on Magnetic Observatories sent a memo to each institution that operates at least one observatory, outlining recommended improvements. Some of these changes would not be easy, requiring modification of instruments. Nevertheless,

some changes were made. For those of you operating magnetographs, this memo should be reviewed to see if there is anything that can be done to assist in this effort.

Most of you are data users. Many are involved in research and in the generation of field data. If you generate original data it is assumed that once primary needs for the data have been served you will then be willing to release the data for use by other scientists. We know of no better way to serve this community than through the world data centre system. As you may know copies of data may be sent to any one of the four centres (Kyoto, Moscow, Copenhagen and Boulder) and that centre will provide copies for the other centres, so that ultimately all centres will have copies of all available data.

We are very concerned about some institutions which are collecting valuable data and do not share them with their fellow scientists. And here we are not talking about only the standard, permanent observatories. We are also concerned about records from temporary stations, records that are forgotten once the research project is completed and the results are published. Who knows the potential values of these records? They may have cost hundreds of thousands of dollars of public funds and, once the purpose for which they were collected has been served, they should be sent to the world data centre for preservation and possible future use. Write to the world data centre, describing what you have. They will make arrangements for transfer of the data.

As for the permanent observatories it is well known that present geographic distribution is uneven. There are more observatories in Europe than are necessary and too few in many other parts of the world. There are too few in Latin America to tell us all we want to know about what is happening to the magnetic field in that region. For example, a group of scientists has prepared maps of equipotential magnetic contours for the Northern Hemisphere. They would like to prepare the same for the Southern Hemisphere, to compare the two hemispheres, but the data centre does not have enough data from both South America and Africa. It is highly important that the few existing stations share their data with the outside world and the sooner the data are released the more useful they are for research.

The world data centre has many customers whose orders cannot be completely filled because of lack of data. In such cases customers are told which records are not available at the centre and that they will be requested from the stations. Unhappily, sometimes the stations do not reply to the letters. In other cases, it may be better to suggest that the customer write directly to the station. Again, sometimes the customer does not get a reply.

Why are copies of the data not sent to the world data centres or in response to individual requests? Sometimes we are told that there are no local facilities for copying of records. To solve this problem, we have sometimes furnished film, and even cameras. Sometimes it is said that the necessary manpower is not available. Unfortunately, perhaps, we cannot furnish this. In some difficult situations we have arranged to have the records sent to the centre by the safe diplomatic pouch. They are filmed at the centre and returned to the station by pouch. As mentioned earlier, as a last resort we will visit the station with portable microfilming apparatus.

It is sometimes suspected that there is fear of exposing the data to critical eyes. Perhaps someone will spot errors, or even discover malfunctioning equipment. This will embarrass the operator. We think it is best that the errors are found. Sometimes this is the only way that malfunctioning equipment can be detected and corrected. We have often been able to assist in material ways, in obtaining replacements for faulty parts. Sometimes our influence has helped in arranging for new instruments. We think it pays to work with the world data centres. As previously mentioned, at World Data Centre A some data may be obtained in exchange.

It has been admitted by some operators that they do not want outsiders to use their data before they themselves have finished with their own research. This is, of course, their privilege. But it is hoped that their own investigation will be completed in a reasonable length of time, and that they will then release the data to others.

Perhaps the answer is often simply a case of office politics. These things are, of course, insoluble.

At the present time there are about 190 permanent magnetic observatories in the world. The world data centres receive data from about 75% of these. This is a good showing, but there is room for improvement, particularly since the 25% not sending data are in regions where the density of observatories is lightest. There is also room for improvement in the speed of transmission. Most customers are interested in recent data. If your institution is not now making its data available through the world data centre system, all we can do is respectfully request that you try to do so. You will probably never know how many scientists will appreciate what you do.

And finally, much data are being collected under the International Geodynamics Project (IGP). Don't let it get lost. When your paper is finished, send the data to the world data centre.

In closing, I would like to comment that not all of the preceding remarks about problems of data collection apply to Latin American institutions. In general, we receive excellent cooperation from them. We would, however, like to receive their results on a more current basis.

Discussion:

Mr. R. Geller:

I think most of you are aware that the Inter-American Geodetic Survey has traditionally tried to cooperate and facilitate the collection of magnetic data and that we do have offices in most countries. We do have the facilities for microfilming or for transmittal of data under more secure circumstances than international mail. We remain at your disposition in this matter and we hope to continue to do this. One other point. You mention that you hope to collect the data after it has served its function at the point of observation. Quite often data are observed and submitted in the hopes that somebody else will do something with them and I would just like to mention a return of products to Latin America from international centres whether it is the current world magnetic charts produced by the U.S. Navy, isogonic charts or others, even written analyses. If you can get analyses, papers, publications to us we will try to distribute them to the interested contributors in Latin America.

Mr. K. Svendsen:

Very good suggestion. We have a mailing list, of course, and there are many things that we distribute through the world data centre to our customers. I neglected to mention one very important thing in connection with this paper.

When I was speaking about many observatories being reluctant to cooperate, I was speaking of the world-wide picture and this does not apply to Latin America actually. As I mentioned we received complete cooperation from Latin America. Sometimes a little slow but everybody contributes.

Prof. G. P. Woollard:

I hate to be taking up too much time around here but there is a lot of value in getting your data to the data centres because it's a feed-back loop that frequently brings out errors. I remember many years ago looking at a magnetogram from Puerto Rico which showed there had been a tremendous magnetic storm. No other observatory had recorded this and when investigated it was found the "magnetic storm" was actually a beetle crawling on the record. Another example might be the one degree averages referred to by Dr. Wilcox. I got a copy of these averages for the Pacific region and from the print-outs they look like Dr. Wilcox claims: they have been evaluated, they have been adjusted and they have been put on file. When you plot those data there is one area where you have got one of the world's biggest gravity anomalies, an anomaly that no one else has ever reported and which correlates with nothing, I have not written him about this yet but it does emphasize that with public data mistakes usually get caught early before someone makes a real fool of himself.

Ing. R. Salgueiro:

Vamos a escuchar al próximo expositor el Sr. W. S. Callahan que habrará sobre **"Sistemas de Datos Meteorológicos en América Latina".**

Mr. W. S. Callahan:

This morning I would like to give you some background as to how Latin America fits into the world picture with regard to global weather forecasting. As you know, this is one of the disciplines in which there has been a free exchange of data throughout the years. In the time since we have first been able to communicate our meteorological data using modern transmission systems there has never been anything held back. Possibly during the first few years there was an occasional attempt to withhold data or place restrictive codes on them but other than that there has always been a free exchange largely because all nations realized the importance of the data to one another and how much they would benefit from such an exchange.

The beginnings of the system go back to 1963 when the World Meteorological Organization (WMO) first approved the world weather-watch concept, an idea to try and tie together all members (I believe there are 124) of the organization in a network. The purpose of this plan was the development of a system that would make basic meteorological and related environmental data available to all members of the organization so they could enjoy the most efficient and effective weather service possible. In establishing this global system, those responsible divided the globe into five regions. Region 1 is Africa, 2 is Asia, 3 is South America, 4 is North and Central America and 5 is the South Pacific. It was also realized that certain centres would have to be designated as major nodes in the system to serve not only as main data and forecast centres, but also as telecommunications centres. There are three such centres with the first being Melbourne, Australia, the second Moscow and the third Washington. These World Meteorological Centres are tied to what we call regional centres or telecommunication hubs. Those secondary centres are located at Bracknell (England), Brazilia, Cairo, Nairobi, New Delhi, Offenbach, Paris, Peking, Prague and Tokyo. The regional telecommunications network is shown in Fig. 1.

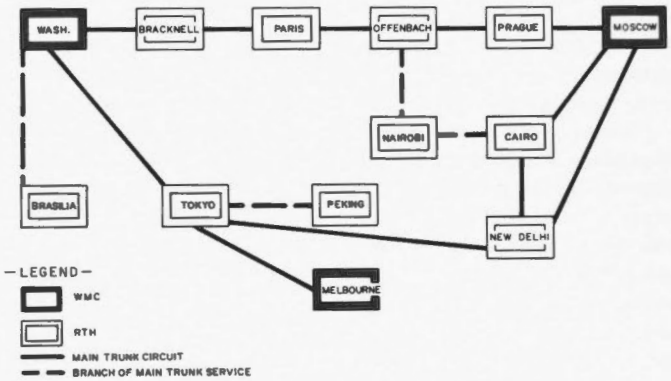

Figure 1. World Meteorological Centres (WMC) and Regional Telecommunication Hubs (RTH) of the World Meteorological Organization.

The regional centres of Fig. 1 are tied to national networks which collect the basic meteorological data. Once the outlying stations have made their observations the data are forwarded to the national centre and from there to the regional and the world centre. These weather observations, synchronized on a world-wide basis, are used to produce a forecast within 2½ hours of the time they are taken. The key to the success is of course the global telecommunications system I am describing here.

The observational network actually consists of two subsystems — a surface and a satellite sub-system. The surface subsystem ideally should have stations every 150 km. However, it is realized this is impossible in sparsely populated areas and the requirement is extended to 500 km. Over the oceans the land stations are supplemented by weather ships. Surface observations are taken a minimum of 4 and preferably 8 times daily and upper atmosphere observations are taken twice daily. Many of you have seen the excellent photographs provided by our weather satellites. These play an important role in weather forecasting.

If I may turn to Latin America I should first point out that the network has been vastly improved in the last 15 years. There are now some 850 surface observation stations with 108 capable of taking upper air weather observations. The telecommunications system for South America is shown in Fig. 2. Washington of course is the World Meteorological Centre. Brasilia, Buenos Aires and Maracay are both regional telecommunications and meteorological centres and receive data from other national centres as indicated. At this point I might mention that the data are processed by what we call the global data processing system. This processing capability is integrated downward whenever the capability exists within a country to process its own data in the context of global forecasts. Where this capability does not exist this function is carried out by either the regional or world centre. This flexibility in communications is very important in the tropics during the hurricane season where we are particularly interested in tropical storm warnings and advisories.

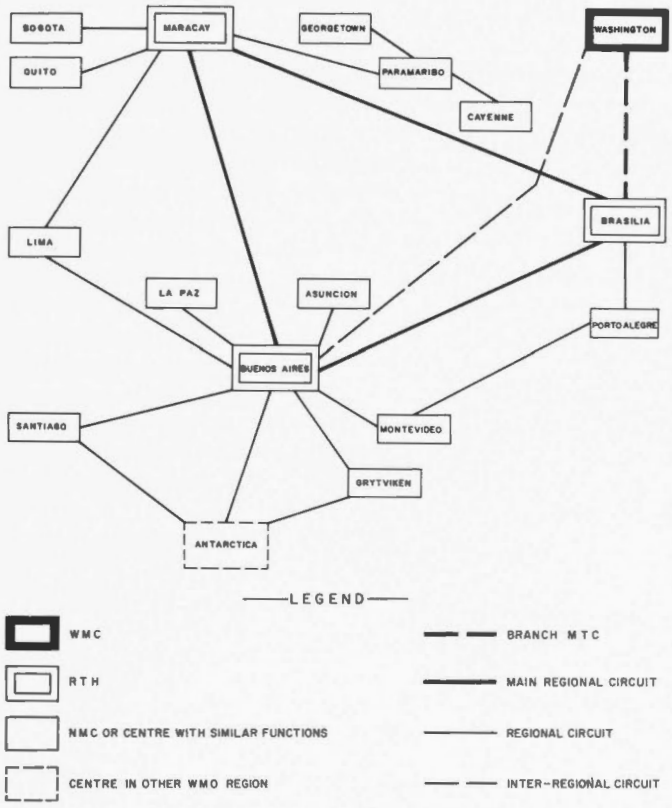

Figure 2. The region telecommunications system for South America.

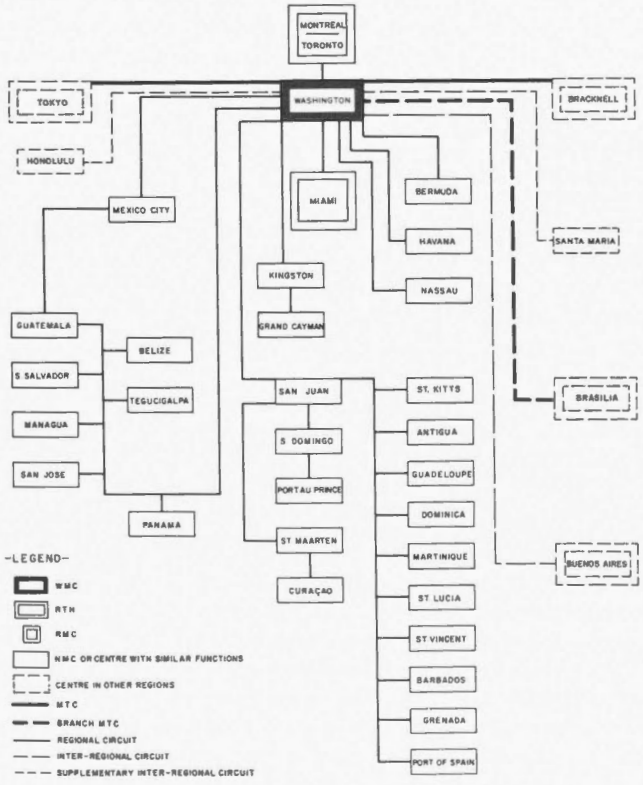

Figure 3. The meteorological telecommunication system for Mexico, Central America and the Carribbean.

Region 4 covers all of North and Central America but for this talk we are only interested in that portion dealing with Mexico, Central America and the Caribbean. The WMO has done an excellent job of establishing the telecommunications and meteorological networks throughout the region (Fig. 3). Each capital has a station that provides upper air measurements of temperature, pressure and relative humidity and winds up to approximately 10 millibars. Each of these national stations is usually tied to a regional network linked by a single side band radio network. The communications system is continually being expanded both in space and in quality. For example, many stations in the network in Central America and the Caribbean are equipped for radio FAX transmissions which enable photographs and other visual data to be transmitted quickly and efficiently. Currently the stations in the network are being outfitted to make pollution measurements.

I hope this brief description has provided you with some insight into what is a vast and complex world weather watch system.

Ing. R. Salgueiro:

Muchas gracias Sr. Callahan por su información sobre datos meteorológicos en América Latina vamos a continuar con el siguiente expositor Dr. G. Lachapelle quien nos va a hablar de **"Geodesia Física Aplicada del Conocimiento Geodésico del Canadá".**

Dr. G. Lachapelle:

The task of the Geodetic Survey of Canada Division of the Surveys and Mapping Branch, Department of Energy, Mines and Resources, is to establish basic reference systems of position and elevation for all purposes, including mapping, and to determine the configuration of that territory with respect to the overall figure of the earth (Moore, 1975). The major task at present is the improvement and readjustment of the primary horizontal framework and the extension and integration of the secondary horizontal control (McLellan, 1967). The target date for this Canadian readjustment is 1977. The information and experience gained during and after this project will be used for the readjustment of the North American horizontal framework scheduled to take place in 1983.

As a part of the requirements for the 1977 Canadian adjustment and the 1983 North American adjustment, a Geoid Project has been initiated at Geodetic Survey. Its objective is to provide geoid undulations and deviations of the vertical in Canada using all data available for this purpose. Three types of data have been considered up to now: potential coefficients derived from a satellite or a combined satellite-gravimetric solution, surface gravity anomalies and astrogeodetic deviations of the vertical. While the first two types of data refer to a geocentric reference system, the third type, i.e. astrogeodetic deviations of the vertical, refers in principle to a non-geocentric system. However, this difficulty can now be easily overcome because the 1977 Canadian Geodetic Reference System (abbreviated as CGS77 in the sequel) will be defined through the satellite Doppler system (Kouba, 1976) which is, in practice, geocentric. Since the relation between CGS77 and the geocentric system is known, it is possible to transform astrogeodetic deviations to a geocentric system, evaluate geoid undulations and deviations of the vertical at all points where required and transform these quantities onto CGS77.

Several methods are available for combining potential coefficients with surface gravity data in order to evaluate geoid undulations (e.g. Vincent *et al.*, 1975; Rapp *et al.*, 1975). These methods make use of Stokes' formula applied on mean gravity anomalies. The method used here and summarized in the next Section also makes use of Stokes' formula for evaluating geoid undulations and Vening Meinesz's formula for evaluating deviations of the vertical. However, Stokes' and Vening Meinesz' formulae are used here only to calculate the effect of the outer-zone ($0°.7 \leqslant \psi_{oz} \leqslant 20°$). The effect of the inner-zone ($\psi_{iz} \leqslant 1°$) is calculated by using least squares collocation applied on point gravity anomalies. This method is particularly advantageous when evaluating deviations of the vertical because the contribution of the inner-zone on the deviations is very important. Another advantage is that, in the inner-zone, gravity anomalies and astrogeodetic deviations of the vertical can be used together to evaluate directly the effect of that inner-zone on the geoid undulation and deviation of the vertical.

Evaluation of geoid undulations and deviations of the vertical using a combined integral formulae and collocation approach.

The method summarized here is described in more detail in (Lachapelle, 1976b). At any point, the geoid undulation N and the two components of the deviation of the vertical (ξ-meridian component and η-prime vertical component) can be evaluated as follows

$$N = N_0 + N_1 + N_2 + N_3 \tag{1}$$

$$\xi = \xi_1 + \xi_2 + \xi_3 \tag{2}$$

$$\eta = \eta_1 + \eta_2 + \eta_3 \tag{3}$$

with

$$N_1(\phi,\lambda) = R \sum_{n=2}^{\ell} \sum_{m=0}^{n} \left(\bar{J}^*_{nm} \bar{R}_{nm}(\phi,\lambda) + \bar{K}_{nm} \bar{S}_{nm}(\phi,\lambda) \right) \tag{4}$$

$$\xi_1(\phi,\lambda) = -\sum_{n=2}^{\ell} \sum_{m=0}^{n} \left(\bar{J}^*_{nm} D_\phi \bar{R}_{nm}(\phi,\lambda) + \bar{K}_{nm} D_\phi \bar{S}_{nm}(\phi,\lambda) \right) \tag{5}$$

$$\eta_1(\phi,\lambda) = -\frac{1}{\cos\phi} \sum_{n=2}^{\ell} \sum_{m=0}^{n} \left(\bar{J}^*_{nm} D_\lambda \bar{R}_{nm}(\phi,\lambda) + \bar{K}_{nm} D_\lambda \bar{S}_{nm}(\phi,\lambda) \right) \tag{6}$$

$$\begin{bmatrix} N_2 \\ \xi_2 \\ \eta_2 \end{bmatrix} = \begin{bmatrix} \underline{C}_{Nx} \\ \underline{C}_{\xi x} \\ \underline{C}_{\eta x} \end{bmatrix} \underline{C}_{xx}^{-1} \underline{x}'(\sigma_1) \tag{7}$$

$$N_3 = \frac{R}{4\pi\bar{\gamma}} \iint_{\phi_2} (\Delta g - \Delta g_1 - \Delta g_p)\, S(\psi)\, d\sigma \tag{8}$$

$$\begin{Bmatrix} \xi_3 \\ \eta_3 \end{Bmatrix} = \frac{1}{4\pi\bar{\gamma}} \iint_{\phi_2} (\Delta g - \Delta g_1 - \Delta g_p) \frac{dS(\psi)}{d\psi} \begin{Bmatrix} \cos\alpha \\ \sin\alpha \end{Bmatrix} d\phi \tag{9}$$

where

$$\underline{x}'(\sigma_1) = \underline{x}(\sigma_1) - \underline{x}_1(\sigma_1) \tag{10}$$

$$D_\phi \bar{R}_{nm}(\phi,\lambda) = \frac{\partial \bar{R}_{nm}(\phi,\lambda)}{\partial\phi} = \cos m\lambda \; \frac{\partial \bar{P}_{nm}(\sin\phi)}{\partial\phi} \tag{11a}$$

$$D_\phi \bar{S}_{nm}(\phi,\lambda) = \frac{\partial \bar{S}_{nm}(\phi,\lambda)}{\partial\phi} = \sin m\lambda \; \frac{\partial \bar{P}_{nm}(\sin\phi)}{\partial\phi} \tag{11b}$$

$$D_\lambda \bar{R}_{nm}(\phi,\lambda) = \frac{\partial \bar{R}_{nm}(\phi,\lambda)}{\partial\lambda} = -m\sin m\lambda \; \bar{P}_{nm}(\sin\phi) \tag{11c}$$

$$D_\lambda \bar{S}_{nm}(\phi,\lambda) = \frac{\partial \bar{S}_{nm}(\phi,\lambda)}{\partial\lambda} = m\cos m\lambda \; \bar{P}_{nm}(\sin\phi) \tag{11d}$$

$$\Delta g_1(\phi,\lambda) = \bar{\gamma} \sum_{n=2}^{\ell} (n-1) \sum_{m=0}^{n} \left(\bar{J}^*_{nm} \bar{R}_{nm}(\phi,\lambda) + \bar{K}_{nm} \bar{S}_{nm}(\phi,\lambda) \right) \tag{12}$$

R is the mean radius of the earth, N_o the (unknown) zero-order undulation of the geoid, $\bar{J}^*_{nm} = \bar{J}_{nm} - \bar{J}'_{nm}$ with $\bar{J}'_{nm}$ being the potential coefficients of the normal reference field (in practice, all $\bar{J}'_{nm}$ are zero except $\bar{J}'_{20}$ $\bar{J}'_{40}$ and $\bar{J}'_{60}$), $\bar{J}_{nm}$ and $\bar{K}_{nm}$ fully normalized potential coefficients, $\bar{P}_{nm}$ fully normalized associated Legendre funcions, ℓ the maximum degree of potential coefficients, $\bar{\gamma}$ the average gravity value over the earth, $S(\psi)$ the Stokes' function, $dS(\psi)/d\psi$ Vening Meinesz's function, $x(\sigma_1)$ the vector containing the measurements (free-air gravity anomalies and/or geocentric astrogeodetic components of the deviation of the vertical) available in the inner-zone σ_1 and referring to the chosen ellipsoid, $\underline{x}_1(\sigma_1)$ the corresponding quantities derived from the potential coefficients using equations (5), (6) and (12). The measurements $\underline{x}'(\sigma_1)$ refer then to the surface implied by the set of potential coefficients. $\underline{C}^T_{Nx}$ is the signal crosscovariance vector between N and $\underline{x}'(\sigma_1)$, $\underline{C}_{\xi x}$ the signal crosscovariance vector between ξ and $\underline{x}'(\sigma_1)$, $\underline{C}_{\eta x}$ the signal crosscovariance vector between η and $\underline{x}'(\sigma_1)$, $\underline{C}_{xx}$ the covariance matric of $\underline{x}'(\sigma_1)$ which can be written as

$$\underline{C}_{xx} = \underline{C}_{s's'} + \underline{C}_{nn} \tag{13}$$

where $\underline{C}_{s's'}$ is the signal covariance matrix of $\underline{x}'(\sigma_1)$ and $\underline{C}_{nn}$ its error covariance matrix. N_2, ξ_2, η_2 are evaluated by least squares collocation (Moritz, 1972). Vectors $\underline{C}^T_{Nx}$ $\underline{C}^T_{\xi x}$, $\underline{C}^T_{\eta x}$ and matrix $\underline{C}_{s's'}$ are calculated from the autocovariance function $K(T_A,T_B)$ of the free-air anomalous potential which is related to the autocovariance function $C(\Delta g_A, \Delta g_B)$ of the free-air gravity anomalies. Since we are dealing with measurements $\underline{x}'(\sigma_1)$ whose first harmonics up to degree ℓ have been removed, the corresponding harmonics of the covariance function used to calculate $\underline{C}^T_{Nx}$, $\underline{C}^T_{\xi x}$, $\underline{C}^T_{\eta x}$ and $\underline{C}_{s's'}$ are to be removed as well. This is done by

omitting the first harmonics up to degree ℓ in the spherical harmonics expansion of $C(\Delta g_A, \Delta g_B)$ (Lachapelle, 1975):

$$C^r(\Delta g_A, \Delta g_B) = \sum_{n=\ell+1}^{\infty} c_n \left[\frac{R_b^2}{r_A r_B}\right]^{n+2} P_n(\cos\psi_{AB}) \quad (14)$$

where $C^r(\Delta g_A \Delta g_B)$ is then the covariance function of the "residual" gravity anomalies, i.e. the gravity anomalies referring to the surface implied by the potential coefficients up to degree and order ℓ, c_n are anomaly degree variances, $P_n(\cos\psi_{AB})$ conventional Legendre polynomials, r_A and r_B geocentric radii to points A and B and R_b the radius of the so-called "Bjerhammer sphere" (Tscherning *et al.*, 1974). When the low harmonics are completely removed from the covariance function as in equation (14), one assumes that the potential coefficients used to calculate c_n and $x_1(\sigma_1)$ are error free. Otherwise, errors in $\bar{J}_{nm}$, $\bar{K}_{nm}$ can be taken into account (Meissl, 1971).

Δg_P in equation (8) is the gravity anomaly at P, predicted using the data $\underline{x}'(\sigma_1)$ located in the inner-zone σ_1:

$$\Delta g_P = \underline{C}_{gx}^T \underline{C}_{xx}^{-1} \underline{x}'(\sigma_1) \quad (15)$$

where $\underline{C}_{gx}$ is the signal crosscovariance vector between Δg_P and $\underline{x}'(\sigma_1)$. Δg_P must be removed from the measured free-air gravity anomaly because the least squares collocation equation (7) does not only predict the effect of the gravity field located in the inner-zone but implicitly predicts the gravity anomaly field everywhere on the terrestrial sphere except at the very measuring points $\underline{x}'(\sigma_1)$ and gives the total effect of that predicted gravity anomaly field; cf. to (Lachapelle, 1976b) for further details.

In principle, it would be easier to evaluate the effect of zones σ_1 and σ_2 together by simply applying least squares collocation on all measurements located in zones σ_1 and σ_2, i.e. by replacing $\underline{x}'(\sigma_1)$ by $\underline{x}(\sigma_1+\sigma_2)$ in equation (7). Thus, it would be possible to use astrogeodetic deviations located in the outer-zone σ_2 as well while this is not possible with the method described above. However, the number of measurements would be relatively large (up to several thousands) and the cost in terms of computer time would increase tremendously. This is the drawback with least squares collocation. When using the combined approach, the time consuming least squares collocation method provides an accurate solution for the important contribution of the inner-zone using up to a few hundred measurements located in that zone while the less time consuming Stokes' and Vening Meinesz's formulae provide the less critical contribution of the outer-zone. This combined method illustrates well the fact that least squares collocation and integral formulae complement each other (Moritz, 1976).

In practice, formulae (8) and (9) are replaced by summations over mean gravity anomalies located in the outer-zone σ_2. The size of this zone depends upon the degree ℓ up to which the potential coefficients are used.

Comparison of predicted deviations with astrogeodetic deviations of the vertical.

The method described in the previous Section was used to evaluate both components of the deviation of the vertical as some 223 stations scattered all over continental Canada except in the Rocky Mountains area. Positions (ϕ and λ) of these stations are given in Table I together with the predicted and geocentric astrogeodetic components of the deviation of the vertical. The differences ($\delta\xi$ and $\delta\eta$) between astrogeodetic and predicted components are also tabulated.

TABLE I
Comparison of Predicted Deviations with Astrogeodetic Deviations of the Vertical in Canada

NBR	LATITUDE	LONGITUDE	ξ_a	η_a	ξ_p	η_p	$\delta\xi$	$\delta\eta$
644	60 56 13.	283 10 27.	−4.04	−8.69	−6.51	−8.02	2.47	−.67
645	60 1 32.	283 23 48.	−.64	−11.13	−1.15	−10.26	.51	−.87
651	58 51 29.	283 22 18.	−4.28	−7.27	−5.84	−5.12	1.56	−2.15
395	55 26 37.	287 23 21.	.28	−6.23	−.45	−5.51	.73	−.72
396	55 53 53.	284 42 34.	.82	−4.80	.51	−4.39	.31	−.41
397	56 37 17.	284 44 16.	.80	−5.29	.53	−4.86	.27	−.43
277	56 47 39.	291 3 33.	−1.24	−6.87	−2.45	−6.85	1.21	−.02
278	58 5 48.	291 35 1.	−2.58	−11.67	−3.29	−12.28	.71	.61
424	57 53 48.	287 19 36.	−1.71	−8.42	−2.08	−7.15	.37	−1.27
425	58 12 15.	289 44 29.	1.14	.15	.29	1.50	.85	−1.35
535	61 33 24.	282 32 10.	−4.31	−7.02	−4.87	−8.19	.56	1.17
601	61 16 59.	287 29 45.	−.56	−.90	−2.60	−.81	2.04	−.09
602	60 16 57.	289 4 48.	−4.66	−5.29	−6.57	−4.32	1.91	−.97
654	61 36 0.	283 29 52.	1.88	−15.78	−1.58	−15.19	3.46	−.59
655	61 15 18.	282 35 44.	.40	−9.23	−.72	−10.65	1.12	1.42
643	59 15 31.	283 13 13.	−1.01	−6.79	−2.41	−5.67	1.40	−1.12
658	57 59 12.	383 47 31.	−4.54	−7.66	−5.59	−6.15	1.05	−1.51
653	58 23 21.	383 25 35.	−4.26	−7.25	−4.88	−7.20	.62	−.05
652	60 27 56.	283 5 23.	−1.35	−12.52	−2.05	−11.86	.70	−.66
783	63 0 55.	247 55 58.	−.82	2.82	−1.82	4.27	1.00	−1.65
784	64 0 34.	246 3 17.	−4.40	3.81	−5.25	4.25	.85	−.44
785	64 58 6.	247 55 7.	−2.39	7.17	−2.83	7.00	.44	.17
786	64 58 52.	245 40 52.	−1.81	7.20	−2.79	4.44	.98	2.76
787	63 5 58.	240 9 23.	1.26	9.37	.64	10.22	.62	−.85
788	66 59 35.	247 55 16.	1.57	6.85	1.15	5.90	.42	.95

TABLE I (Cont'd)
Comparison of Predicted Deviations with Astrogeodetic Deviations of the Vertical in Canada

NBR	LATITUDE	LONGITUDE	ξ_a	η_a	ξ_p	η_p	$\delta\xi$	$\delta\eta$
789	65 37 40.	241 31 7.	−1.27	5.45	−1.08	5.02	−.19	.43
790	63 57 21.	248 1 12.	−3.03	8.19	−3.43	7.77	.40	.42
760	68 20 45.	223 52 7.	11.98	6.60	8.84	6.05	3.14	.55
438	68 35 37.	248 53 23.	−13.79	11.92	−11.62	10.96	−2.17	.96
439	68 49 37.	250 28 56.	−6.30	13.94	−6.34	13.05	.04	.89
444	49 37 24.	249 38 13.	2.62	−4.06	2.29	−3.68	.33	−.38
387	52 24 16.	257 21 25.	8.10	2.96	7.57	1.99	.53	.97
334	50 6 30.	262 7 32.	8.34	7.38	5.81	4.55	2.53	2.83
850	48 45 7.	273 39 40.	−1.25	8.38	−1.05	5.79	−.20	2.59
816	45 20 21.	279 58 20.	1.26	−6.71	.51	−3.82	.75	−2.89
652	60 27 56.	283 5 23.	−1.35	−12.52	−2.05	−11.86	.70	−.66
9574	49 7 47.	293 31 9.	14.12	−15.30	13.02	−12.71	1.10	−2.59
9999	46 46 50.	288 43 12.	−3.69	−1.91	−4.10	−.56	.41	−1.35
294	50 16 27.	295 13 24.	−11.09	−5.09	−7.42	−5.05	−3.67	−.04
724	44 52 35.	294 41 36.	−4.19	−3.00	−1.66	−3.08	−2.53	.08
118	47 34 37.	290 37 1.	4.31	−8.23	3.14	−4.94	1.17	−3.29
261	49 59 31.	302 16 38.	7.56	−20.53	5.23	−21.35	2.33	.82
262	51 37 19.	304 5 22.	−.83	−15.76	−1.02	−15.56	.19	−.20
265	48 15 33.	301 12 0.	2.63	−18.52	1.94	−15.66	.69	−2.86
279	47 28 26.	304 32 24.	−4.81	−9.53	−2.86	−9.31	−1.95	−.22
398	53 48 13.	300 8 58.	−.53	−11.71	−2.46	−11.06	1.93	−.65
795	53 18 30.	299 38 7.	7.94	−10.51	7.03	−11.90	.91	1.39
827	45 54 17.	287 28 23.	9.23	−10.49	9.42	−9.37	−.19	−1.12
722	45 1 2.	295 28 50.	−7.73	−3.55	−7.30	−.75	−.43	−2.80
656	45 37 48.	284 34 40.	−1.92	−2.35	−.96	−2.57	−.96	.22
657	45 38 33.	284 3 25.	−3.14	−2.07	−1.59	−2.10	−1.55	.03
772	46 8 59.	289 43 19.	2.02	−5.35	1.99	−5.66	.03	.31
773	46 7 24.	289 23 57.	.70	−4.57	.21	−4.07	.49	−.50
774	46 42 25.	288 44 42.	−1.03	−2.31	−.68	−1.67	−.35	−.64
775	46 23 56.	287 43 10.	−.16	−5.32	.20	−4.83	−.36	−.49
776	46 31 8.	287 57 59.	−1.46	−4.50	−.59	−4.46	−.87	−.04
798	48 12 25.	293 5 24.	−1.20	−7.45	−7.94	−10.09	6.74	2.64
799	45 18 43.	287 45 28.	−3.39	−.59	−4.00	−.30	.61	−.29
828	46 11 35.	287 38 4.	3.22	−8.05	3.45	−7.28	−.23	−.77
829	45 38 48.	287 38 32.	5.77	−10.32	4.49	−8.48	1.28	−1.84
830	45 25 28.	288 24 57.	−.41	−5.49	−.73	−2.75	.32	−2.74
831	45 26 51.	288 52 45.	2.18	−1.12	.72	−3.05	1.46	1.93
832	45 56 53.	289 9 42.	4.33	−1.62	3.06	−.46	1.27	−1.16
833	46 4 7.	288 43 37.	3.01	.91	1.08	2.33	1.93	−1.42
834	46 20 9.	288 51 29.	8.04	−3.81	6.66	−3.03	1.38	−.78
646	44 57 48.	283 53 47.	.58	−4.82	.57	−3.28	.81	−1.54
647	45 13 22.	284 59 4.	3.14	−8.88	4.21	−6.83	−1.07	−2.05
648	44 44 29.	283 9 40.	−.44	−4.17	−1.16	−1.94	.72	−2.23
649	45 2 44.	283 19 50.	−.71	−1.26	−.52	.54	−.19	−1.80
650	45 4 6.	284 27 2.	1.97	−4.33	.43	−3.33	1.54	−1.00
719	42 57 20.	277 35 57.	−.81	.47	−.35	.80	−.46	−.33
720	42 45 59.	277 33 30.	.08	−.20	−.09	.69	.17	−.89
721	42 37 7.	277 33 5.	1.24	.37	.44	.80	.80	−.43
728	43 1 17.	277 41 36.	−.31	−.21	.13	.65	−.44	−.86
729	43 43 24.	280 15 54.	.11	1.72	−.51	1.90	.62	−.18
730	43 32 27.	279 50 46.	.03	1.07	−.63	1.91	.66	−.84
766	43 14 4.	280 54 59.	5.58	−.93	4.17	−1.22	1.41	.29
767	43 3 0.	280 41 31.	3.70	−2.60	3.11	−1.50	.59	−1.10
768	42 52 56.	280 19 4.	2.01	−1.88	.62	−.74	1.39	−1.14
769	42 58 29.	280 2 34.	2.53	−.85	1.14	−.13	1.39	−.72
770	42 54 14.	279 8 10.	−.44	.19	−1.17	.84	.73	−.65
771	42 52 8.	279 31 41.	.15	.47	−.09	.78	.24	−.31
807	44 26 57.	279 51 28.	1.78	1.07	2.24	2.36	−.46	−1.29
808	43 52 51.	281 16 22.	−4.89	−.84	−4.05	.19	−.84	−1.03
810	43 56 17.	281 3 29.	−3.45	−1.38	−4.11	.05	.66	−1.43
811	43 51 15.	280 49 29.	−2.07	−.23	−2.60	.81	.53	−1.04

TABLE I (Cont'd)

Comparison of Predicted Deviations with Astrogeodetic Deviations of the Vertical in Canada

NBR	LATITUDE	LONGITUDE	ξ_a	η_a	ξ_p	η_p	$\delta\xi$	$\delta\eta$
812	44 22 17.	279 45 3.	2.77	1.93	3.09	3.19	−.32	− 1.26
813	43 54 37.	280 30 46.	−1.07	−1.13	−1.41	−.01	.34	−1.12
181	44 55 40.	280 42 50.	−2.23	−1.82	−1.90	−1.48	−.33	−.34
817	45 13 52.	278 21 42.	2.51	−3.23	2.47	−1.71	.04	−1.52
818	45 0 1.	278 47 4.	3.85	−2.09	1.33	−.79	2.52	−1.30
819	43 58 58.	278 55 50.	1.44	−2.01	2.11	−.68	−.67	−1.33
820	43 44 1.	279 2 43.	.81	−1.03	.75	.11	.06	−1.14
821	43 20 25.	278 59 27.	.21	−.08	−.85	1.34	1.06	−1.42
822	44 24 46.	283 49 30.	−1.50	−3.11	−1.24	−2.32	−.26	−.79
823	44 40 57.	283 54 20.	−1.97	−4.56	−.54	−3.09	−1.43	−1.47
704	45 27 25.	295 36 28.	−3.68	−3.56	−2.58	−3.61	−1.10	.05
705	45 33 11.	296 46 33.	−1.83	−3.73	−.92	−3.54	−.91	−.19
706	45 25 43.	298 9 2.	−2.87	−2.58	−1.38	−2.54	−1.49	−.04
707	44 38 17.	296 29 23.	−3.68	−4.48	−1.96	−4.44	−1.72	−.04
717	44 36 37.	294 34 6.	−3.47	−4.96	−2.41	−.21	−1.06	−4.75
718	44 28 2.	295 29 56.	.47	−.91	.52	−.52	−.05	−.39
725	44 19 9.	295 18 37.	−3.21	−1.96	−1.33	−1.09	−1.88	−.87
726	44 15 40.	295 26 33.	−2.22	−2.06	−2.08	−.90	−.14	−1.16
780	44 55 27.	297 30 0.	−5.82	−7.03	−3.96	−4.76	−1.86	−2.27
781	44 44 26.	296 40 4.	−2.65	−4.77	−2.48	−3.85	−.17	−.92
835	43 54 59.	293 57 33.	−3.26	3.52	−1.69	3.76	−1.57	−.24
836	43 57 36.	294 3 57.	−1.65	2.63	−1.79	2.35	.14	.28
158	48 46 41.	279 13 19.	1.99	−1.60	1.37	−.62	.62	−.98
379	48 54 3.	272 22 50.	.99	−.06	3.89	1.64	−2.90	−1.70
809	48 33 56.	278 37 44.	−.94	1.40	−1.12	2.48	.18	−1.08
814	49 33 15.	276 59 24.	1.26	−2.65	2.51	−1.81	−1.25	−.84
815	48 1 35.	275 15 53.	2.62	−3.46	−:42	−.70	3.04	−2.76
837	46 13 30.	277 34 6.	−7.76	−.23	−5.19	−.86	−2.57	.63
838	46 16 28.	276 34 16.	−.97	1.89	−.89	1.51	−.08	.38
839	46 12 4.	276 2 41.	−.62	3.01	.40	2.26	−1.02	.75
840	46 32 13.	275 41 3.	.57	3.15	−.09	2.59	.66	.56
841	47 4 31.	275 37 1.	3.40	−2.18	1.61	.25	1.79	−2.43
842	46 52 2.	276 22 59.	−1.37	−1.49	−2.15	−2.38	.78	.89
843	47 49 43.	275 5 56.	.62	−1.95	1.50	−2.71	−.88	.76
844	48 17 47.	275 6 44.	6.63	−.55	4.08	−1.42	2.55	.87
845	47 24 53.	275 26 28.	−.21	−4.74	−1.55	−1.13	− 1.34	−3.61
846	48 37 47.	274 48 35.	2.68	−.21	2.04	.07	.64	−.28
847	48 50 50.	274 12 31.	1.55	2.82	1.94	1.33	−.39	1.49
848	48 23 27.	274 14 42.	3.40	−2.10	3.14	.22	.26	−2.32
849	48 45 14.	273 24 53.	−1.45	−4.26	−1.12	−2.69	−.33	−1.57
851	49 3 48.	272 3 44.	1.10	3.19	−.16	.08	1.26	3.11
852	49 1 7.	271 33 46.	−1.46	4.07	−.49	4.14	−.97	−.07
853	50 20 11.	270 51 24.	3.94	4.56	2.88	4.73	1.06	−.17
854	49 38 30.	271 31 16.	1.14	3.54	.35	1.21	.79	2.33
855	50 17 58.	269 17 14.	.64	1.05	.45	−.18	.19	1.23
856	50 8 59.	269 48 44.	3.13	−.06	2.27	−.33	.86	.27
857	49 45 32.	266 54 51.	3.25	3.50	1.34	3.31	1.91	.19
858	50 5 21.	267 59 59.	2.37	6.21	1.28	3.85	1.09	2.36
859	50 10 23.	369 2 6.	3.50	.57	2.84	−.47	.66	1.04
860	49 50 37.	266 33 31.	−.84	4.25	−.99	3.37	.15	.88
862	49 59 35.	265 55 42.	.99	2.35	.71	1.86	.28	.49
865	50 3 37.	265 12 16.	1.62	6.35	1.63	4.30	−.01	2.05
866	50 1 40.	267 31 50.	2.35	4.04	−.41	3.60	2.76	.44
867	46 11 36.	276 59 44.	−1.44	−2.96	−1.21	−.84	−.23	−2.12
868	46 7 44.	278 15 30.	−2.82	.68	−2.78	1.40	−.04	−.72
881	45 56 26.	282 27 18.	.85	−3.29	2.25	−1.37	−1.40	−1.92
882	47 40 10.	280 24 11.	4.00	2.83	3.92	4.53	.08	−1.70
883	48 8 53.	279 57 45.	−1.13	.82	−1.33	1.55	.20	−.73
884	48 11 11.	280 36 3.	−3.08	1.55	−1.45	1.78	−1.63	−.23
885	48 22 38.	279 43 45.	2.37	−1.37	2.40	−1.22	−.03	−.15
886	48 27 57.	278 41 48.	1.00	−.91	.92	1.30	.08	−2.21

TABLE I (Cont'd)

Comparison of Predicted Deviations With Astrogeodetic Deviations of the Vertical in Canada

NBR	LATITUDE	LONGITUDE	ξ_a	η_a	ξ_p	η_p	$\delta\xi$	$\delta\eta$
887	48 54 6.	279 22 14.	4.70	−1.60	3.76	1.06	.94	−2.66
333	50 3 42.	263 26 1.	4.94	4.24	4.48	2.06	.46	2.18
335	50 0 23.	262 33 42.	2.97	7.35	3.42	6.06	−.45	1.29
336	49 56 9.	260 35 52.	4.23	4.29	4.58	2.24	−.35	2.05
337	49 52 12.	259 59 34.	3.01	3.86	4.17	.96	−1.16	2.90
338	49 57 9.	263 6 46.	3.40	2.83	2.94	2.99	.46	−.16
339	49 9 54.	260 41 29.	1.58	5.38	2.38	5.17	−.80	.21
340	49 11 57.	260 8 25.	3.69	3.74	4.46	2.91	−.77	.83
341	49 1 16.	260 19 56.	2.70	6.38	3.95	5.45	−1.25	.93
342	49 42 33.	260 9 36.	6.79	3.04	6.92	2.11	−.13	.93
343	50 3 23.	261 12 39.	5.11	4.61	5.23	4.03	−.12	.58
344	50 3 55.	261 41 29.	4.82	6.52	4.71	5.75	.11	.77
345	49 17 15.	260 20 36.	2.28	4.86	3.12	3.87	−.84	.99
346	49 21 27.	260 6 40.	3.80	2.47	3.94	1.84	−.14	.63
347	49 54 9.	260 52 9.	4.49	3.71	4.55	3.12	−.06	.59
348	49 29 29.	260 22 7.	4.23	3.08	4.36	2.80	−.13	.28
349	49 0 56.	260 40 12.	1.79	6.23	3.60	5.76	−1.81	.47
350	49 31 42.	260 5 34.	4.00	2.52	4.58	1.21	−.58	1.31
366	50 9 38.	260 38 59.	1.33	−.50	3.76	3.86	−2.43	−4.36
367	49 15 28.	261 26 44.	.37	4.59	1.62	4.68	−1.25	−.09
368	49 15 57.	262 30 5.	3.38	5.80	4.22	5.00	−.84	.80
369	49 17 53.	263 4 1.	2.92	3.26	3.28	2.89	−.36	.37
370	49 13 29.	261 5 17.	−1.08	4.43	.17	4.15	−1.25	.28
371	49 4 44.	263 54 30.	1.39	3.43	2.81	2.75	−1.42	.68
372	49 28 22.	263 28 57.	1.67	3.05	2.66	2.77	−.99	.28
373	51 13 9.	260 7 59.	6.34	5.74	5.71	4.45	.63	1.29
374	51 21 32.	258 38 58.	−1.12	5.57	1.22	4.11	−2.34	1.46
375	51 12 51.	259 29 43.	6.35	10.12	6.24	8.10	.11	2.02
376	51 9 8.	259 4 39.	5.03	9.74	4.36	8.85	.67	.89
377	50 22 55.	260 26 11.	2.56	1.16	4.21	6.82	−1.54	−5.66
378	50 51 6.	260 28 2.	6.12	1.39	9.19	7.40	−3.07	−6.01
383	50 35 39.	260 31 51.	5.76	7.68	6.77	8.19	−1.01	−.51
426	51 33 47.	258 29 20.	1.16	5.03	1.49	5.19	−.33	−.16
861	49 50 22.	264 36 6.	.31	2.15	.56	2.73	−.25	−.58
863	49 39 18.	263 47 59.	1.64	3.26	1.01	2.77	.63	.49
864	50 8 30.	264 19 12.	4.43	1.67	4.47	1.21	−.04	.46
380	51 37 22.	257 40 36.	4.78	2.55	5.37	−.30	−.59	2.85
381	51 32 39.	258 17 37.	−2.08	7.69	.62	5.29	−2.70	2.40
384	51 56 37.	257 27 59.	3.27	4.38	2.35	2.14	.92	2.24
385	52 13 40.	257 25 34.	4.93	2.36	3.23	1.94	1.70	.42
386	52 28 13.	256 59 45.	7.02	5.33	6.73	4.10	.29	1.23
388	51 30 35.	257 48 21.	3.22	1.11	3.35	−.13	−.13	1.24
389	51 41 10.	258 8 18.	1.42	3.17	2.23	1.58	−.81	1.59
427	51 21 28.	257 59 42.	2.66	3.56	2.28	2.55	.38	1.01
428	51 59 52.	257 1 38.	.22	4.06	1.38	3.77	−1.16	.29
429	52 9 31.	256 28 5.	2.21	2.39	2.37	2.55	−.16	−.16
430	52 29 8.	256 32 37.	6.07	4.96	5.51	4.04	.56	.92
431	52 24 28.	256 2 60.	3.21	2.39	3.26	2.22	−.05	.17
432	52 41 46.	255 56 17.	5.07	3.09	5.00	2.73	.07	.36
433	53 1 4.	255 24 48.	3.96	.94	3.93	.58	.03	.36
434	53 5 55.	254 48 8.	4.85	2.36	5.05	2.25	−.20	.11
435	52 46 57.	254 31 27.	3.68	4.42	4.04	3.39	−.36	1.03
474	53 17 51.	250 17 43.	5.15	.86	4.44	−1.10	.71	1.96
475	53 3 24.	250 33 30.	5.36	.49	4.60	−.93	.76	1.42
476	52 59 14.	251 7 4.	7.11	.70	5.69	−.84	1.42	1.54
477	52 48 1.	251 25 1.	7.66	.21	6.11	.33	1.55	−.12
478	52 46 37.	251 42 5.	3.79	1.36	5.22	−.14	−1.43	1.50
622	51 29 10.	250 0 47.	1.39	.43	.07	−.66	1.32	1.09
735	52 28 1.	251 27 24.	4.15	3.35	2.25	−.01	1.90	3.36
736	51 54 15.	250 48 26.	.56	2.71	−.31	.96	.87	1.75
737	51 59 16.	251 8 40.	1.93	−.48	−.46	−1.99	2.39	1.51

TABLE I (Cont'd)

Comparison of Predicted Deviations With Astrogeodetic Deviations of the Vertical in Canada

NBR	LATITUDE	LONGITUDE	ξ_a	η_a	ξ_p	η_p	$\delta\xi$	$\delta\eta$
738	51 41 34.	250 27 25.	1.03	2.63	.09	.99	.94	1.64
761	51 7 50.	255 6 38.	3.31	.34	2.87	1.14	.44	−.80
762	52 41 50.	252 58 59.	3.80	.40	3.45	.59	.35	−.19
763	52 37 57.	253 20 49.	5.10	−1.36	4.22	−1.48	.88	.12
764	52 39 8.	253 35 24.	4.28	−.41	3.66	−.73	.62	.32
765	52 38 35.	253 49 45.	4.12	1.03	3.27	.77	.85	.26
826	52 32 38.	251 3 33.	4.75	.94	3.86	−.55	.89	1.49
872	49 0 43.	252 11 34.	1.70	.67	1.33	−.20	.37	.87
873	49 11 11.	252 7 43.	2.12	.96	1.06	.48	1.06	.48
874	49 5 39.	251 8 27.	.82	.64	1.52	−.16	−.70	.80
875	49 6 5.	250 27 20.	.42	−.42	1.11	−2.35	−.69	1.93
876	49 8 46.	254 12 20.	2.11	.56	2.77	.67	−.66	−.11
877	49 7 7.	253 43 24.	.97	−.42	1.65	−1.01	−.68	.59
878	49 17 25.	252 45 6.	1.83	−.85	1.59	−.55	.24	−.30
879	49 10 43.	253 10 5.	2.12	.46	1.17	.33	.95	.13

The components of the deviation of the vertical were predicted using Goddard Earth Model 8 (GEM8) and surface gravity data. GEM8 is the latest set of potential coefficients complete up to degree and order 25 derived by Goddard Space Flight Center (Wagner *et al.*, 1976). It has been derived from a combination of satellite and 5° x 5° mean gravity anomalies. About 300,000 gravity measurements relatively well distributed (Gibb *et al.*, 1976) over approximately 80% of Canada and provided by the Gravity Division of the Earth Physics Branch were used for the computations. In addition to this, 340,000 gravity measurements covering the continental United States were kindly provided by National Geodetic Survey, U.S. National Oceanic and Atmospheric Administration. The Canadian and U.S. gravity data was not used as such but its distribution was first "regularized" by taking 5′ x 10′ (Canada) and 5′ x 5′ (United States) mean gravity anomalies. This produced two gravity files containing about 77,000 (Canada) and 74,000 (United States) gravity anomalies. These mean gravity anomalies of small blocks were considered as being point gravity anomalies in the subsequent computations. Two extra files were created from these "regularized" point values: one file containing 15′ x 15′ (ϕ < 50°) and 15′ x 30′(ϕ > 50°) mean gravity anomalies for both Canada and the United States and the other 1° x 1° mean gravity anomalies for both countries as well. All mean gravity anomalies (5′ x 5′, 5′ x 10′, 15′ x 15′, 15′ x 30′ and 1° x 1°) were evaluated by least squares collocation using basically the method described in (Lachapelle, 1975, Section 2-4). 5′ x 5′ and 5′ x 10′ mean anomalies were evaluated on Geodetic Reference System 1967 (GRS67), i.e. on the reference ellipsoid defined by GRS67 (International Association of Geodesy, 1970) and the corresponding gravity anomalies implied by GEM8 were then calculated using equation (12) and subtracted from the corresponding values referring to GRS67 in order to obtain "residual" gravity anomalies ($\Delta g - \Delta g_1$ according to equations 8 and 9) referring to the surface implied by GEM8. The 15′ x 15′, 15′ x 30′ and 1° x 1° mean gravity anomalies were calculated by using directly the residual gravity anomalies described above. These mean gravity anomalies are then residual mean gravity anomalies referring also to the surface implied by GEM8. All these residual gravity anomalies, point and mean, were used when evaluating equations (7), (8) and (9). All geoid undulations and deviations of the vertical evaluated in this Section and the next one were derived from residual gravity anomalies and GEM8. The method which was used to access rapidly the gravity data needed to evaluate either N, ξ or η for any point located in Canada or the United States is described in Section V. The normal gravity field used in all computations described in this paper is GRS67.

The radius of the inner-zone used to evaluate ξ,η at the stations was 0°.75. The number of point gravity anomalies available within each inner-zone varied between 50 and 270 with an average of about 130. The covariance function used to predict the effect of the inner-zone by least squares collocation was obtained by removing the first 25 harmonics from the global covariance function of (Tscherning *et al.*, 1974) at an altitude of 9.5 km. Such a covariance function has a C_0 value of 639 mgal^2. The technique used to derive such a local covariance function from a global one is described in (Lachapelle, 1975, Section 2.3). The signal covariances required between N, ξ, η, Δg were calculated at close intervals (2 arcsec proved to be adequate) using subroutine COVA described in (Tscherning *et al.*, 1974) and stored into vectors. The continuous recomputation of signal covariances was then avoided and this decreased the total computer time required by a factor of 2.5 to 3. The error variance of any point gravity anomaly was assumed to be 5 mgal^2; this value was entered in matrix $\underline{C}_{n\eta}$ (cf. equation 13).

The radius of the outer-zone σ_2 extended from 0°.75 to 8°. In the area bounded by 0°.75 $\leqslant \psi \leqslant$ 3°.00, 15′ x 30′ (σ > 50°) or 15′ x 15′ (σ_2< 50°) mean gravity anomalies were used while 1° x 1° mean values were used for the remaining part (3° $\leqslant \psi \leqslant$ 8°).

The predicted components of the deviation of the vertical are listed and compared with the corresponding geocentric astrogeodetic values in Table I. The astrogeodetic values were transformed onto the geocentric system by using the datum shift recommended for the CGS77 (Kouba, 1976) which is very close to the datum shift of NAD1927:

$\Delta X = -15$ m
$\Delta Y = 165$ m
$\Delta Y = 175$ m

The ξ,η values predicted on the basis of GEM8 and surface gravity data agree generally very well with the corresponding astrogeodetic values. The root mean square (rms) differences between astrogeodetic and predicted values are 1".26 (ξ) and 1".48 (η). This is remarkable if one considers that the astrogeodetic values used here are computed from preliminary geodetic and astronomical coordinates which are to receive many corrections, some of which are of systematic nature over large parts of the territory. When final astrogeodetic components become available rms differences are expected to decrease by a small amount.

When only the data located in the inner-zone are used together with least squares collocation, rms differences are 1".47 (ξ) and 1".69 (η) which indicates that the contribution of the outer-zone is significant. One way to improve the results would be to increase the radius of the inner-zone. However, increasing this radius by a factor of 2 would probably increase the cost in terms of computer time by a factor of 5. Therefore, according to the results obtained here, the present choice of the size of the inner-zone seems to be a reasonable compromise between accuracy and cost. The choice of the size of the inner-zone depend also on the density of the data.

In these computations, the astrogeodetic deviations were not used as input data because we were mostly interested here to predict ξ and η solely on the basis of GEM8 and surface gravity data. When time comes to predict all the deviations required for the final readjustment of the Canadian horizontal framework to take place in 1977, all astrogeodetic deviations available will be used as well as GEM8 and surface gravity data in order to predict geoid undulations and deviations required. We estimate that at least one astrogeodetic deviation of the vertical is available within a radius of 0°.75 to 1°.0 around 70% to 80% of the primary horizontal control stations in Canada. In such cases, the predicted components of the deviation should have an accuracy close to 1".

The components of the deviation were also predicted at some stations located in the Rocky Mountains area, namely in the province of Alberta. For a group of 27 stations located between latitudes 49° and 54° and longitudes 246° and 250°, the rms differences between predicted and astrogeodetic components were 1".5 (ξ) and 2".4 (η) when using the data located in the inner-zone only, 1".7 (ξ) and 4".4 (η) when including the effect of an outer-zone with $\psi_{oz} \leq 8°$, 1".9 (ξ) and 5". 0 (η) when including the effect of an outer-zone with $\psi_{oz} \leq 20°$. Systematic differences occurred between predicted and astrogeodetic components. It is particularly large in the case of η the mean difference is 2".0 when using the inner-zone only, 4".0 when using an outer-zone with $\psi_{oz} \leq 8°$ and 4".5 when using $\psi_{oz} \leq 20°$. The predicted components, instead of improving as expected, worsened when including the outer-zone and enlarging its radius. The reason for this is not fully understood at present. The fact that the outer-zone extends into the Rockies and that the gravity data coverage is poor or non-existant in some area has certainly something to do with it. Also, despite the fact that the gravity data coverage is relatively good in some limited areas, it is still poor when considering the topography. It is possible that mean gravity anomalies are biased if the gravity measurements are not well distributed as a function of the elevation. The present problem will be reconsidered in the next Section where Doppler derived undulations are compared with combined GEM8-gravimetric undulations.

Comparison of predicted geoid undulations with Doppler derived undulations

Geocentric geoid undulations can be derived at any Doppler station provided that the orthometric height of the station is known:

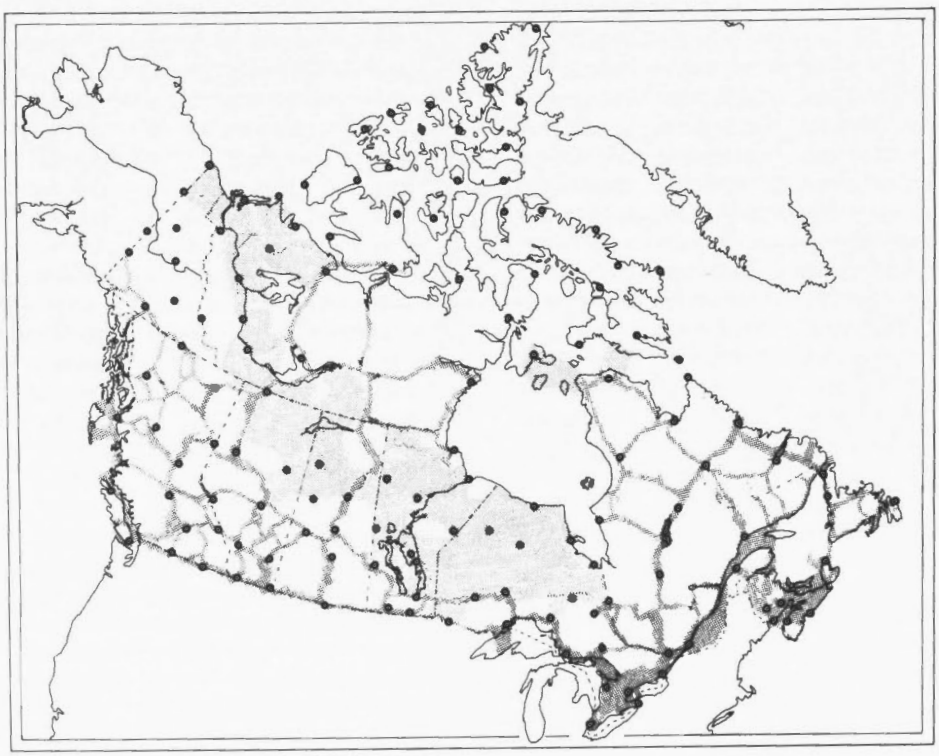

Figure 1. Doppler Stations in Canada.

$$N_D = h - H$$

where h is the geocentric ellipsoidal height of the Doppler station and N , the geocentric Doppler undulation. The quantity h is derived from observations on Doppler satellites. In Canada, 134 such Doppler undulations were available at the end of 1975. The method used to derive Doppler coordinates is described in (Kouba *et al.*, 1976). The location of these Doppler stations is shown in Fig. 1. Out of these 134 undulations, only 42 were derived using levelled orthometric heights. The orthometric heights of the remaining stations were obtained either by trigonometric or barometric levelling. All Doppler coordinates were scaled down by a factor of 1 ppm (Kouba, 1976) prior to the computation of h.

Geoid undulations can also be evaluated from a set of potential coefficients, surface gravity data and astrogeodetic deviations of the vertical. Referring to equation (1), N_1 is the contribution of the set of potential coefficients calculated according to equation (4), N_2 the contribution of an inner-zone of a certain radius calculated by using point gravity anomalies and/or astrogeodetic components of the deviation of the vertical (equation 7) and N_3, the contribution of the outer-zone calculated by applying Stokes' formula (equation 9) on mean gravity anomalies. N_o, the zero-order undulation of the geoid depend upon the normal reference field used during the computations. It can be calculated accurately provided that the real mass and potential of the earth are known. Since this is not the case, it is customary to replace equation (1) by

$$N^* = N_1 + N_2 + N_3 \tag{18}$$

in which case

$$N = N^* + N_o \tag{19}$$

which means that geoid undulations N^* are determined within an unknown scale factor. However, the comparison of N^* with N_D enables us to determine that scale factor N_o and hence the semi-major axis a_{me} of the mean earth ellipsoid (Heiskanen *et al.*, 1967, Section 2-19):

$$a_{me} = a_{ref\ ell} + N_o \tag{20}$$

N^* and N_D values can be compared through a one-parameter solution in N_o. This presupposes that the origin of the Doppler system (NWL 9D) coincides with the origin of the system to which N^* values refer, i.e. both origins coincide with the centre of mass of the earth. Otherwise, a comparison through a four-parameter solution in N_o ΔX, ΔY and ΔZ is possible. Such a solution is reliable in ΔX, ΔY and ΔZ provided that the stations involved in the solution are well distributed around the globe. Rapp *et al.*, (1976) were able to calculate such a four-parameter solution using 40 Doppler stations globally distributed. They obtained values of −1.1m (ΔX), 1.6 m (ΔY) and 0.6 m (ΔZ) which indicates that the origin of the Doppler system (NWL 9D) is practically at the centre of mass of the earth.

In the present case, N_D values at the 134 Doppler stations located in Canada were first compared with the corresponding undulations derived solely from GEM8 according to equation (4). The N_D values were weighted according to the type of levelling used to obtain the orthometric heights:

$$\begin{aligned} \sigma^2(N_D) &= 1\ m^2 \text{ differential levelling} \\ \sigma^2(N_D) &= 4\ m^2 \text{ trigonometric levelling} \\ \sigma^2(N_D) &= 9\ m^2 \text{ barometric levelling} \end{aligned} \tag{21}$$

A one-parameter solution in N gave

$$N_o = -29.8\ m \quad N_o \quad \sigma(\Delta N_i) = 2.62\ m \tag{22}$$

where $\sigma(\Delta N_i)$ is the standard deviation of one observation, i.e. one geoid undulation difference (N_D − N(GEM8)). The a_{me} value implied by this N_o is

$$a_{me} = a_{ref\ ell} + N_o = 6378160\ m - 29.8m = 6378130.2\ m \tag{23}$$

The surface gravity data were then combined with GEM8 in order to obtain N^* undulations according to equation (18). N_2 was evaluated by least squares collocation using the same covariance function and same inner-zone size as in the previous section. N_3 was evaluated according to equation (8). The outer-zone σ_2 was the area bounded by ($0°.75 < \psi_{oz} < 8°$). These N^* were then compared with the corresponding 134 N_D. A one-parameter solution in N_o gave

$$\begin{aligned} N_o &= -27.0\ m \qquad \sigma(\Delta N_i) = 3.77\ m \\ a_{me} &= 6378133.0\ m \end{aligned} \tag{24}$$

This result is surprising because one would expect the N^* undulations to be slightly more accurate than GEM8 undulations in which case $\sigma(\Delta N_i)$ should be decreasing instead of increasing. However, it was found out that N^* undulations are systematically smaller than N_D undulations at all stations located in the Rocky Mountains area. Thirty-four stations were then removed and a comparison at the remaining 100 stations gave

$$\begin{aligned} N_o &= -28.3\ m \qquad \sigma(\Delta N_i) = 2.74\ m \\ a_{me} &= 6378131.7\ m \end{aligned} \tag{25}$$

The corresponding N_o value obtained when comparing GEM8 undulations with N_D undulations was

$$\begin{aligned} N_o &= -30.0\ m \qquad \sigma(\Delta N_i) = 2.67\ m \\ a_{me} &= 6378130.0\ m \end{aligned} \tag{26}$$

These results indicate that the use of detailed surface gravity data in addition to GEM8 does not produce more accurate geoid undulations than the sole use of GEM8. However, one must be careful here because many Doppler undulations were derived using trigonometric and barometric levelling which are not more accurate than two to three metres at best. Hence, a new comparison was made at 42 stations distributed across Canada where differential levelling was used to derive the Doppler undulations. These stations are listed in Table II together with Doppler, GEM8 and combined GEM8-gravimetric undulations which will be described below. A comparison between Doppler and GEM8 undulations at these 42 stations gave

$$\begin{aligned} N &= -29.4\ m \qquad \sigma(\Delta N_i) = 1.85\ m \\ a_{me} &= 6378130.6\ m \end{aligned} \tag{27}$$

A comparison of Doppler and N^* undulations ($\psi_{oz} \leq 8°$) gave

$$\begin{aligned} N_o &= -26.5\ m \qquad \sigma(\Delta N_i) = 2.93\ m \\ a_{me} &= 6378133.5\ m \end{aligned} \tag{28}$$

The N^* undulations used in this comparison (but to which a constant N_o of −30 m was added) are listed in Table II. It is surprising to obtain a standard deviation which is significantly larger than when using solely GEM8 undulations. In fact, just the opposite was anticipated. The removal of some 16 stations located in the Rockies produced different N_o values when comparing firstly GEM8 undulations (−29.5 m) and secondly N^* undulations (−27.8 m) with Doppler undulations but the same standard deviation, namely 1.90 m.

In order to verify whether increasing the radius of the outer-zone would improve the results, all 1° x 1° mean gravity anomalies located inside a radius of 20° were used. The resulting N^* undulations are also tabulated in Table II. A comparison

TABLE II

Doppler, GEM8 and Combined GEM8-Gravimetric Geoid Undulations at Doppler Stations Located in Canada

NBR	LATITUDE	LONGITUDE	N_D	N(GEM8)	N(S)(ψ)) ψ=8°	N(S(ψ)) ψ=20°	N(S'(ψ)) ψ=8°	N(S'(ψ)) ψ=20°
650001	53 18 30.	299 38 6.	−38.15	−37.42	−41.96	−46.37	−39.17	−39.49
231020	46 35 49.	299 36 8.	−43.85	−41.90	−41.17	−41.11	−42.48	−43.26
202040	48 49 15.	292 26 45.	−52.42	−52.52	−57.94	−56.49	−54.30	−53.79
552150	49 30 15.	285 36 58.	−63.87	−62.41	−67.81	−66.33	−63.71	−64.01
653050	48 33 56.	278 37 44.	−66.47	−67.55	−70.23	−72.35	−66.02	−66.04
683024	42 18 14.	277 10 24.	−64.10	−64.12	−67.17	−65.78	−63.71	−64.06
523030	48 34 13.	271 9 57.	−63.80	−64.03	−67.52	−67.52	−65.84	−65.52
749159	74 43 6.	265 0 48.	−37.20	−38.47	−37.16	−35.89	−36.82	−36.18
644000	56 51 39.	258 56 4.	−63.36	−66.39	−64.21	−70.24	−64.07	−63.69
666002	53 29 12.	246 33 27.	−50.36	−51.27	−55.45	−60.34	−51.46	−51.50
236000	49 5 41.	246 32 11.	−44.20	−47.79	−49.45	−56.52	−46.27	−47.36
629102	62 28 29.	245 33 40.	−56.14	−54.66	−57.26	−60.30	−56.13	−56.71
639045	67 49 13.	244 53 14.	−49.79	−52.24	−50.26	−52.13	−50.23	−49.64
510990	48 40 33.	243 40 3.	−44.97	−47.92	−45.55	−55.74	−42.56	−42.91
546090	55 54 46.	242 17 31.	−47.21	−48.26	−53.74	−58.45	−47.38	−48.65
657004	49 6 58.	240 19 31.	−45.11	−48.82	−50.77	−57.26	−46.61	−44.17
507050	55 53 53.	239 52 42.	−44.20	−45.45	−52.60	−55.36	−45.04	−45.99
689004	61 44 49.	238 46 0.	−43.96	−42.99	−48.40	−52.87	−43.46	−44.94
367170	53 54 9.	237 17 43.	−42.47	−44.00	−53.08	−58.12	−44.91	−46.82
677016	48 24 49.	236 40 34.	−47.98	−49.64	−55.75	−57.98	−50.54	−52.22
758001	61 58 57.	227 33 8.	−25.92	−24.62	−36.48	−35.71	−28.52	−29.23
749151	69 26 15.	226 58 9.	−34.72	−32.82	−36.92	−37.73	−36.15	−36.10
648000	60 43 35.	224 54 41.	−21.81	−22.08	−31.30	−32.54	−25.54	−25.82
448070	62 27 22.	219 9 1.	−15.44	−17.20	−24.21	−25.01	−18.92	−18.90
723002	51 16 34.	279 22 0.	−70.57	−69.69	−72.55	−73.85	−69.32	−69.77
293160	46 30 16.	279 1 55.	−65.40	−65.89	−68.86	−68.05	−64.50	−64.38
653050	48 33 56.	278 37 44.	−66.47	−67.55	−70.22	−72.34	−66.01	−66.04
723007	49 33 15.	276 59 25.	−67.01	−68.52	−70.07	−69.99	−66.65	−66.48
673211	52 59 14.	272 38 27.	−72.87	−70.95	−74.11	−75.40	−71.80	−72.69
523030	48 34 13.	271 9 57.	−66.88	−64.03	−67.52	−67.52	−65.84	−65.52
573190	50 5 21.	267 59 59.	−62.82	−62.09	−64.17	−65.20	−62.43	−61.85
673221	48 43 22.	265 38 59.	−58.37	−58.05	−59.46	−61.92	−58.30	−58.65
254020	49 8 30.	262 14 50.	−54.23	−55.13	−55.23	−58.64	−55.07	−55.30
640000	56 51 39.	258 56 4.	−63.44	−66.39	−64.22	−70.25	−64.07	−63.70
649032	69 6 59.	254 56 31.	−60.03	−56.25	−60.11	−60.40	−59.77	−60.87
510980	48 48 28.	254 40 55.	−45.86	−49.63	−47.55	−54.29	−47.74	−47.96
705026	51 41 47.	254 27 13.	−50.64	−53.43	−52.13	−59.44	−52.20	−52.43
305130	53 3 23.	254 9 33.	−52.91	−55.39	−54.42	−61.32	−54.32	−54.42
665007	52 44 29.	251 34 41.	−50.76	−53.37	−53.05	−58.64	−51.53	−51.45
266110	50 40 4.	248 44 4.	−48.02	−49.69	−52.31	−58.98	−49.25	−49.73
666200	55 55 1.	247 55 13.	−52.26	−54.10	−56.46	−59.39	−52.81	−52.99
586080	59 54 54.	242 57 55.	−49.02	−49.74	−52.54	−55.70	−48.52	−49.05

NB: Normal reference field used: GRS67 with a = 6378160 m and f = 1/298.247
A N_0 value of −30 metres was added to all N(S(ψ)) and N(S'(ψ)) undulations

between these N^* undulations and Doppler undulations at the 42 stations gave

$$N_o = -23.9 \text{ m} \qquad \sigma(\Delta N_i) = 4.14 \text{ m} \qquad (29)$$
$$a_{me} = 6378136.1 \text{ m}$$

Again, the difference between this result and the one obtained by using solely GEM8 is partly due to the stations located in the Rockies (cf. Table II).

In order to verify whether the results presented above were consistent with other data, the same type of comparison was made at 60 Doppler stations located in the United States provided by the National Geodetic Survey. Latitudes, longitudes, Doppler, GEM8 and combined GEM8-gravimetric undulations at these stations are listed in Table III. The gravity data files described in Section III were also used to evaluate N^* undulations. An inner-zone of 0°.70 was used in order to keep the number of measurements small in the inner-zone.

A first comparison between GEM8 undulations and Doppler undulations gave

$$N_o = -32.2 \text{ m} \qquad \sigma(\Delta N_i) = 1.89 \text{ m} \qquad (30)$$
$$a_{me} = 6378129.8 \text{ m}$$

TABLE III
Doppler, GEM8 and Combined GEM8-Gravimetric Geoid Undulations at Doppler Stations Located in the United States

NBR	LATITUDE	LONGITUDE	N_D	N(GEM8)	N(S)(ψ)) ψ=8°	N(S(ψ)) ψ=20°	N(S'(ψ)) ψ=8°	N(S'(ψ)) ψ=20°
510230	47 11 54.	291 26 47.	−54.76	−53.65	−57.97	−55.19	−54.62	−56.45
510220	44 35 60.	290 24 45.	−57.98	−55.27	−57.69	−55.35	−55.31	−57.10
510210	41 51 19.	290 2 58.	−60.14	−58.31	−57.46	−56.92	−57.01	−59.12
510950	43 13 24.	289 18 27.	−56.10	−57.06	−57.56	−55.87	−55.81	−58.07
511180	42 37 22.	288 30 41.	−58.73	−58.08	−59.02	−56.71	−57.17	−58.75
510200	44 54 29.	286 42 30.	−60.54	−58.56	−61.38	−59.71	−58.79	−61.85
510190	42 14 38.	286 13 24.	−62.50	−59.62	−63.22	−61.59	−61.20	−63.96
510170	41 0 58.	283 39 42.	−63.73	−61.45	−63.83	−63.76	−62.69	−63.30
510180	44 15 33.	283 25 35.	−63.76	−61.48	−66.06	−63.99	−63.61	−66.02
600010	39 1 40.	283 10 27.	−64.82	−62.68	−63.07	−61.02	−61.00	−65.12
510080	34 2 10.	281 50 40.	−67.14	−65.45	−67.37	−66.51	−66.55	−65.79
510110	37 18 52.	281 33 38.	−62.78	−63.08	−62.22	−59.82	−60.45	−62.12
510960	43 1 27.	281 2 3.	−66.92	−62.85	−66.82	−65.28	−64.44	−68.14
511140	38 26 14.	280 10 5.	−60.71	−62.26	−62.73	−62.33	−61.31	−63.43
520160	41 47 38.	279 50 2.	−64.18	−63.03	−65.59	−64.01	−63.37	−66.47
510150	25 53 25.	279 41 35.	−55.57	−59.25	−55.90	−55.82	−56.14	−56.22
510690	32 45 31.	279 26 37.	−62.31	−61.90	−62.46	−61.99	−62.02	−62.08
510140	27 57 25.	279 26 32.	−59.09	−60.64	−58.54	−59.28	−59.48	−59.13
510040	38 22 11.	278 24 33.	−64.23	−61.92	−65.11	−63.26	−63.64	−65.61
510680	30 41 45.	278 15 59.	−57.85	−59.76	−58.25	−58.89	−58.90	−59.16
510070	34 35 8.	277 56 36.	−61.15	−60.31	−61.29	−61.03	−60.88	−61.90
510130	27 55 12.	277 18 25.	−54.81	−56.82	−55.20	−55.85	−55.89	−55.57
511010	42 18 14.	277 10 24.	−66.29	−64.12	−64.66	−63.16	−63.43	−65.90
510100	33 3 38.	277 5 30.	−59.65	−59.08	−58.12	−58.68	−58.26	−59.66
510050	36 57 21.	275 53 9.	−59.44	−60.62	−61.05	−60.85	−60.54	−63.18
511260	30 31 36.	276 12 32.	−57.55	−57.35	−57.01	−58.56	−58.34	−57.92
510060	35 9 6.	275 6 56.	−61.28	−59.18	−60.34	−59.52	−60.34	−63.20
510120	30 39 5.	274 11 38.	−58.22	−56.61	−57.10	−58.94	−58.50	−57.49
510090	33 7 3.	273 30 2.	−60.28	−57.78	−58.44	−61.01	−59.84	−59.50
511250	30 36 6.	273 2 0.	−56.37	−56.65	−56.51	−58.62	−58.09	−57.41
510310	38 38 14.	271 39 2.	−60.70	−61.48	−60.36	−60.81	−60.66	−61.56
510320	39 37 28.	268 58 35.	−62.82	−60.98	−61.66	−61.95	−61.88	−63.96
510280	36 34 37.	268 22 25.	−58.43	−59.56	−58.52	−57.96	−58.22	−60.92
511210	30 37 54.	267 50 4.	−57.01	−57.93	−57.87	−58.11	−58.22	−59.48
510250	30 54 24.	266 23 57.	−57.23	−57.82	−57.89	−57.41	−57.64	−59.19
510270	36 10 23.	265 52 41.	−59.18	−58.42	−58.05	−56.63	−57.13	−59.29
510290	39 16 51.	265 13 51.	−63.10	−58.27	−62.89	−62.09	−61.04	−62.47
510260	33 38 22.	264 58 57.	−55.89	−57.67	−58.38	−57.01	−56.71	−57.92
510240	29 2 31.	264 39 51.	−55.54	−56.05	−56.56	−56.15	−56.12	−57.55
510330	41 42 13.	264 21 21.	−58.44	−57.03	−58.24	−57.03	−56.92	−62.89
510300	35 47 1.	262 1 13.	−57.58	−55.61	−56.93	−55.37	−55.04	−58.60
510670	32 57 44.	261 54 37.	−57.17	−55.50	−60.93	−59.02	−58.27	−59.88
511240	31 2 6.	259 55 10.	−51.89	−53.53	−52.64	−50.81	−50.93	−54.12
510410	41 38 27.	258 24 4.	−48.82	−50.44	−51.45	−50.09	−49.56	−55.49
510390	30 52 15.	258 4 1.	−53.34	−52.50	−55.78	−53.18	−53.05	−55.67
511230	30 40 16.	255 58 39.	−49.41	−52.34	−53.86	−51.71	−51.24	−54.00
510480	34 56 43.	253 32 26.	−49.54	−52.06	−53.00	−48.50	−49.91	−58.61
511030	32 4 19.	253 31 7.	−53.67	−53.70	−57.24	−54.00	−54.35	−55.94
510440	41 36 56.	252 12 57.	−43.97	−44.96	−50.35	−46.58	−45.90	−52.15
510430	44 48 2.	251 39 20.	−41.63	−44.55	−49.80	−45.70	−45.97	−53.03
510520	32 43 25.	248 29 8.	−61.25	−59.25	−62.05	−63.22	−60.89	−68.27
510560	40 38 36.	248 1 46.	−46.30	−45.59	−54.05	−47.87	−49.79	−42.90
510570	40 23 42.	244 47 35.	−48.85	−48.54	−53.68	−47.42	−49.93	−45.29
520930	47 40 34.	243 41 25.	−44.84	−47.35	−57.38	−48.19	−47.82	−62.63
100320	34 57 51.	242 5 11.	−60.44	−63.84	−63.36	−63.86	−62.66	−73.03
510580	39 49 38.	241 0 57.	−54.43	−54.70	−56.37	−55.36	−55.10	−57.90
520630	36 54 51.	239 26 49.	−62.82	−62.92	−61.89	−64.32	−64.00	−65.77
510660	44 23 32.	238 42 17.	−51.39	−51.90	−56.40	−51.86	−50.92	−62.95
510890	38 8 32.	238 16 38.	−62.97	−61.87	−60.42	−62.62	−62.69	−63.26
100550	37 29 53.	237 30 10.	−61.98	−63.94	−59.81	−62.17	−61.45	−63.46

NB: Normal reference field used: GRS67 with a = 6378160 metres and f = 1/298.247
A N_0 value of −30 metres was added to all N(S(ψ)) and N(S'(ψ).) undulations.

A comparison between N^* ($\psi_{oz} \leqslant 8°$) and Doppler undulations gave

$$N_o = -28.8 \text{ m} \qquad \sigma(\Delta N_i) = 2.78 \text{ m} \qquad (31)$$
$$a_{me} = 6378131.2 \text{ m}$$

and a comparison between N^* ($\psi_{oz} \leqslant 20°$) and Doppler undulations gave

$$N_o = -27.7 \text{ m} \qquad \sigma(\Delta N_i) = 3.86 \text{ m} \qquad (32)$$
$$a_{me} = 6378132.3 \text{ m}$$

Then, similar comparisons were made with the 46 stations located east of longitude 255°. The first comparison made between GEM8 and Doppler undulations gave

$$N_o = -30.5 \text{ m} \qquad \sigma(\Delta N_i) = 1.86 \text{ m} \qquad (33)$$
$$a_{me} = 6378129.5 \text{ m}$$

and the second one made between N^* ($\psi_{oz} \leqslant 8°$) and Doppler undulations gave

$$N_o = -29.6 \text{ m} \qquad \sigma(\Delta N_i) = 1.50 \text{ m} \qquad (34)$$
$$a_{me} = 6378130.4 \text{ m}$$

Finally, the third comparison made between N^* ($\psi_{oz} \leqslant 20°$) and Doppler undulations gave

$$N_o = -29.7 \text{ m} \qquad \sigma(\Delta N_i) = 1.64 \text{ m} \qquad (35)$$
$$a_{me} = 6378131.3 \text{ m}$$

In the last two comparisons, the agreement between N^* and Doppler undulations is better then the one between GEM8 and Doppler undulations. However, when all 60 stations are taken into account, this is not the case anymore. Again, this is because the surface gravity data located in the Rocky Mountains area is used to evaluate the geoid undulations at some 14 stations located west of longitude 255°.

The large systematic difference between combined GEM8-gravimetric undulations and GEM8 undulations in the Rocky Mountains area is not unique to this investigation but it was also obtained by (Vincent *et al.*, 1975). Nagy *et al.* (1975) also obtained a large difference in the same area between combined Standard Earth II-gravimetric undulations and Standard Earth II (Gaposchkin *et al.*, 1969) undulations. This bias, although obtained consistently by several investigators, is not fully understood. Although the combined GEM8-gravimetric solution should, in principle, be better than the GEM8 solution, the relatively better agreement between GEM8 and Doppler undulations in the Rockies suggests the contrary. This is also confirmed by results obtained in the previous Section, namely by comparing predicted components with astrogeodetic components of the deviation of the vertical near the Rockies. Hence, it appears that no reliable estimate of either the geoid or deviations can be obtained in the Rockies on the basis of surface gravity data. GEM8 yields a solution for the geoid which is in much better agreement with Doppler undulations than the combined GEM8-gravimetric solution. There are many possible reasons for this, some of which are: a poor gravity coverage (non-existent in some parts), the actual gravity measurements may not be regularly distributed as a function of the elevation, hence a misuse of the data and an inappropriate derivation of mean gravity anomalies.

An interesting question related to the problem mentioned above is whether the use of a truncated Stokes' function containing only the harmonics higher than degree 25 would produce better results than the use of standard Stokes' function. The use of a truncated function is justified because GEM8 up to degree and order 25 is used as the reference field assuming that the coefficients of GEM8 are assumed to be error free. In principle, the use of either the standard or the truncated Stokes' function should not make any difference when the Stokes' integration extend over the complete sphere, in which case $\psi_{oz} \leqslant 180°$, because of the orthogonality of the Legendre functions; details concerning the application of a truncated Stokes' function are to be found in (Wong *et al.*, 1969). In practice, we may assume that the outer-zone extend up to 180° but that the residual gravity anomalies outside a certain radius ($\psi \leqslant 20°$) are negligible because of their distance from the computation point. The spherical (zonal) harmonics expansion of Stokes' function is (Heiskanen *et al.*, p. 97):

$$S(\psi) = \sum_{n=2}^{\infty} \frac{2n+1}{n-1} P_n(\cos\psi) \qquad (36)$$

while the close formula is (*Ibidem*, p. 94):

$$S(\psi) = \frac{1}{\sin(\psi/2)} - 6\sin\frac{\psi}{2} + 1 - 5\cos\psi - 3\cos\psi \ln\left(\sin\frac{\psi}{2} + \sin^2\frac{\psi}{2}\right) \qquad (37)$$

An accurate estimate of the truncated (without the first 25 harmonics) Stokes' function $S'(\psi)$ can then be obtained by writing

$$S'(\psi) = S(\psi) - \sum_{n=2}^{25} \frac{2n+1}{n-1} P_n(\cos\psi) \qquad (38)$$

where $S(\psi)$ is calculated by using equation (37). Both $S(\psi)$ and $S'(\psi)$ are listed in Table IV. Equation (8) then becomes

$$N_3 = \frac{R}{4\pi\bar{\gamma}} \iint_{\sigma_2} (\Delta g - \Delta g_1 - \Delta g_P)\, S'(\psi)\, d\sigma \qquad (39)$$

The combined GEM8-gravimetric geoid undulations were calculated at the 42 Canadian stations and the 60 U.S. stations using a truncated Stokes' function. The resulting N^* values are also listed in Tables II and III. A comparison between N^* ($\psi_{oz} \leqslant 8°$) and Doppler undulations at the 42 Canadian stations gave

$$N_o = -29.5\text{m} \qquad \sigma(\Delta N_i) = 1.28 \text{ m} \qquad (40)$$
$$a_{me} = 6378130.5 \text{ m}$$

A similar comparison made at the 60 U.S. stations gave

$$N_o = -30.1 \text{ m} \qquad \sigma(\Delta N_i) = 1.60 \text{ m} \qquad (41)$$
$$a_{me} = 6378129.9 \text{ m}$$

When comparing N^* ($\psi_{oz} \leqslant 20°$) with Doppler undulations, we obtained

$$N_o = -29.2 \text{ m} \qquad \sigma(\Delta N_i) = 1.49 \text{ m} \qquad (42)$$
$$a_{me} = 6378130.8 \text{ m}$$

for the Canadian stations and

$$N_o = -30.0 \text{ m} \qquad \sigma(\Delta N_i) = 1.69 \text{ m} \qquad (43)$$
$$a_{me} = 6378130.0 \text{ m}$$

for the U.S. stations.

The agreement between these combined GEM8-gravimetric undulations obtained by using a truncated Stokes' function to evaluate the effect of the outer-zone and Doppler undulations is better than the corresponding agreement when using the standard Stokes' function. Also, the N_o values obtained when using a truncated Stokes' function are in better agreement with the ones obtained when comparing GEM8 undulations with Doppler ones. Hence, the systematic difference between combined GEM8-gravimetric undulations and GEM8 or Doppler derived undulations practically disappear in the Rocky Mountains area when using a truncated Stokes' function.

All N_o values obtained in this Section are listed in tables V (Canada) and VI (United States). The different values implied for

TABLE IV

Stokes' Function and Truncated Stokes' Function with the First 25 Harmonics Removed

$\psi°$	$S(\psi)$	$S'((\psi)$	$\psi°$	$S(\psi)$	$S'(\psi)$
.1	163.04	1103.72	82.0	−2.14	.24
.5	241.45	182.36	84.0	−2.08	.09
1.0	124.74	66.38	86.0	−2.00	−.12
1.5	85.28	28.12	88.0	−1.92	−.24
2.0	65.28	9.75	90.0	−1.83	−.17
2.5	53.11	−.39	92.0	−1.73	.03
3.0	44.89	−6.22	94.0	−1.62	.19
3.5	38.93	−9.48	96.0	−1.51	.21
4.0	34.40	−11.07	98.0	−1.39	.07
4.5	30.82	−11.51	100.0	−1.27	−.12
5.0	27.92	−11.16	102.0	−1.14	−.22
5.5	25.51	−10.25	104.0	−1.00	−.14
6.0	23.47	−8.98	106.0	−.86	.04
8.0	17.68	−2.68	108.0	−.72	.19
10.0	13.99	2.03	110.0	−.57	.19
12.0	11.38	3.35	112.0	−.43	.05
14.0	9.41	1.98	114.0	−.28	−.13
16.0	7.86	−.23	116.0	−.13	−.21
18.0	6.58	−1.61	118.0	.03	−.12
20.0	5.50	−1.51	120.0	.18	.05
22.0	4.58	−.41	122.0	.33	.19
24.0	3.78	.72	124.0	.48	.18
26.0	3.08	1.11	126.0	.64	.03
28.0	2.45	.64	128.0	.79	−.14
30.0	1.89	−.19	130.0	.93	−.21
32.0	1.39	−.74	132.0	1.08	−.11
34.0	.94	−.68	134.0	1.22	.07
36.0	.53	−.14	136.0	1.36	.20
38.0	.16	.42	138.0	1.50	.18
40.0	−.17	.60	140.0	1.64	.02
42.0	−.47	.32	142.0	1.77	−.16
44.0	−.74	−.16	144.0	1.89	−.22
46.0	−.99	−.47	146.0	2.01	−.11
48.0	−1.21	−.40	148.0	2.13	.09
50.0	−1.40	−.05	150.0	2.24	.24
52.0	−1.58	.30	152.0	2.34	.20
54.0	−1.73	.40	154.0	2.44	.00
56.0	−1.86	.20	156.0	2.53	−.21
58.0	−1.97	−.14	158.0	2.62	−.27
60.0	−2.07	−.34	160.0	2.69	−.12
62.0	−2.15	−.28	162.0	2.77	.14
64.0	−2.21	−.01	164.0	2.83	.31
66.0	−2.25	.24	166.0	2.89	.25
68.0	−2.29	.30	168.0	2.94	−.03
70.0	−2.30	.13	170.0	2.98	−.33
72.0	−2.31	−.13	172.0	3.02	−.42
74.0	−2.30	−.28	174.0	3.04	−.16
76.0	−2.28	−.21	176.0	3.06	.35
78	−2.24	.01	178.0	3.08	.85
80.0	−2.20	.21	180.0	3.08	1.06

the semi-major axis (a_{me}) of the mean earth ellipsoid on the basis of these N_0 values vary between 6378129.5 m and 6378136.1 m with a most probable value of about 6378131 m. This value agrees with the one obtained by Strange *et al.* (1975) by comparing U.S. Doppler undulations with a combined potential coefficient-gravimetric geoid derived by Marsh and Vincent of Goddard Space Flight Center. On the other hand, Rapp *et al.* (1976) recently obtained a value of 6378135 m when comparing U.S. Doppler positions with a combined GEM8-gravimetric geoid. The difference of 4 metres between that result and the one obtained in this paper is not fully understood. According to (Rapp *et al.*, 1976), it could be due in part to the fact that the gravity data which they used was corrected for the effect of the atmosphere while the data used in the present investigation was not.

Data retrieval and computation time estimates

The handling of gravity data files such as the ones described in Section III could be a time consuming process when performing the type of computations described in the two previous sections if an adequate filing system is not used, even if a powerful computer is available. In this type of computation, much data retrieval is required. Hence, the use of random access files, where any part of a file can be accessed about as quickly as any other part, has an enormous advantage over the use of sequential files such as magnetic tapes.

The four gravity files described in Section III were created as random access files (word addressable) using FORTRAN extended subroutines OPENMS and WRITMS (Control Data Corporation, 1971). As any other type of random access files, they must be created and used on a mass storage device such as a disk. However, they can be catalogued on magnetic tapes for storage purposes and this is much more economical than disk storage. When needed, they can be copied back and kept on disks for as long as needed. Any record of a particular file contains here the gravity data located in a certain block which is bordered and indexed as functions of the latitude and longitude. This gravity data consists, in the case of the two point gravity anomaly files, of an identification number, latitude, sine and cosine of latitude, longitude, elevation, free-air gravity anomaly referring to GRS67 and free-air gravity anomaly referring to the surface implied by GEM8. Hence, there are eight quantities attached to each point gravity anomaly. The block size is 1° x 1°. In the case of the two files containing mean gravity anomalies, the block sizes are 4° x 4° (15′ x 30′ for $\phi > 50°$ and 15′ x 15′ for $\phi < 50°$) and 5° x 5° (1° x 1°). Each mean gravity anomaly is described by seven quantities: an identification number, latitude, sine and cosine of latitude, longitude, mean free-air gravity anomaly referring to the surface implied by GEM8 and its variance.

The use of these random access files proved to be very satisfactory. The Central Processor (CP) time required to retrieve the data necessary to predict N, ξ, η at any point located either in Canada or the United States when using an outer-zone having a radius of 8° was estimated to be well below 1 second. All CP time estimates given here were obtained on the Control Data Cyber 74 of the Department of Energy, Mines and Resources.

The computer program which was used to predict both components of the deviation of the vertical and geoid undulations is set up to evaluate either N, ξ, η simultaneously or N separately from ξ, η. In any case, the prediction of either one (N), two (ξ,η) or three (N,ξ,η) quantities does not change much the CP time required because the most time consuming computations have to be performed once in any case. As an example, the prediction of N, ξ, η at the 60 Doppler stations located in the United States took 15 seconds of CP time per station as an average. This was when the outer-zone was extended to a radius of 8°. The number of point gravity anomalies located in the inner-zone was 150 per station as an average. When the outer-zone was extended to a radius of 20°, the CP time required per station went up to 22 seconds.

TABLE V

Zero-Order Undulations of the Geoid Derived From Comparisons of Doppler Undulations Located in Canada and Various Geoid Solutions

Nbr of stations	GEM8	S(ψ) 8°	S(ψ) 20°	S′(ψ) 8°	S′(ψ) 20°
134	−29.8	−27.0			
	(2.62)	(3.77)			
100	−30.0	−28.3			
	(2.67)	(2.74)			
42	−29.4	−26.5	−23.9	−29.5	−29.2
	(1.85)	(2.93)	(4.14)	(1.28)	(1.49)

NB: All values are given in metres
Reference ellipsoid: a = 6378160 m f = 1/298.247
Values in bracket are standard deviations of one observation

TABLE VI

Zero-Order Undulations of the Geoid Derived From Comparisons of Doppler Undulations Located in the United States and Various Geoid Solutions

Nbr of stations	GEM8	S(ψ) 8°	S(ψ) 20°	S′(ψ) 8°	S′(ψ) 20°
60	−30.2	−28.8	−27.7	−30.1	−30.0
	(1.89)	(2.78)	(3.86)	(1.60)	(1.69)
46	−30.5	−29.6	−29.7		
	(1.86)	(1.50)	(1.64)		

As mentioned in Section III, the fact that the signal covariances required during the least squares collocation evaluation of the effect of the inner-zone were calculated once at regular intervals and stored in vectors decreased the CP time required by a factor of 2.5 to 3.

Conclusions

The combined least squares collocation — integral formulae of Stokes and Vening Meinesz method used in this paper to predict components of the deviation of the vertical and geoid undulations is advantageous because the effect of the inner-zone can be evaluated accurately by applying least collocation on the point measurements located in the inner-zone while the effect of the outer-zone can be quickly evaluated by applying Stokes' and Vening Meinesz's formulae on mean gravity anomalies.

The agreement (rms differences) between astrogeodetic and predicted components of the deviation on the basis of GEM8 and surface gravity data was found to be 1".26 (ξ) and 1".48 (η). The 223 stations involved in this comparison are located across the continental part of Canada except in the Rocky Mountains area (cf. Table I). This result is quite satisfactory if one considers that the astrogeodetic deviations used for comparison purpose were calculated using preliminary geodetic and astronomical values only.

Comparisons made between Doppler derived undulations located both in Canada and the United States and undulations predicted on the basis of surface gravity data and/or GEM8 gave a semi-major axis of about 6378131 metres for the mean earth ellipsoid. A systematic difference occurs in the Rocky Mountains area between combined GEM8-gravimetric and Doppler geoid undulations. However, Doppler undulations agree well with GEM8 undulations in that area. This, and some other comparisons made between predicted and astrogeodetic components of the deviation of the vertical in the same area, suggest that the use of the present gravity data in the Rockies produces unreliable deviations of the vertical and geoid undulations. The main reasons are believed to be a poor data coverage and related problems associated with the determination of the anomalous potential and its components in areas of rugged topography.

However, the use of a truncated Stokes' function to evaluate the effect of the outer-zone on the geoid undulation produced geoid undulations agreeing better with Doppler undulations than the corresponding ones derived when using the standard Stokes' formula (cf. Tables V and VI). Furthermore, the systematic difference between combined GEM8-gravimetric geoid and GEM8 geoid previously noticed in the Rocky Mountains area when using the standard Stoke's function practically disappear when using the truncated Stokes' function, i.e. the standard Stokes' function minus the first 25 harmonics.

Finally, the comparisons made here suggest that, when combining surface gravity data with GEM8 in order to predict components of the deviation of the vertical and geoid undulations, an integration zone extending to a radius of 8° is sufficient.

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SIXTH SESSION
Wednesday, September 29

SIXIÈME SÉANCE
Le mercredi 29 septembre

SEXTA SESIÓN
Miércoles, 29 de septiembre

INFORMATION SYSTEMS IN GEOPHYSICS

SYSTÈMES INFORMATISÉS EN GÉOPHYSIQUE

SISTEMAS DE INFORMACION EN GEOFISICA

Chairman/Président/Presidente
PADRE J. E. RAMÍREZ

Speakers/Conférenciers/Expositores

ING. V. MAZZINI
ING. J. MONGES
DR. M. A. SHEA
DR. D. F. SMART
DR. A. GIESECKE
MR. R. GELLER
MR. P. J. WINTER
ING. A. FONSECA
DR. T. FEININGER
MR. L. M. SEBERT
MR. J. JORDAN

Padre J. E. Ramírez:

El primer expositor del día de hoy es el Ing. Victor Mazzini, de la Argentina, quién nos presentará su papel titulado **"Traversas de Gravedad en los Andes".**

Ing. V. Mazzini:

Como parte del programa del estudio de los cambios seculares de gravedad en los Andes dirigido por el Dr. Woollard, el Servicio Hidrografía Naval y la Universidad de Buenos Aires, materializaron durante el año 1973 la reocupación de viejas estaciones de gravedad. La publicación de los resultados en la Reunión de Panamá en noviembre de 1973, a consultas por la magnitud de las variaciones encontradas y ello fue motivo para recalcular y verificar exhaustivamente las viejas observaciones. Para ello se tomaron en cuenta las calibraciones de los gravímetros Worden 51 y Mott-Smith C.14 utilizados en las antiguas mediciones y los LaCoste and Romberg G 190 y G 194 en las nuevas observaciones controlados en tramos de la Base de Calibración Argentina.

Mediante controles entre polígonos de Metán a Resistencia y entre Parana y Sagastune, medidos en 1952 se obtuvo el factor de calibración de valores del Mott-Smith C.14 logrados en 1942 y 1943 entre Tartagal y Trelew se obtuvo el factor de calibración F = 0,99480 utilizado en el Perfil Norte Por comparación de valores del Mott-Smith C.14 logrados en 1942 y 1943 entre Tartagal y Trelew se obtuvo el factor de calibración F_{MS}= 1,000825 utilizado en 1943 en el Perfil Centro, por último se dedujo el factor del Worden 51 para el Perfil Sur Fs = 0,99372 medido en 1954. De la misma forma se obtuvieron los factores de escala de los LaCoste and Romberg para los geotransversales propuestos.

Perfil norte

Este perfil (Fig. 1), que se desarrolla a través de 34 estaciones separadas entre si en unos 30 km entre los 24° y 27° de latitud S, presenta una diferencia de altitud de 3500 metros entre Resistencia y Paso Socompa, del mismo sólo son comparables las observaciones entre Resistencia y Salta ya que hacia el oeste no existían viejas estaciones, el perfil altimétrico y la anomalía de aire libre y Bouguer que responde a la relación topográfico con una pequeña anomalia de 10 mgal negativa a la altura de Roque Sáenz Peña.

El perfil que muestra la relación de gravedad entre las viejas y las nuevas mediciones, es decir, la variación; presenta una constante negativa de −0,3 de mgal hasta Roque Sáenz Peña donde se produce un salto de 0,41 mgal, manteniendose luego como una constante de +0,50 mgal.

Para poder relacionar este fenómeno es necesario replantear la estructura geológica y tectónica de la región. La misma está comprendida dentro de la cuenca Chaco-Paranense y en su extremo septentrional, se caracteriza a su vez porque en superficie los sedimentos son horizontales, no encontrándose deformados o dislocados, mientras que en profundidad presenta una estructura de bloques fallados diferencialmente, interesando aún al substrato proterozoico, observándose la existencia de pilares y fosas con superficies inclinadas. Todos estos bloques han sufrido hundimientos y ascensos diferenciales. Los bloques en que está dividido el subsuelo de la región N de esta cuenca, van ganando altura de S a N, de manera tal que fuera del terrotorio, ya en Paraguay, van apareciendo como cerros aislados de tipo rocoso, constituídos por areniscas cuarcíticas silúricas.

Inversamente los bloques se hunden uno con respecto al otro hacia el centro de la cuenca, formando en conjunto un graben produndo, es decir, que se suceden en produndidad depósitos

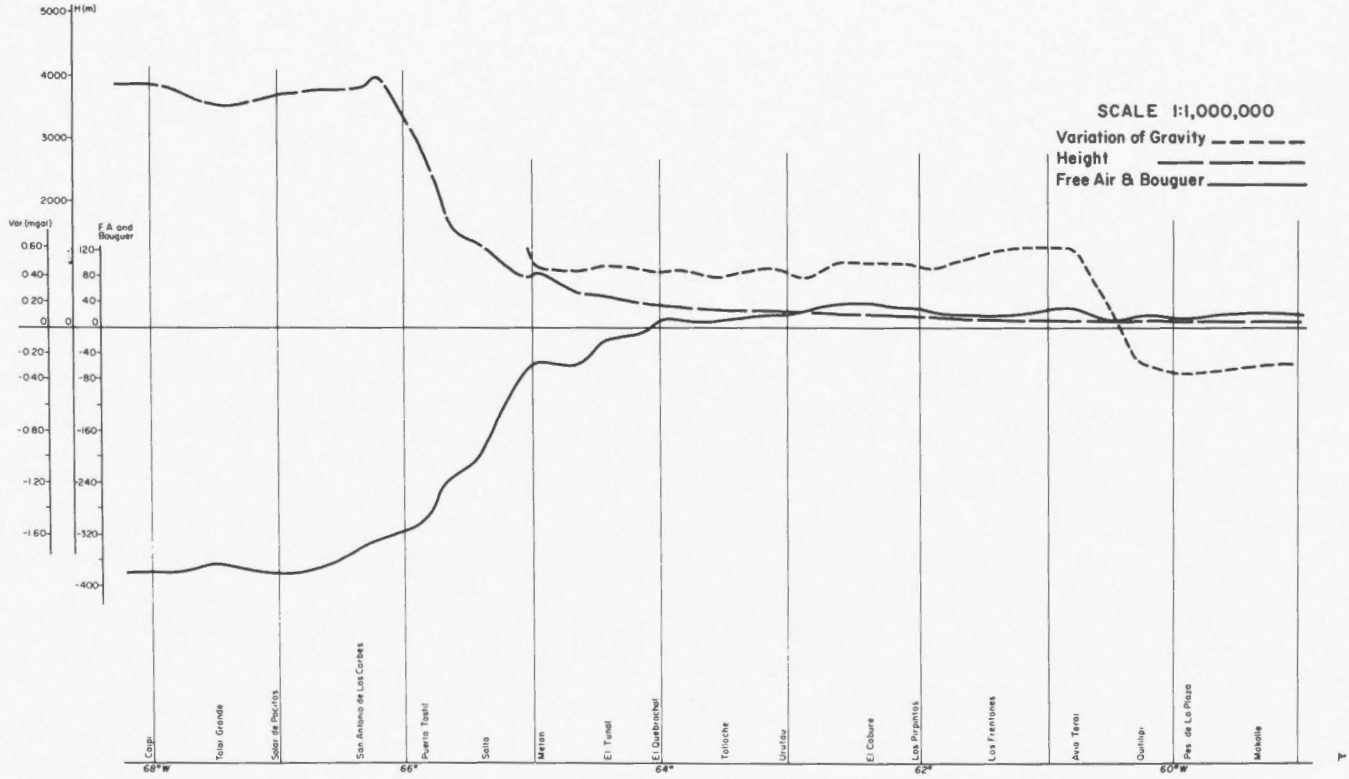

Figura 1. Diagrama de gravedad del perfil norte de Argentina a través de 34 estaciones separadas entre si en unos 30 km entre 24° y 27° de latitud S.

sedimentarios asentados en el substratum proterozoico, abarcando en conjunto más de mil metros de espesor.

Coincidentemente con la débil inclinación de los bloques hacia el S, el espesor y posiblemente con ello la inclinación de los estratos, aumenta levemente en dicha dirección. Un sistema de fallas pre-cretácicas, de rumbo NNE a SSW, paralelas la río Paraguay y provenientes presumiblemente de las fallas que limitan el umbral-escalón paraguayo, originan la depresión de Mariano Boedo, que fue posteriormente rellenada por los sedimentos y efisivas basálticas del Cretácico.

Esta circunstancia produjo esquemas estructurales distintos para el E y el W formoseño-chaqueño, estableciendo una diferenciación estratigráfica, al estar presentes unos horizontes en el lado oriental y faltar el occidental.

Los desplazamientos de origen tectónico correspondientes al Pleistoceno inferior a medio, originaron el elevamiento del Ensenadense del W de Formosa y produciendo como consecuencia en el Cuartario, diferencias estratigráficas de los lados occidental y oriental de la misma. La elevación del centro del territorio provincial en tiempos posteriores al Lujanense modificó la morfología superficial, hecho reflejado en el cambio en la red de drenaje y la estructura del subsuelo, debiéndose agregar entonces a lo ya expresado anteriormente, la modificación de la disposición de los depósitos de la cuenca, que cambian sus inclinaciones suavemente hacia el W en el lado occidental de la elevación y hacia el E en el lado oriental.

En resumen, podemos decir que, las variaciones de gravedad, bien pueden estar poniendo en evidencia al borde la Serra Geral acompañada por acomodamiento de bloques que, por la cubierta sedimentaria no se aprecian desde superficie.

Como aporte a lo expuesto existe un trabajo paralelo que estamos desarrollando con la Universidad de Tucumán y que consiste en la medición de puntos de igual gravedad a través de un perfil con ±0,3 mgal. En un desarrollo de 1300 km. Dicho perfil atraviesa la Provincia de Santiago del Estero de SW a NE para compensar latitud y altitud, notándose que a la altura de Roque Sáenz se produce una discontinuidad de 40 km, siguiendo luego hacia el E. Esta relación nos hace pensar con mayores posibilidades en un proceso de acomodamiento de la corteza en esa zona.

Perfil centro

El mismo (Fig. 2) se desarrolla en la latitud de 33°S con una longitud de aproximadamente 1200 km y 25 estaciones; desde el nivel del mar a los 4000 metros de altura. Es el más importante de los tres, por el conocimiento geológico estructural y la información de sísmica de refracción existente. Los resultados obtenidos, como se verá, destacan netamente las desiguales características de las zonas occidental y centro Atlántica. Las partes más viejas del E (cubiertas por sedimentos cuaternarios en el tramo central del perfil) contrastan con el jóven cinturón andino del oeste. Entre los meridianos 63° y 64° W, los sedimentos superiores (potencia 600 a 1200 m) descansan sobre un regractor de velocidades muy variables: 4,7 km/seg a 5,5 km/seg y 5,9 km/seg.

La configuración actual del edificio andino, obedece a una tectónica reciente (plio cuartaria), cuyas últimas exteriorizaciones observamos en la sismicidad actual entre los 68° y 69° 5′ de longitud W, que contrasta hacia el E con el dominio cratónico o antepaís andino que se extiende desde el pie de los Andes al borde del Atlántico, decreciendo el relieve morfoestructural.

El perfil de aire libre y Bouguer, acompaña en la figura al relieve estructural aumentando los valores negativos hacia el oeste. En la zona de La Carlota donde el basamento aflora, los valores de aire libre y Bouguer son positivos. Desde La Carlota a San Luis no hay valores de refracción pero el camino bordea el

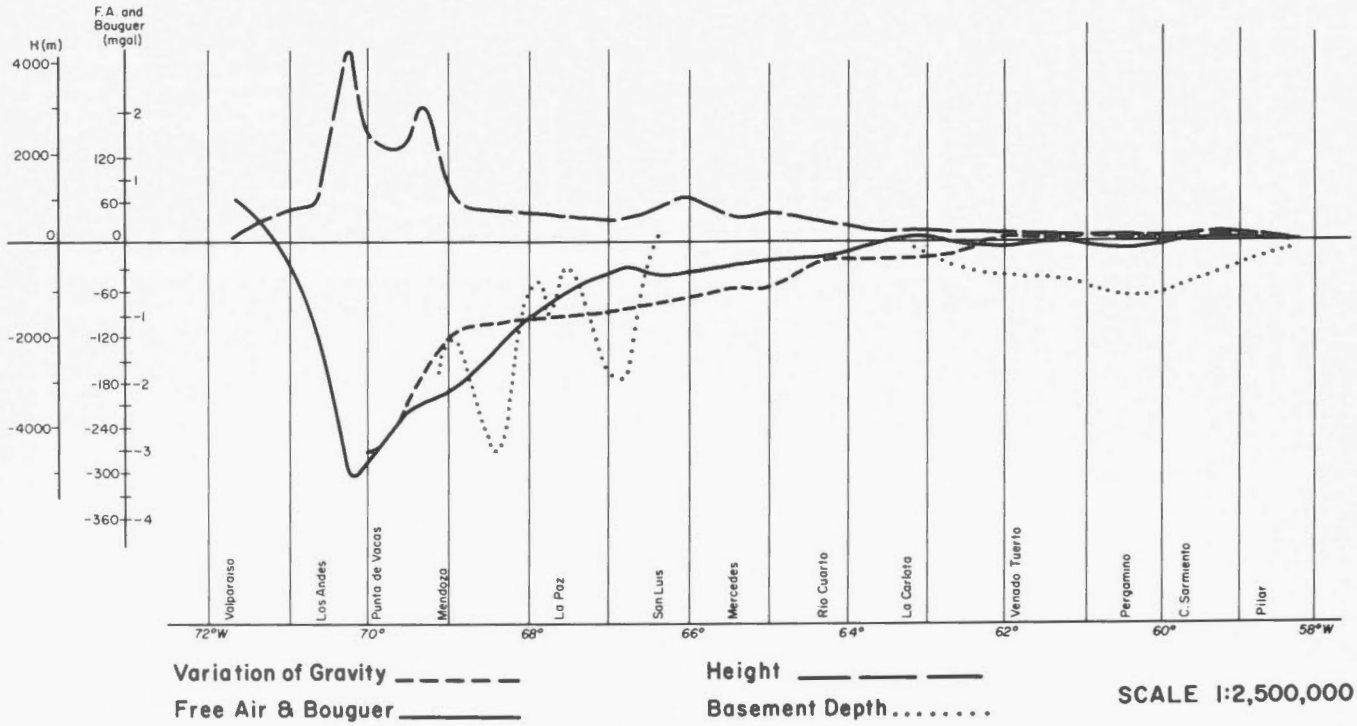

Figura 2. Diagrama de gravedad del perfil central de Argentina desarrollado en latitud 33°S con una longtitud de aproximadamente 1200 km y 25 estaciones.

extremo sur de las serranías Cordobesas. A partir de La Paz el basamento se profundiza rápidamente hasta la ciudad de Mendoza, siendo acompañado por la interpretación gravimétrica de aire libre y Bouguer.

En cuanto a las velocidades adoptadas para el basamento cristalino, YPF Argentino obtuvo valores comprendidos entre 5,9 y 6,3 km/seg, mientras el Ing. Volponi obtuvo en la zona de Cuyo valores de 6,3 y 6,4 km/seg, teniendo en cuenta que la relación entre velocidades y densidades no es única, complicándose por efectos múltiples sobre todo de anisotropía.

Considerando un contraste de densidad corteza-manto de: 0,39 g /cm³ agua océano-corteza de 1,81 g /cm³ se obtiene un espesor de corteza de 32 km con una zona en el meridiano 70° de 67 km de profundidad. para ello se ha considerado la corteza con una densidad: 2,84 g /cm³ y el manto 3,23 g /cm³.

Los valores de diferencias de gravedad entre las viejas estaciones y las nuevas comienzan a tener tendencia negativa a partir de Venado Tuerto, haciéndose mínimo en la zona de Las Cuevas con −2,35 mgal.

Esta disminuación de la atracción gravimétrica ha sido verificada por nivelaciones geométricas de precisión que han mostrado un hundimiento hacia el oeste a partir del terremoto de San Juan (1944), posterior a las primeras observaciones gravimétricas con el Mott-Smith C.14.

Esta evidencias y los trabajos efectuados sobre la placa de Nazca y el cinturón volcánico pueden estar mostrándonos la superposición de dicha placa sobre la continental.

Perfil sur

Del mismo (Fig. 3), se reocuparon por el Servicio de Hidrografía Naval y el Instituto de Geodesia —UBA— viejas observaciones (1943) y nuevas (1973), también tiene un desarrollo de unos 1000 km, ocupando 20 estaciones.

Las viejas estaciones entre San Antonio Oeste y Bariloche fueron medidas con gravímetros Worden 51, controlado sobre la Base de Calibración Argentina en su parte sur, desde Bahía, con un factor de calibración F'_{wss} = 0,993.72. El mismo se desarrolla sobre la meseta patagónica en nuestro sur y las anomalías de aire libre parecen mostrar correspondencia con la topografía a la latitud de 41° S.

Las variaciones de gravedad en este perfil son todas positivas y del mismo orden aproximadamente de +0,40 a +0,65 mgal, lo que nos muestra una relación directa entre la altura y la variación de gravedad.

Como la confiabilidad y calibración de los gravímetros LaCoste and Romberg usados en 1973 nos merece mayor fe que el Worden 51, podemos decir que las variaciones de gravedad están en relación directa con un error en las mediciones del Worden 51, ya que el decrecimiento constante de gravedad con el aumento de altitud pueden atribuirse a la constante del resorte. Esto es lo que he pensado luego de revisar varias veces los posibles errores de calibración.

Discusión:

Dr. Ocola:

Ha observado alguna variación en la gravedad en el perfil norte, en el área de los Andes?

Ing. V. Mazzini:

Lamentablemente, en el perfil norte a partir de Salta, donde no habíamos observado variación, no tenemos viejas mediciones, solamente podemos comparar y calcular anomalías, no hay comparación anterior. Recién podremos hacerlas el año próximo cuando reiteremos ese perfil luego de cuatro años. Tendríamos que agregar con respecto al perfil central, que hace ya un año hubo movimientos en la cordillera que pueden causar variaciones con respecto a lo que estábamos mostrando ahora. No sé si también en la parte norte puedan afectar.

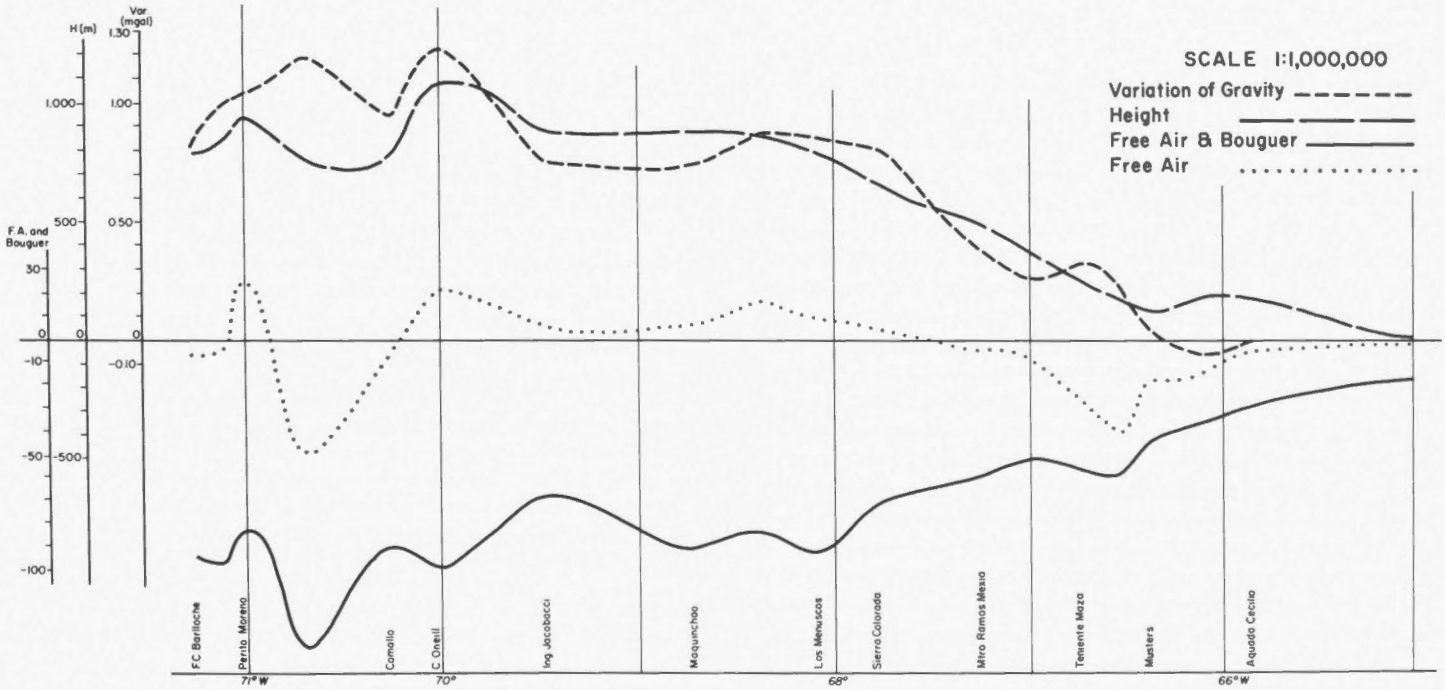

Figura 3. Diagrama de gravedad del perfil sur de Argentina reocuparon viejas estaciones y nuevas también tienen desarrollo de unos 1000 km, ocupando 20 estaciones.

Dr. L. Ocola:

Un programa similar se hizo también en el Perú y estamos en la etapa de procesar los datos. Es una tarea bastante laboriosa conseguirlos, especialmente del instrumental y la historia de la estación misma.

Ing. V. Mazzini:

Sobre todo hay que tener mucho cuidado en que sea la misma estación la reocupada, de no ser así nos induce a suposiciones totalmente erradas.

Dr. L. Ocola:

Eso es, especialmente, las estaciones antiguas son muy difusas en cuanto a la descripción, así que uno no las puede exactamente reocupar.

Prof. G. P. Woollard:

Although Victor suggested that errors in the calibration of Worden 51 might be the reason for the apparent variation in gravity, I would point out that I took his values and plotted them as the function of change of absolute g and found a pattern that cannot be related to differences in calibration. You go through these real breaks in geologic structure, particularly on the northern and the southern profiles. It is a pattern that has no relationship to topography at all. It is related to basement structure in that the changes in gravity observed do not occur until you get right up to the foothills of the Andes in that big basin area. So I think we should not be too quick to ascribe these variations entirely to calibration errors and recognize what appears to be a real geologic correlation.

Padre J. E. Ramírez:

Buen comentario Prof. Woollard. Felicitaciones por su trabajo y gracias por su presentación, Ing. Mazzini.

Vamos a pasar ahora de la parte sur de la América Latina a la parte norte y nos va a hablar el representante de México, Julio Monges, sobre **"Cambios Gravimétricos Seculares".**

Ing. J. Monges:

Cuando el Dr. Woollard estaba reexaminando los datos antiguos de péndulos en la base de calibración de gravedad en Norteamérica, notó que en los resultados de los péndulos (si estos fueran corregidos por los efectos de taras, medioambiente y saltos), se encontraba un cambio sistemático de valores para la ciudad de México en relación con Madison. Al mismo tiempo, en esa época, nosotros estábamos midiendo el norte de México y tomábamos como base la ciudad de México y siempre veíamos que había un error en los gravímetros. Varias veces mandamos a checar la calibración porque no cerraban los circuitos.

Tales errores hicieron pensar al Dr. Woollard que había una variación secular de la gravedad en la zona de la ciudad de México.

Después de hacer los estudios y ajustes necesarios se llegó a la conclusión de que en la ciudad de México había una variación secular de .065 mgal por año.

Donde se perciben los cambios es en el altiplano de México, no así en la costa o hacia el sur.

En la primera reunión de la Comisión de Geofísica, el Ing. Salgueiro nos dió dinero para que buscáramos esos cambios de gravedad en Centro América, entonces yo hice dos perfiles en América Central, sin encontrarse variaciones. Sin embargo, estos trabajos permitieron efectuar remediciones luego del terremoto de Guatemala, medimos y se detectaron muy bien todas las variaciones que hubo de la gravedad debidas al sismo entre la ciudad de Guatemala y Puerto Barrios que era el otro extremo de la línea que dió la casualidad que esa era la línea que yo había medido.

El Dr. Wollard quiso que se hicieran los mismos perfiles en Sudamérica y en México. En México los estamos haciendo poco a poco en las partes sísmicas para ver, después del éxito de lo de Guatemala hemos conseguido dinero para poder hacer perfiles en las partes sísmicas de México y varios puntos para ver si hay variación secular.

Y en Sudamérica se hicieron los siguientes perfiles: El de Colombia en Bogotá, el de Ecuador y el de La Paz lo hicimos cada 20 km se hicieron medidas, si había alguna medida antigua de William Black o de alguien se buscada el sitio y se volvía a medir. El de Colombia va de Buenaventura hasta la Costa del Atlántico, el de Quito, Ecuador, va desde la capital hasta Salinas. Los de Perú, ya el compañero Ocola nos dijo lo que eran, los de Argentina también ya Mazzini, yo iba a ir a Chile, pero me tocó la revolución y mejor no fuí.

Se está trabajando porque el método que usamos es diferente, no usamos, no calculamos todo el circuito ni lo compensamos, sino que se calcula muy bien y se ve entre dos estaciones — trabajamos con diferencia de gravedad — y solamente en puntos donde tenemos la seguridad que fué donde midieron antiguamente. Además de éso se hace el otro trabajo para volver a repetir las líneas y todo, pero para buscar las graduaciones de la gravedad seguimos un método especial y yo sigo un método de cálculo que todavía no ha sido revisado.

En el trabajo de remedición, efectuado en Sudamérica en 1973, tengo una duda sobre la estación en Lima, que espero poder resolver luego de recibir la necesaria información.

Calculadas las mediciones efectuadas en las estaciones reocupadas sin problemas o dudas en la posición, se halló entre los valores obtenidos en 1961, y los de 1975 diferencias del orden de los 0.26 mgal (Quito −.33, Bogota +.15, Asunción −.24, Manaos +.17, Belén −.18).

Estas diferencias se refieren a estaciones pendulares, exceptuando Asunción, que no hay estación pendular sino que es el aeropuerto, pero todavía está la placa y es muy fácil de medir y como queda de paso, las medidas fueron hechas varias veces, están calculadas por varios sistemas para buscar la delta, compensación de tiempo, compensación de todo, y todo puede tener uno o dos centésimas de mgal de diferencia.

Referencias

Monges, J., R. C. Jackens, J. Andrade and J. E. Case, 1976. Comparación de las medidas gravimétricas, antes y después del temblor de Guatemala en 1976. (abs) EOS, **57**, 949.

Woollard, G. P. y J. Monges Caldera, 1970. México área donde ocurren cambios seculares de la gravedad. Geofísica Internacional, **10**, 9.

Discusión:

Ing. R. Argenal:

Quería preguntar si la variación secular que han encontrado cerca de México, no está correlacionada con el drenaje del Valle de México.

Ing. J. Monges:

No, el signo de la variación es diferente al que debería corresponder al hundimiento de la ciudad de México.

Prof. G. P. Woollard:

With regard to Mexico City, gravity connections from two directions give gravity changes of opposite sign. The city itself is sinking and locally if you use Tacubaya as the primary base in contrast to downtown Mexico you will find a change of gravity that is opposite in sign to the change from Monterey into Mexico City. It seems apparent that Mexico City itself is sinking but that the plateau is rising and hence the seeming conflict in the results.

This secular change program that has been described is one that I feel has revolutionized our thinking. I remember four years ago at the International Gravimetric Bureau meeting in Paris the question came up "Is there such a thing as secular change in gravity?" Outside of myself I do not think anyone agreed that such a thing was possible. I saw evidence for it years ago on the Rocky Mountain front in making connections from the mid-continent area (Madison, Wisconsin) to Denver. Every time you measured a different gravity interval and this can not be blamed on calibration because there is perfect agreement with the old measurements practically up to the Rocky Mountain front, but just across that big fault scarp that runs down the front you measure a different gravity interval. I have been convinced of this for a long time and I feel that since the studies of the San Andreas Fault have got underway, they are finding secular changes in gravity that correlate with changes in elevation, although there will sometimes be changes in elevation with no corresponding change in gravity. On the Atlantic Coast right now the United States is sort of going up and down in waves. The central part is rising as is the Hudson Bay area. That whole area is still undergoing isostatic rebound from the last period of glaciation roughly 10,000 years ago so it has not been unloaded very long. I think that gravity is a cheap way of checking out places where you think you have changes of elevation and where the results are encouraging you can go back and relevel them if you wish.

Ing. J. J. Guevara:

Ing. Monges. Como usted sabe, antes del terremoto de Guatemala se había observado en la República de Honduras una línea gravimétrica que parte de Puerto Cortés a Santo Tomás, muy cerca de la zona donde se produjo el terremoto y, posteriormente, para detectar variaciones en la gravedad, se reobservó la línea. Tiene conocimiento si se hallaron variaciones?

Ing. J. Monges:

El Dr. Jackens me informó que acaba de recalcular los vuelos que yo hice en Honduras después del terremoto y no encontró ningún cambio.

Dr. R. C. Jackens:

There were two sets of measurements in Honduras. The flight that you made to re-occupy the northern stations has been reduced and no changes were found from the recent adjustment of the Latin American Gravity Standardization Net. There has been another series of measurements along a line from Puerto Bareos to Puerto Cortes but these have not been reduced to my knowledge.

Padre J. E. Ramírez:

Nuestro siguiente expositor es la Dra. M. A. Shea, quién les presenterá su papel que se titula **"Intercambio de Datos Físicos Solar-Terrestres".**

Dr. M. A. Shea:

Solar-terrestrial physics is a multi-disciplinary area of science comprising studies of the sun, the interplanetary medium and solar effects on the terrestrial environment, particularly the earth's outer atmosphere. The current international and interdisciplinary manner of research in solar-terrestrial physics really began with comprehensive systematic world-wide studies during the International Geophysical Year (IGY) in 1957 and 1958.

Although past emphasis in solar-terrestrial physics has been largely on research for understanding the processes in the upper atmosphere and the physical mechanisms of the effect of a solar-interplanetary phenomena on this atmosphere, there has been a phase of the work directed toward more practical applications. For example, ionospheric measurements have been and continue to be utilized for the purpose of improving the planning and operation of radio telecommunications using the high frequency band where long distance point-to-point communication is made possible by radio wave reflections from the ionosphere. Interruptions to such telecommunication circuits caused by ionospheric disturbances can often be traced to specific solar phenomena such as the emission of solar x-rays. Other types of ionospheric disturbances associated with geomagnetic storms can be forecast in some cases and prompt warnings of the onset of these storms enable telecommunication services to take action to minimize the effect of the disruptions.

In the last few years, as our measurement techniques became more sophisticated and our technology more advanced, we found additional areas of solar-terrestrial physics which have direct application to ordinary daily activities. As it became known that the occurrence of a major solar flare on the sun had both immediate and delayed effects on communication systems, scientists had a need to acquire enough data of these phenomena to describe, model and predict the disturbances to our environment that could be expected after a solar flare was visually observed. In the past few years there has been increasing evidence accumulated that many of the climatic changes over the decades may be related to solar activity although neither direct nor indirect relationships are clearly evident from the data. Certainly economic benefits could be derived from being able to predict long-term changes in the weather patterns in specific areas of the world from the observations of solar activity.

One of the necessary requirements for the study of correlative phenomena such as these is the availability of an adequate data base. To accumulate such a base, contributions must be made from a world-wide network of ground-based observatories and from monitoring observations from satellites in the magnetosphere and the interplanetary medium. In many cases these observations need to extend through several solar cycles in order to delineate and understand the complex time variations.

The world data centres were established to acquire, archive and disseminate data throughout the scientific community. In doing this, these centres have developed an enormous data infor-

TABLE I

World Data Centre System
(Solar and Geophysical Data)

Auspices: International Council of Scientific Unions (non-govermental). Referred to in many uni- and bilateral governmental documents
Started: International Geophysical Year, 1957-1958
Mechanism: ICSU Guide for International Data Exchange
Participation: Voluntary

Locations: Multiple centres for core collection (for safety and convenience)
World Data Centre A in the USA
World Data Centre B in the USSR
World Data Centre C in Europe and Japan
Funding: From national sources

TABLE II
Location of the World Data Centres for Solar-Terrestrial Physics

Discipline	WDC-A	WDC-B	WDC-C
Solar and Interplanetary Phenomena	Boulder, USA	Crimea, USSR Kiev, USSR Moscow, USSR	Arcetri, Italy Freiburg, FRG Meudon, France Munich, FRG Pic-du-Midi, France Rome, Italy Tokyo, Japan Toyokawa, Japan Zurich, Switzerland
Ionospheric Phenomena	Boulder, USA	Moscow, USSR	Slough, England Tokyo, Japan
Flare-Associated Events	Boulder, USA	Moscow, USSR	Itabashi, Japan Meudon, France Ondrejov, Czechoslovakia Slough, England Toyokawa, Japan Umea, Sweden
Geomagnetic Variations	Boulder, USA	Moscow, USSR	Bombay, India Charlottenlund, Denmark Hailsham, England Kyoto, Japan Tokyo, Japan
Aurora	Boulder, USA	Moscow, USSR	Edinburgh, UK Kiruna, Sweden
Cosmic Rays	Boulder, USA	Moscow, USSR	Itabashi, Japan Tokyo, Japan Umea, Sweden
Airglow	Boulder, USA	Moscow, USSR	Mitaka, Japan Paris, France

mation system that can be utilized by anyone throughout the world. Each of the world data centres is responsible for:

1. endeavoring to collect a complete set of data in the field or discipline for which it is responsible,
2. the safekeeping of the incoming data, the correct typing, copying and reproduction of the data and the maintenance of adequate standards of clarity and durability,
3. supplying copies of the data in their data centre to other data centres so that there will be duplicate records in case of loss,
4. the preparation of catalogues of data under its cognizance and
5. making data in the data centre available to the scientific community.

In addition to these responsibilities, countries in which each centre is located also provide investigators with the opportunity of working personally with the material stored in the data centre. A scientist who wishes to visit a data centre for this purpose will be provided with a desk and possibly other facilities to examine data of specific interest. For example, during 1976 two French visitors spent one month visiting World Data Centre A in Boulder, Colorado, USA where they examined 260,000 ionograms in search for a specific phenomenon. In addition to the availability of the data centre archives, visitors such as these have the opportunity of exchanging ideas with data centre personnel on various aspects of data acquisition, utilization and expected scientific achievements. Such an exchange of ideas and suggestions can often result in an improvement of data centre services to the entire scientific community.

Table I illustrates how the world data centre system functions. The data centres as we know them today were organized during the IGY and are now operated under the auspices of the International Council of Scientific Unions (ICSU). Participation in the world data centre program is voluntary. According to the operating policies described in the ICSU Guide for International Data Exchange, all contributors to the data centres may be given, upon request and without charge, a similar amount of data from the data archives. For safety and convenience there are multiple centres of data collection; World Data Centre A located in the United States, World Data Centre B located in the Soviet Union and World Data Centres C, which are discipline-oriented, located in Europe and Japan. In all cases, funding comes from national sources. The location of each of the World Data Centres for Solar-Terrestrial Physics is listed in Table II.

For convenience the broad area of "solar-terrestrial physics" is divided into eight categories as follows:

1. solar and interplanetary phenomena
2. ionospheric phenomena
3. flare-associated events
4. geomagnetic and magnetospheric phenomena
5. aurora
6. cosmic rays
7. airglow
8. miscellaneous

Each of these categories is subdivided into specific types of measurements or measurement techniques.

Scientific data may be submitted to the world data centres in many forms such as photographic film, strip charts, punched cards, magnetic tapes, microfilm or data tabulations. Once the receipt of data is logged into the data centre, the data will either be deposited in the archives directly or be further processed for compatibility with other similar data sets. At the present time World Data Centre A for Solar-Terrestrial Physics is systematically digitizing magnetograms for convenience to the user. A complete record of all data in the archives, filed by both station and discipline, is continuously updated so that requests for data can be promptly filled. Data requested from the data centres are transmitted, as much as possible, in the form that the requestor desires; i.e., on microfilm, strip charts, data tabulations, punched tape, magnetic tape, etc. The only charge for these data is for reproduction costs. As mentioned, previously contributors to the data centre may receive an equal amount of data free of charge in whatever discipline they request.

Each of the World Data Centres for Solar-Terrestrial Physics has some form of publishing selected data sets. Solar Geophysical Data, published monthly in two parts (prompt reports and comprehensive reports) by World Data Centre A for Solar-Terrestrial Physics, contains current data tabulations and information on the most commonly used solar-terrestrial physics data such as solar flares, solar x-ray measurements, solar radio noise bursts, solar particle measurements, sunspot numbers, the solar wind and interplanetary magnetic field measurements, ionospheric and radio wave propagation characteristics, geomagnetic indices and neutron monitor counting rates. A summary of the table of contents of Solar Geophysical Data (listed by discipline) is given in Table III. Other publications such as the Upper Atmosphere Geophysics (UAG) series include data collections for time

TABLE III
Table of Contents of "Solar Geophysical Data"

A. *Solar and Interplanetary Phenomena*		From	To
A.1	Sunspot Drawings	1/67	present
A.1	Sunspot Data (see A05a)	7/57	present
A.2	Zürich Provisional Relative Sunspot numbers, R_Z	7/57	present
A.2	Zürich Final Sunspot numbers, R_Z	7/57	present
A.2	American Relative Sunspot numbers, R'_A	7/57	present
A.2	27-day Plot of Relative Sunspot numbers (see D.1c)	7/57	present
A.2	Sunspot Cycle (smoothed numbers) Graphs-in each issue	7/57	present
A.2	Table of Observed and Predicted Smoothed Sunspot numbers - in each issue since IER-FB-294, updated each month, for period	10/64	present
A.3	Mt. Wilson Magnetograms	9/66	present
A.3	Mt. Wilson Sunspot Magnetic Field Classifications	1/62	present
A.3	Kitt Peak Magnetograms	7/74	present
A.4	H α Spectroheliograms	1/67	present

TABLE III (cont'd)
Table of Contents of "Solar Geophysical Data"

A. *Solar and Interplanetary Phenomena* (continued)		From	To
A.5	Calcium Plage Drawings - McMath (or Catania)	1/67	present
A.5	Calcium Plage (McMath) and Sunspot Regions	7/57	present
A.5	Daily Calcium Plage Index	12/70	present
A.6	Hα Synoptic Charts	6/73	present
A.7	Coronal Line Emission Indices (Provisional)	7/57	5/66
A.7	Coronal Line Emission Indices (Final)	1/60	6/74
A.7	White Light Corona (NRL OSO-7, 1971-083A)	2/72	present
A.7	Solar EUV Spectroheliograms FeXV 284 Å (GSFC OSO-7, 1971-083A)	5/72	3/74
A.7	Solar XUV Coronagrams (NRL OSO-7, 1971-083A)	10/72	12/73
A.8	2800 MHz (ARO-Ottawa) Daily Observed Values of Solar Flux	7/57	present
A.8	2800 MHz (Ottawa) Final - Daily Observed Values of Solar Flux	1/62	12/66
A.8	2800 MHz (ARO-Ottawa) Daily Values Solar Flux Adjusted to 1 A.U.	1/64	present
A.8	2800 MHz (Ottawa) Final - Daily Values of Solar Flux Adjusted to 1 A.U.	1/64	12/66
A.8	470 MHz (Boulder) Daily 3-hourly Averages	7/57	3/58
A.8	167 MHz (Boulder) Daily 3-hourly Averages	7/57	12/58
A.8	200 MHz (Cornell) Daily 3-hourly Averages	7/57	12/58
A.8	9530 MHz (USNRL) Daily Averages	2/58	4/59
A.8	3200 MHz (USNRL) Daily Averages	2/58	4/59
A.8	15400, 8800, 4995, 2695, 1415, 606, 410, 245 MHz (AFCRL) Solar Flux Adjusted to 1 A.U. (15400 MHz began 11/67 and 245 MHz began 1/70)	1/67	present
A.9	9.1 cm (Stanford) Radio Maps of the Sun	4/60	8/73
A.9	9.1 cm Spectroheliogram Data - included in A.5a since 1/69		
A.9	21 cm (Fleurs) Radio Maps of the Sun	12/64	12/73
A.9	8.6 mm (Prospect Hill) Radio Maps of the Sun	4/70	2/74
A.9	8.6 mm (NELC) Radio Maps of the Sun	11/74	present
A.9	2 cm (NELC) Radio Maps of the Sun	6/74	present
A.10	169 MHz (Nançay) Interferometric Observations	7/57	present
A.10	408 MHz (Nançay) Interferometric Observations	11/65	8/71
A.10	21 cm (Fleurs) East-West Solar Scans	10/65	present
A.10	43 cm (Fleurs) East-West Solar Scans	4/66	present
A.10	10.7 cm (Ottawa-ARO) East-West Solar Scans	6/68	present
A.11	Solar X-ray Background Levels (NRL) (satellites, see below)	1/64	4/74
A.11	Solar X-ray Background Levels (NRL Graphs) (satellites, see below)	3/65	4/74
A.11	Solar X-ray Background Levels (Boulder) (satellites, see below)	12/65	11/68
A.11	Solar X-ray Background Levels (France) (satellites, see below)	4/66	5/66
A.11	Solar X-ray Background Levels (Aberdeen, S. D.)	1/66	11/68
	Popular Name — Satellite Designation		
	SOLRAD 7A — 1964-1D	1/64	10/64
	SOLRAD 7B — 1965-16D	3/65	12/65
	SOLRAD 8 — 1965-93A (Explorer 30)	1/66	12/67
	OGO-4 — 1967-73A		
	OSO-4 — 1967-100A	1/68	3/68
	SOLRAD 9 — 1968-17A (Explorer 37)	3/68	7/72
	(Beginning 12/68 daily/hourly averages presented)	6/73	4/74
	SOLRAD-10 — 1971-58A (Explorer 44)	8/72	6/73
A.11	Solar X-ray Background Levels, 0-20Å Injun 1/SOLRAD-3, 1961-02	6/61	12/61
A.11	Solar X-ray Background Levels (Vela 1,2; 1963-39A,C)	(10/63)	
A.11	Solar X-ray Background Levels (McMath) (OSO-3; 1967-20A), 8-12A	3/67	8/67
A.11	Solar X-ray (OSO-5; 1969-6A) Spectroheliograms	7/69	11/72
	(University College London, Leicester Univ.)	7/74	6/75
A.11	Solar X-ray (GSFC OSO-7, 1971-083A) Spectroheliograms	12/72	7/74
A.11	Solar X-ray Background Levels (SMS-1/GOES, 1974-033A); (SMS-2/GOES, 1975-011A)	11/74	present
A.11	Solar X-ray	8/75	present
A.12	Solar Protons, Daily-hourly Values, JPL/GSFC (satellites, see below)	5/67	5/73

TABLE III (cont'd)
Table of Contents of "Solar Geophysical Data"

		From	To
A.	*Solar and Interplanetary Phenomena* (continued)		
A.12	Solar Protons, Graphs, JPL/GSFC (satellites, see below)	5/67	5/73
	Popular Name — Satellite Designation		
	Explorer 34 — 1967-51A, Ep >10, >30, >60 Mev	5/67	5/69
	Explorer 41 — 1969-53A, Ep >10, >30, >60 Mev	6/69	12/72
	Explorer 43 — 1971-19A, Ep >10, >30, >60 Mev	11/71	5/73
A.12	Cosmic Ray Protons, Ep 0.6-13, 13-175, >175 Mev, Univ. of Chicago (Pioneer 6; 1965-105A and Pioneer 7; 1966-75A)	3/69	present
A.12	Cosmic Ray Protons, Ep >13.9, >64 or >40 Mev, Univ. of New Hampshire (Pioneer 8; 1967-123A and Pioneer 9; 1968-100A)	12/69	present
A.12	Cosmic Ray Protons, Ep 5-21, 21-70 Mev, Aerospace (ATS-1; 1966-110A)	1/70	8/72
A.12	Low Energy Protons (NOAA satellites 1972-082A, 1973-086A, 1974-089A)	7/74	present
A.13	Solar Wind (Pioneer 6, 1965-105A; and Pioneer 7, 1966-75A) NASA Ames	12/65	present
A.13	Solar Wind, M.I.T.		
	Pioneer 6, 1965-105A	3/69	2/70
		12/73	present
	Pioneer 7, 1966-75A	6/69	12/69
A.13	Solar Wind (Vela 3, 1964-40A; Vela 5, 1965-58A)	1/69	6/72
A.13	Solar Wind from IPS Measurements (UCSD)	1/75	present
A.17	Interplanetary Magnetic Field		
	Pioneer 8, 1967-123A	10/72	present
	Pioneer 9, 1968-100A	4/72	present
A.17	Inferred Interplanetary Magnetic Field	12/71	present
A.18	Interplanetary Electric Field		
	Pioneer 8, 1967-123A	5/72	present
	Pioneer 9, 1968-100A	4/72	present
B.	*Ionospheric (and Radio Wave Propagation) Phenomena*		
B.10	Radar Meteor Indices, perpetual, based upon 1958-1962 data for N45 latitude — see issues 246, 251		
B.51	NARWS Quality Figures and Forecasts (NBS/ESSA)	7/57	12/65
B.51	NARWS Comparison Graphs (NBS/ESSA)	7/57	12/65
B.51	NPRWS Quality Figures and Forecasts (NBS)	7/57	12/65
B.51	NPRWS Comparison Graphs (NBS)	7/57	10/64
B.51	High Latitude Quality Figures and Forecasts (ESSA/OT)	11/64	present
B.51	High Latitude Comparison Graphs (ESSA/OT)	11/64	11/73
B.52	North Atlantic Graphs of Useful Frequency Ranges (German PTT)	7/57	present
B.53	Quality Figures Based Upon Frequency Ranges (German PTT)	1/70	present
C.	*Flare-Associated Events*		
C.1	H-α Solar Flares (Preliminary)	7/57	present
C.1	H-α Solar Flares (including Standardized Data) (Divided into Confirmed and Unconfirmed Flares as of 1/68)	9/66	present
C.1	H-α Subflares	7/57	present
C.1	H-α Flare Patrol (the most recent issue listed for a month contains the comprehensive flare patrol.)	7/57	present
C.1	H-α Flare Index (daily)	9/69	present
C.1	H-α Flare Index (by region)	9/70	present
C.1	Frequency of Occurrence of Confirmed Solar Flares	1/68	6/68
C.3	2800 MHz (Ottawa) Outstanding Occurrences	7/57	present
C.3	2800 MHz (Ottawa) Hours of Observation	7/57	present
C.3	470 MHz (Boulder) Outstanding Occurrences	7/57	3/58
C.3	167 MHz (Boulder) Outstanding Occurrences	7/57	10/60
C.3	167 MHz (Boulder) Hours of Observation	1/59	12/59
C.3	200 MHz (Cornell) Outstanding Occurrences	7/57	12/58
C.3	9530 MHz (USNRL) Outstanding Occurrences	2/58	4/59
C.3	3200 MHz (USNRL) Outstanding Occurrences	2/58	4/59
C.3	200 MHz (Hawaii) Outstanding Occurrences	6/59	8/59
C.3	108 MHz (Boulder) Outstanding Occurrences	1/60	6/66
C.3	108 MHz (Boulder) Hours of Observation	1/60	6/66

TABLE III (cont'd)
Table of Contents of "Solar Geophysical Data"

C. *Flare-Associated Events* (continued)		From	To
C.3	221 MHz (Boeing-Seattle) Outstanding Occurrences (Interferometric) — Changed to 223 MHz in May 1963	4/62 -	7/63
		5/65 -	11/65
C.3	107 MHz (Haleakala) Outstanding Occurrences	6/65 -	3/66
C.3	10700, 2700, 960 MHz (Pennsylvania State Univ.) Outstanding Occurrences	7/64 -	present
C.3	486 MHz (Washington State Univ.) Outstanding Occurrences	7/66 -	4/69
C.3	18 MHz Bursts (Boulder) (reported in C.6 1/63 - 11/66, C.6ab prior to 1/63)	11/67 -	present
C.3	35000, 15400, 8800, 4995, 2695, 1415, 606, 410, 245 MHz (AFCRL - Sagamore Hill) Outstanding Occurrences (15400 MHz began 11/67, 35000 and 245 MHz began early 1969, 410 MHz began 1971)	1/66 -	present
C.3	184 MHz (Boulder) Outstanding Occurrences	3/67 -	7/72
C.3	7000 MHz (Sao Paulo) Outstanding Occurrences	11/67 -	present
C.3	408 MHz (San Miguel) Outstanding Occurrences	10/67 -	4/72
C.3	18 MHz (McMath-Hulbert) Bursts	1/68 -	present
C.3	43.25, 80 and 160"MHz (Culgoora) Selected Bursts	12/72 -	present

Note: Beginning with the data for April 1966, in CRPL-FB-261, the C.3 entries on Solar Radio Outstanding Occurrences for the western hemisphere observatories and frequencies were combined into a single table "Solar Radio Emission Outstanding Occurrences, C.3." Beginning with June 1969 data, the table was expanded to worlwide coverage and the various observatories are no longer indexed separately.

C.4	Solar Radio Spectrograms of Events (Fort Davis)	7/57 -	12/58
	100 - 580 MHz	7/57 -	12/58
	25 - 580 MHz	1/59 -	12/62
	50 - 320 MHz	1/63 -	3/65
	25 - 320 MHz	4/65 -	12/66
	10 - 580 MHz	1/67 -	2/70
	10 - 1000 MHz	3/70 -	4/70
	10 - 2000 MHz	5/70 -	5/73
	20 - 4000 MHz	5/73 -	3/74
	25 - 320 MHz	4/74 -	present
C.4	2100-3900 MHz Solar Radio Spectrograms of Events (Fort Davis)	1/60 -	12/61
C.4	Solar Radio Spectrograms of Events (Boulder)		
	7.6 - 41 MHz	3/61 -	8/68
	7.6 - 80 MHz/	9/68 -	present
C.4	450-1000 MHz Solar Radio Spectrograms of Events (Owens Valley)	11/60 -	10/61
C.4	Solar Radio Spectrograms of Events (Culgoora)		
	10 - 210 MHz	1/67 -	7/69
	8 - 2000 MHz	8/69 -	2/70
	8 - 4000 MHz	3/70 -	10/70
	8 - 8000 MHz	11/70 -	present
C.4	30-1000 MHz Solar Radio Spectrograms of Events (Weissenau, GFR)	3/68 -	present
C.4	Solar Radio Spectrograms of Events (AFCRL — Sagamore Hill)		
	19 - 41 MHz	1/68 -	7/70
	24 - 48 MHz	7/70 -	8/75
	25 - 75 MHz	8/75 -	present
C.4	20-60 MHz Solar Radio Spectrograms of Events (Clark Lake)	4/70 -	9/70
C.4	160-320 MHz Solar Radio Spectrograms of Events (Dwingeloo)	1/74 -	present
C.4	100-1000 MHz Solar Radio Spectrograms of Events (Dürnten)	1/74 -	present
C.4	24-48 MHz Solar Radio Spectrograms of Events (Manila)	4/74 -	present
C.5	Solar X-ray Events (Vela 1,2; 1963-39A,C)	(10/63)	
C.5	Solar X-ray Events (Univ. of Iowa)		
	Explorer 33; 1966-58A (2-12Å)	7/66 -	10/71
	Explorer 35; 1967-70A (2-12Å)	12/67 -	7/72
C.5	Solar X-ray Events (NRL Tabulation)	1/64 -	10/64
	(See A.11ab for NRL Graphs and list of Satellites)	and 3/65 -	present
C.5	Solar X-ray Events (McMath-Hulbert) OSO-3; 1967-20A (8-12Å)	3/67 -	8/67
C.5	Solar X-ray Events (SMS-1/GOES; 1974-033A; SMS-2, 1975-011A)	11/74 -	present
C.6	Sudden Ionospheric Disturbances (SID)	1/63 -	present
C.6	Sudden Ionospheric Disturbances (SWF)	7/57 -	included in C.6 after 12/62

TABLE III (cont'd)
Table of Contents of "Solar Geophysical Data"

		From	To
C. *Flare-Associated Events* (continued)			
C.6	Sudden Ionospheric Disturbances (SCNA, SEA, bursts)	1/58	included in C.6 after 12/62
C.6	Sudden Ionospheric Disturbances (SPA)	6/61	included in C.6 after 12/62
C.7	Solar Proton Events — Direct Measurement — same as A.12	5/67	present
C.8	Solar Proton Events — Riometer Confirmed Polar Cap Absorption Events (ESSA)	1/67	6/67
C.8	Solar Protons, 26 MHz Riometer Events (South Pole) Provisional	9/63	11/67
C.8	Solar Protons, 30 MHz Riometer Events (Frobisher Bay)	1/65	5/65
C.8	Solar Protons, 30 MHz Riometer Events (Great Whale River)	6/65	2/67
D. *Geomagnetic and Magnetospheric Phenomena*			
D.1	Geomagnetic Indices Ci, Cp, Kp, Ap, aa, Selected Days (aa first published 1/74)	7/57	present
D.1	27-day Chart of Kp for Year	7/57	present
D.1	27-day Chart of Kp Indices	7/57	present
D.1	27-day Chart of C9 for Year	7/57	present
D.1	Principal Magnetic Storms	7/66	present
D.1	Reduced Magnetograms	1/67	present
D.1	Sudden Commencements and Solar Flare Effects	1/66	present
D.1	Equatorial Indices Dst	5/73	present
F. *Cosmic Rays*			
F.1	Cosmic Ray Daily Averages Neutron Monitors (Deep River — graph of hourly values, daily averages begin 11/65)	1/59	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Climax)	9/60	3/72
	Daily averages and graph of hourly values	12/74	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Dallas)	1/64	3/74
F.1	Cosmic Ray Daily Averages Neutron Monitors (Churchill)	5/64	6/72
F.1	Cosmic Ray Daily Averages Neutron Monitors (Alert) Graph of hourly values (Alert)	7/66	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Calgary — also graph of hourly values)	1/71	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Sulphur Mountain — also graph of hourly values)	1/71	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Thule — also graph of hourly values)	4/73	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Tokyo — also graph of hourly values)	12/73	present
F.1	Cosmic Ray Daily Averages Neutron Monitors (Kiel — also graph of hourly values)	12/73	present
H. *Miscellaneous*			
H.60	Alert and Special World Interval Decisions (IUWDS Geophysical Alerts)	7/57	present
H.61	International Geophysical Calendar	1/62	12/62
H.62	Abbreviated Calendar Record	12/68	present
H.63	Retrospective World Intervals	1/66	12/67

periods of special interest, as shown in Table IV, or other specialized data collections or indices. Examples of publications and services available from World Data Centre A for Solar-Terrestrial Physics are given in the information booklet entitled Solar-Terrestrial Physics Services and Publications which is available from World Data Centre A for STP, NOAA, Boulder, Colorado, 80302, USA.

Fig. 1 is a map of the western hemisphere illustrating locations where solar-terrestrial physics observations are being conducted. During the past year data acquired at many of these stations have been sent to scientists in all parts of the world. For example, in the period July 1975 to July 1976, World Data Centre A for STP received 34 individual requests for ionospheric vertical sounding data acquired in South America. These 34 requests represented 899 station-months of data. Sixty-six separate requests were made for geomagnetic data from South American locations representing a total of 1535 station-months of data.

During the next three years requests for data are expected to increase markedly as scientists participate in the International Magnetospheric Study project in an attempt to gain a better understanding of the earth's magnetosphere, the interplanetary medium and the interaction between the two. The exchange of scientific data through the world data centre system for projects such as the International Magnetospheric Study should prove

TABLE IV

UAG Report on Selected Solar-Terrestrial Events

UAG-5:	"Data on Solar Event of May 23, 1967 and its Geophysical Effects", compiled by J. Virginia Lincoln, World Data Centre A, Upper Atmosphere Geophysics, ESSA, February 1969.
UAG-8:	"Data on Solar Geophysical Activity October 24-November 6, 1968", Parts 1 and 2, compiled by J. Virginia Lincoln, World Data Centre A, Upper Atmosphere Geophysics, ESSA, March 1970.
UAG-9:	"Data on Cosmic Ray Event of November 18, 1968 and Associated Phenomena", compiled by J. Virginia Lincoln, World Data Centre A, Upper Atmosphere Geophysics, ESSA, April 1970.
UAG-12:	"Solar Geophysical Activity Associated with the Major Geomagnetic Storm of March 8, 1970", Parts 1, 2 and 3, compiled by J. Virginia Lincoln and Dale B. Bucknam, World Data Centre A, Upper Atmosphere Geophysics, NOAA, April 1971.
UAG-13:	"Data on the Solar Proton Event of November 2, 1969 through the Geomagnetic Storm of November 8-10, 1969", compiled by Dale B. Bucknam and J. Virginia Lincoln, World Data Centre A, Upper Atmosphere Geophysics, NOAA, May 1971.
UAG-21:	"Preliminary Compilation of Data for Retrospective World Interval July 26-August 14, 1972", compiled by J. Virginia Lincoln and Hope I. Leighton, World Data Centre A for Solar-Terrestrial Physics, November 1972.
UAG-24:	"Data on Solar-Geophysical Activity Associated with the Major Ground Level Cosmic Ray Events of 24 January and 1 September 1971", Parts 1 and 2, compiled by Helen E. Coffey and J. Virginia Lincoln, World Data Centre A for Solar-Terrestrial Physics, December 1972.
UAG-26:	"Data Compilation for the Magnetospherically Quiet Periods February 19-23 and November 29-December 3, 1970", compiled by Helen E. Coffey and J. Virginia Lincoln, World Data Centre A for Solar-Terrestrial Physics, May 1973.
UAG-28:	"Collected Data Reports on August 1972 Solar-Terrestrial Events", Parts 1, 2 and 3, edited by Helen E. Coffey, World Data Centre A for Solar-Terrestrial Physics, July 1973.

most fruitful, not only for the scientists participating in these programs, but also for the increased understanding of the environment in which we live and the subsequent benefit for mankind.

References

Buhmann, R. W., J. G. Roederer, M. A. Shea and D. F. Smart, 1974. *Master Station List for Solar-Terrestrial Physics Data at WDC-A for Solar-Terrestrial Physics.* World Data Centre A for Solar-Terrestrial Physics, Boulder, Colorado, UAG Report No. 38.

Secretariat of the ICSU Panel on World Data Centres, Washington, D.C. December, 1973. *Guide to International Data Exchange through the World Data Centres.*

Secretariat of the Special Committee for Solar-Terrestrial Physics, Washington, D.C., 1975. *Solar-Terrestrial Physics and Meteorology: A Working Document.*

Shea, M. A. and J. Virginia Lincoln, 1976, (in press). Overview of the International Effort in Solar-Terrestrial Physics Data Exchange with Emphasis on Latin American Participation. Revista Geofisica, Solar Geophysical Data (prompt and comprehensive reports) published monthly in two parts by World Data Centre A for Solar-Terrestrial Physics.

The National Geophysical and Solar-Terrestrial Data Centre, Boulder, Colorado, September 1975. *Solar-Terrestrial Physics Services and Publications.*

World Data Centre A for Solar-Terrestrial Physics, Boulder, Colorado, 1973. *Catalogue of Data on Solar-Terrestrial Physics.* UAG Report No. 30.

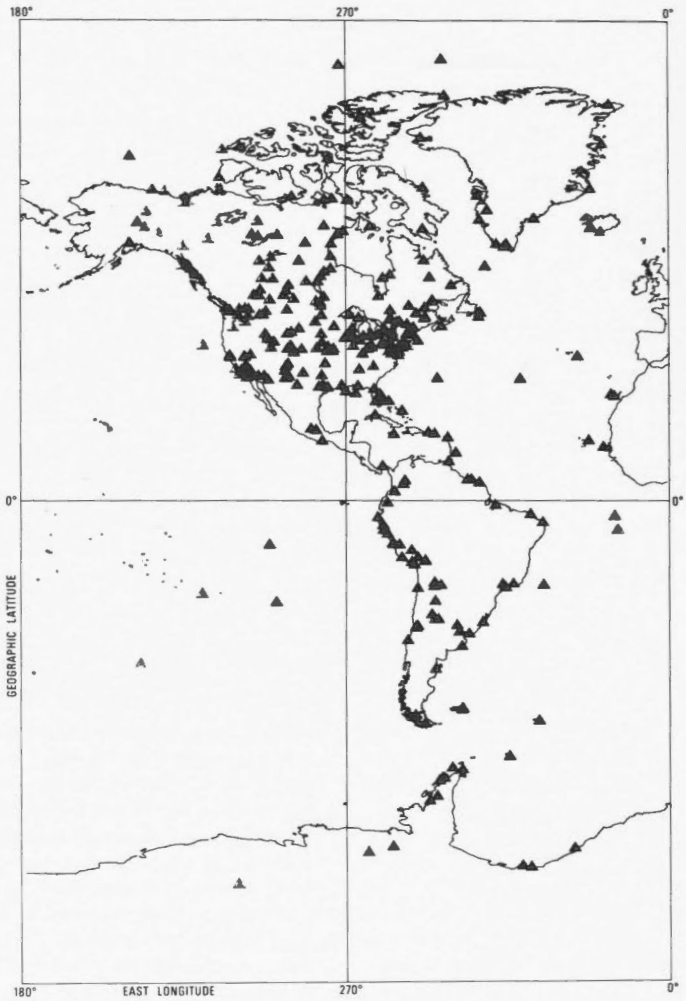

Figure 1. A map of the western hemisphere where the triangles denote locations at which solar-terrestrial physics observations are being conducted. (Courtesy of World Data Centre A for Solar-Terrestrial Physics.)

Padre J. E. Ramírez:

Nuestro siguiente expositor es el Dr. D. F. Smart quién nos presentará su papel que se titula **"SILAF y Evento Especiales Protón".**

Dr. D. F. Smart:

The study of solar proton events, with their associated disturbances on the terrestrial environment, has been of interest to geophysicists for many years, particularly since the 1930's and 1940's when it was shown that the occurrence of a large solar flare

was associated with geomagnetic disturbances at the earth a day or two later. (See standard works such as Chapman and Bartels (1940) or Stormer (1953) for summaries of early research in what is now called solar-terrestrial physics.) This entire subject area has been researched by many people interested in solar-terrestrial physics — from scientists interested in solar physics to those interested in many other aspects of the entire subject area including the interplanetary medium, the magnetosphere, the aurora, the geomagnetic field, the ionosphere and the more applied area of communications. One of the most fascinating and intriguing problems that most of these researchers have tried to solve, in one way or another, is the problem of predicting these events in advance.

This problem has many aspects such as:

1. how can we predict the occurrence of a solar flare on the sun?
2. once a solar flare is visually observed, how can we predict if the flaring region has accelerated energetic solar protons with sufficient flux to have terrestrial effects?
3. if we know that solar protons have been accelerated and released into the interplanetary medium, how can we predict the intensity of these protons to be expected at the earth and, in turn, the magnitude of the terrestrial effects?

This paper summarizes some recent work done on the prediction of solar particle fluxes at the earth after the occurrence of a solar flare and discusses some related aspect to socio-economic conditions in Latin America.

Fig. 1 conceptually illustrates the control the sun exerts over the interplanetary medium and the earth. The solar wind flows radially outward from the sun carrying "frozen in" magnetic field lines. The rotation of the sun makes the Archimedean spiral pattern of the interplanetary magnetic field. The earth's magnetic field acts as an obstacle to the flow of the solar wind plasma and the interaction of the plasma flow around the earth's magnetic field generates the earth's magnetosphere and its trapped radiation belts.

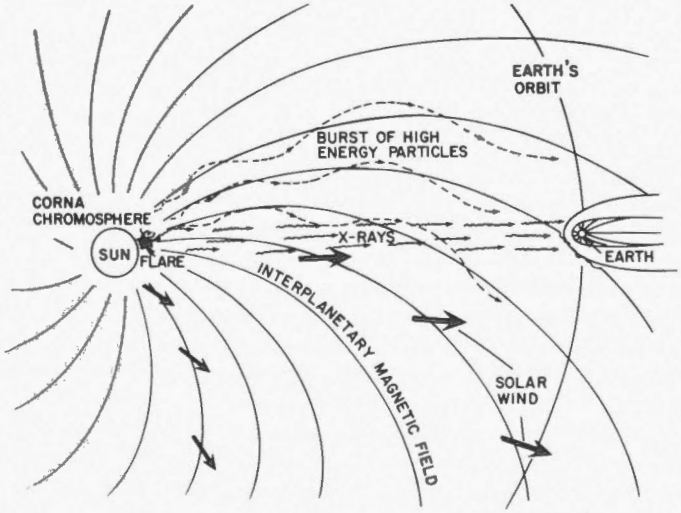

Figure 1. A conceptual illustration of the sun and solar emissions that control the interplanetary medium.

The solar-terrestrial environment is controlled by the energy outflow from the sun. When there are transient increases in the solar energy outflow, such as occurs during the phenomenon called the solar flare, there are corresponding effects in the high atmosphere of the earth in time scales ranging from minutes to many hours as schematically illustrated in Fig. 2.

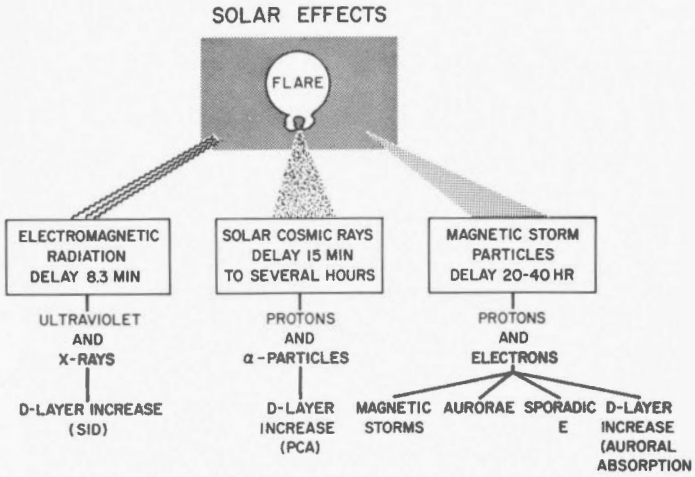

Figure 2. Schematic illustration of solar effects.

Many of the more spectacular solar flare initiated effects are not familiar to people living in Central and South America because the influx of solar particles is restricted by the earth's magnetic field to the polar regions. However, there are exceptions when extremely large, but infrequent events (at most a few per solar cycle) may generate particles with sufficient energy to penetrate to low latitudes. Whenever a solar flare occurs, the X-ray emission from the solar flare has an almost immediate effect on the sunlit ionosphere, irrespective of geomagnetic latitude, such that high frequency radio communications may be temporarily disrupted.

At the present time there is no reliable method to predict the occurrence of a solar flare on the sun even an hour or two in advance. However, once a flare occurs, there is now a reliable predictor that indicates if this flare produced and/or accelerated a sufficient number of solar protons so that a polar cap absorption event (as detected by riometer measurements in the polar caps) would be expected to occur within a few hours of the visual flare. This predictor (Castelli *et al.*, 1967) is found in the solar radio spectrum observations as illustrated in Fig. 3. The distinctive "U" shape present in the three curves in this figure is now the accepted criterion that the sun has emitted solar protons capable of producing polar cap absorption and consequently disrupting high frequency radio communications in the earth's Arctic and Antarctic regions. To the best of our knowledge this predictor, which represented a major breakthrough in proton prediction techniques, is an excellent predictor of the production of these solar protons from a flare on the visual hemisphere. Solar proton events have occurred with no known flare association on the visual hemisphere. In these cases, the presence of a known active region on the invisible hemisphere leads to the assumption that a flare on the invisible hemisphere was responsible for these particles. There is no method of predicting these events in advance short of satellite-borne detectors situated such that they can detect solar activity on the invisible hemisphere.

Once the solar radio observation indicates that the occurrence of a solar flare would most likely produce solar particles, the electromagnetic emission characteristics of the solar flare are

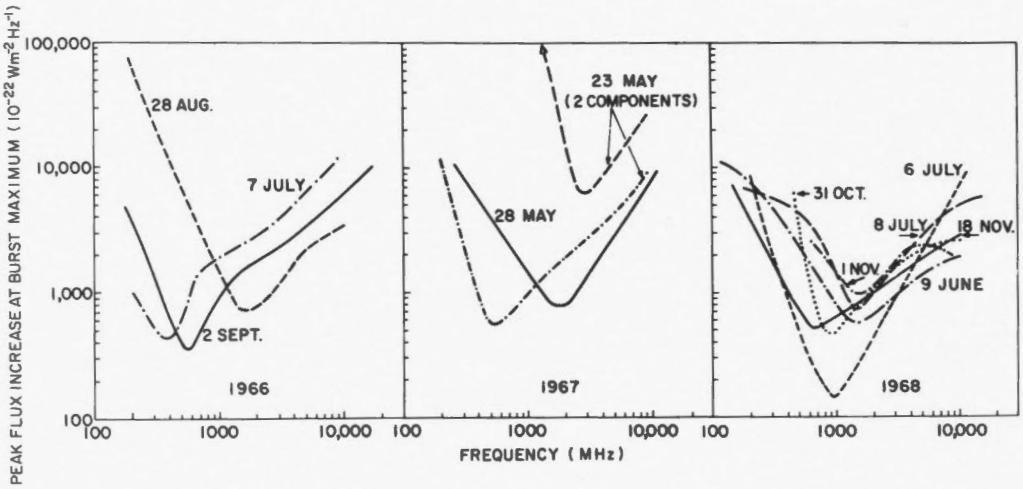

Figure 3. Spectra of solar radio bursts associated with principal PCA events (1966-1968). Flux values are based on published data from many sources.

entered into a large computer program to theoretically predict the flux of solar particles to be expected at the earth at various energy ranges throughout the next few days. The resulting flux profile is highly dependent upon the location on the sun where the flare occurred; e.g., a solar flare located at the far eastern part of the solar hemisphere may not result in as many particles being detected at the earth as will an identical flare on the western part of the solar hemisphere.

This computer program predicts a time/intensity proton flux profile for as many as 15 different energy intervals as much as 300 hours in the future. In addition the program can handle several different solar proton events simultaneously, a phenomena which often occurs during solar active periods when the particle flux from a new solar proton event may be detected at the earth before the flux from a previous event has decayed. The computer program can be used in conjunction with real time solar optical and solar radio data in addition to using real time solar wind data (if available) to define better the interplanetary propagation conditions existing between the sun and the earth at the time of the solar proton event. Illustrated examples of the predicted output for several energy channels of various widths from 0.5 to 60 MeV are illustrated in Fig. 4. One of the important things to note is the tremendous dynamic range that the solar emission covers.

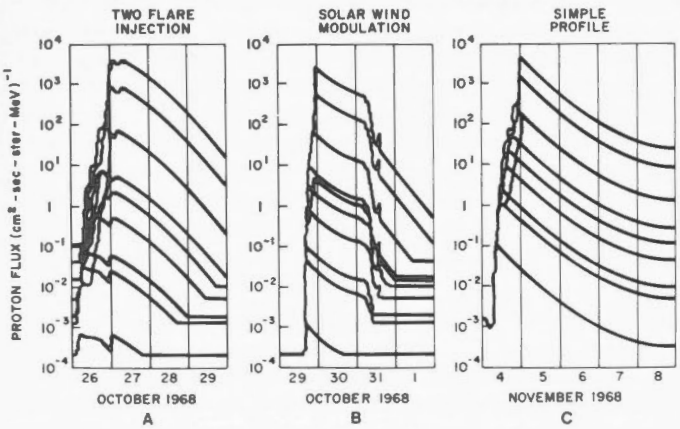

Figure 4. Illustration of predicted solar proton flux profile.

Although this case covers eight decades of magnitude, extremely large events can cover as many as 12 or 13 decades. Fig. 4 illustrates some of the differences between the profiles generated for three sample cases. Fig. 4A illustrates the predicted flux from a two flare injection of solar particles (one flare at 32°E, 0046 UT, 26 October, 1968 followed by a second flare at 2353 UT). Fig. 4B illustrates the effects of solar wind modulation on the predicted particle fluxes at the earth as indicated by the sudden decrease in the predicted particle flux on all energy channels on 31 October, 1968. Fig. 4C illustrated a relatively simple time/intensity profile generated from a flare at 90°W, 0524 UT, on 4 November, 1968.

Although this computer program was originally prepared for use by the USAF Space Environment Support Program, a special version of the program has been prepared to operate on the computer system at the National Oceanic and Atmospheric Administration Solar Forecast Centre in Boulder, Colorado. This version of the program utilizes the X-ray data available to the NOAA Space Environment Support Centre from the SMS/GOES satellites with the proton energy intervals adjusted to match the energy channels from the Solar Proton Monitoring Experiment on the SMS/GOES satellites and the NOAA satellites.

An obvious question to be asked is "Why is the advanced prediction of solar particle fluxes at the earth of importance or of interest in everyday activities?". Whenever polar cap absorption is present there is an anomalous absorption of radio signals in the polar cap. People who live in the northern hemisphere and who try to utilize transatlantic communication or communication circuits in the Arctic frequently find that high frequency radio communications on normal frequencies are not possible during these events and that other methods must be utilized. The prediction of the time/intensity profile of the polar cap absorption would permit communications people to estimate when the disruption would begin, how severe the disruption would be on various propagation paths and when the disturbance would end so that normal operations could be resumed.

One of the most spectacular effects of major solar events is the presence of an aurora. Although usually confined to the higher latitudes, aurora as far south as northern Mexico or as far north as southern Chile and Argentina have been observed, albeit

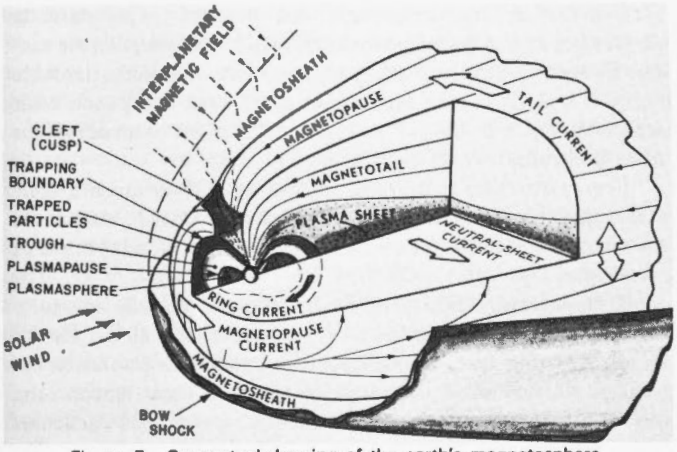

Figure 5. Conceptual drawing of the earth's magnetosphere.

rarely, in the past. Fig. 5 is an artist's concept of the earth's magnetosphere. This is actually a huge dynamic current system that surrounds the earth and perturbations to this system can affect the ionosphere. Electron precipitation events are caused by low energy particles precipitating out of the magnetosphere, a phenomenon often accompanied by aurora and geomagnetic storms.

Fig. 6 is an infrared image of an aurora as detected by separate passes of a meteorological satellite over North America. Close inspection of the figure reveals the North American continental outline in addition to which major cities can be identified. In this particular photograph the aurora is confined to the auroral zone latitudes, although major events result in aurora further south with a corresponding disruption in communication circuits in these areas.

Fig. 7 is a composite image taken over the southern polar regions in August 1972. The absence of major inhabited areas makes geographical orientation difficult, but lights of cities in the southern Australian continent can be identified in the upper centre portion of the figure.

At the present time perturbations of the magnetosphere with the resulting terrestrial effects such as changes in the geomagnetic field may have long term effects of which we are not fully aware. For example, recent research seems to indicate correlations between geomagnetic activity and weather patterns in some regions of the world.

As mentioned previously, most of the effects of solar flares on the terrestrial environment are confined to the polar regions as evidenced by the presence of polar cap absorption, aurora and geomagnetic disturbances. However, the sun does have an impact on the social and economic patterns of life in Latin America, particularly with respect to high frequency point-to-point communications. People in locations with communication systems depending on the ionosphere realize that there are times when the "normal frequencies" cannot be utilized. This may be because solar radio noise may suddenly jam the normal frequencies so that they cannot be used for communications or solar X-ray emission may cause sudden ionospheric disturbances.

The possibility that solar cycle changes may have effects on weather or climatic patterns is another potential area where solar-terrestrial physics research may prove to be useful on social and economic conditions in Latin America as well as the rest of the world.

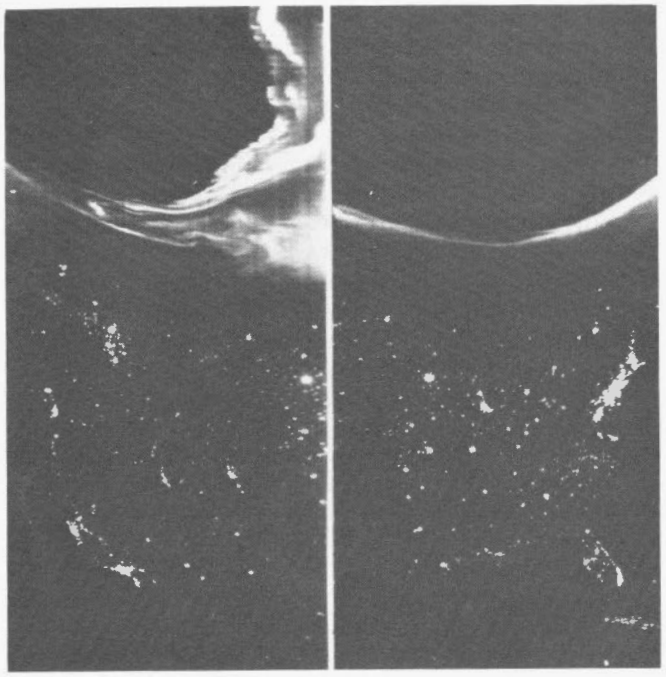

Figure 6. Satellite obtained infrared image showing North American cities and aurora.

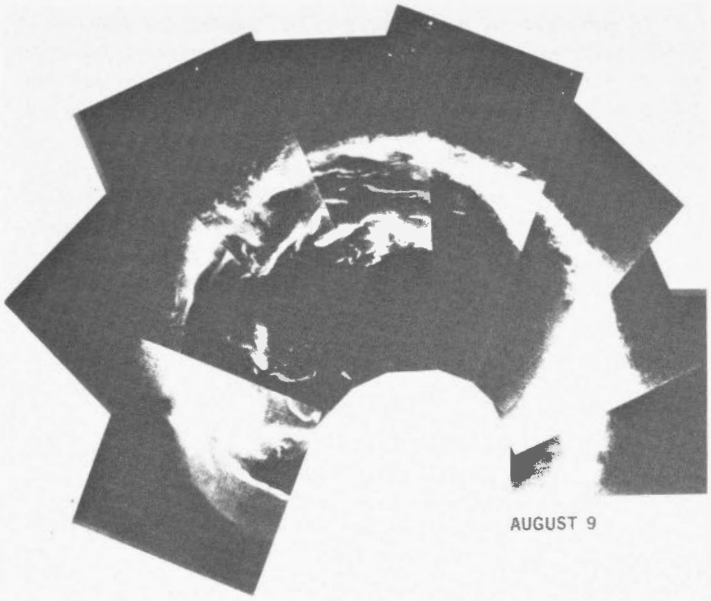

Figure 7. Satellite obtained infrared image showing auroral displays over the Antarctic during 9 August, 1972.

Research in many areas of solar-terrestrial physics often necessitates the utilization of some basic geophysical parameters. Unfortunately, the generation of many of these basic parameters requires sophisticated computer programming and/or extensive computer time. It has been suggested by Prof. Sandro Radicella of Argentina that a special handbook be prepared containing the more commonly used geophysical parameters for use by researchers in the Latin American area. Some of the suggested parameters include the following:

1. a contour map of geomagnetic vertical cut-off rigidities utilized primarily by cosmic ray physicists,

2. tables of geomagnetic field data such as the total field, the inclination and the "L" value at intervals of five degrees over the Latin American region, calculated at both the surface and 50 kilometres,
3. tables of solar zenith angles for selected locations in Latin America where ionospheric measurements are routinely conducted — these tables would be calculated as a function of local time and season of the year.

These calculations are presently being made and the final publication of this station handbook is anticipated in 1977.

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Padre J. E. Ramírez:

Nuestro siguiente expositor es el Dr. A. Giesecke quién nos presentará su papel que se titula **"Intercambio de Datos Sísmicos"**

Dr. A. Giesecke:

El tema que me ha asignado el Dr. Kausel esta mañana a última hora, porque esto es una sorpresa, se refiere al intercambio de información sísmica. Hemos escuchado las exposiciones del Sr. Svendsen y de la Dra. Margaret Shea respecto al centro de información (el Centro Mundial "A" en Estados Unidos), en lo que se refiere a geomagnetismo en particular y en la parte que se refiere a física solar terrestre, y cuando hablamos de centros o sistemas latinoamericanos tendríamos que considerar el contexto de esos centros en relación con las funciones que ya cumplen los centros que tienen una capacidad global.

La filosofía detrás de la creación de SILAG, SILAS, SIDAM y los sistemas latinoamericanos ha sido presentada cuando el Dr. Salgueiro presidía la Comisión de Geofísica del IPGH.

Quisiera comentar sobre esto, que cada uno de estos sistemas tiene una filosofía y una razón de ser distinta, no se pueden unificar criterios, sencillamente porque son casos distintos. En el caso de un sistema de sismología, tenemos que pensar que hay posiblemente tres o más criterios en cuanto se refiere al tipo de información que debe ofrecerse e intercambiarse.

La información inmediata, casi en tiempo verdadero, necesaria cuando ocurre un terremoto o un movimiento sísmico fuerte. Hay una angustia por tener información de la mayor cantidad de estaciones posibles, tanto para fines de defensa civil, medidas de emergencia, como para la información al público en general. Aún cuando no sean terremotos catastróficos, la información pública es una función muy importante dentro de la sismología.

No podemos pensar en que esa información tenga un carácter científico, pero no deja de ser un servicio público que requiere un sistema de intercambio de información precoz e inmediato.

Otro tipo se información es el que se refiere a la recopilación de hechos en una región más o menos localizada, cuando en los distintos países se inician programas para la evaluación del riesgo sísmico.

Este tipo de estudio tiene un creciente interés, y por parte de nuestros gobiernos, en latinoamérica, existe conciencia en ese sentido. El acopio de información que requiere, no necesariamente abarca a toda la región latinoamericana, sino que puede estar localizada dentro de los confines nacionales o por lo menos en los países limítrofes.

Este es otro tipo de información que no necesariamente ha de estar disponible inmediatamente, pero sí debe estar lo más al día posible para que sea lo suficientemente completa para los estudios a realizarse.

Y finalmente, el tipo de información que se debe de intercambiar a nivel de la investigación. Hemos escuchado al Dr. Kausel cuando nos dijo que, analizando únicamente las publicaciones como el Journal of Geophysical Research y otras, encontraba solo cuatro trabajos latinoamericanos, entre 336 artículos publicados, y parecería entonces, que no se justificaría la creación de un centro aislado a nivel latinoamericano en función de investigadores latinoamericanos dentro de ese tipo de contexto.

Sin embargo, estos son sólo comentarios con respecto al tipo de información que se piensa intercambiar.

Ahora, evidentemente la cantidad de datos que existen aún en los centros mundiales es bastante incompleta. Hemos hecho un examen de casos específicos para períodos específicos y cuando hablo de "hemos" me refiero a la labor que se ha hecho en CERESIS, labor un poco incipiente, pero sin embargo, analizando la cantidad de eventos que llegan a ser tomados en cuenta por los organismos como NOA, o el centro mundial "A", encontramos que se pierden eventos en una proporción bastante alarmante, es decir, se pierden en el sentido de que no son reportados, no son considerados y finalmente quedan en los sismogramas enterrados en los archivos nacionales. En un período de tres meses, en un análisis que se hizo de datos del año pasado para una determinada región, encontramos que se podían recuperar casi un 20% a 25% de eventos adicionales que son muy importantes para estos estudios de sismicidad y evaluación de riesgos sísmicos, o sea, que hay toda una fuente de requerimientos en cuanto a flujo e intercambio de datos.

La razón para ello, es que a veces las estaciones sencillamente no informan. En determinadas áreas hubo un período donde las facilidades de cómputo de NOA fueron cambiadas, modificadas, y donde el IECC, Centro Internacional, asumió esa tarea. Se hizo un informe sobre el número de estaciones que enviaban datos directamente al IECC y realmente el análisis es bastante triste, porque la cantidad de datos que llegan al Centro sencillamente no guarda relación con el número de estaciones, ni el número de eventos, ni las posibilidades del flujo de información que este ofrece.

Por otro lado, algunas de las estaciones que informan los datos lo hacen con demasiado atraso, más allá de las fechas límites para las cuales se puedan procesar determinados eventos.

En otros casos, como está automatizado el procesamiento de datos, estos deben ir en determinados formatos, y si los mensajes sísmicos no van en el formato correcto, la computadora los rechaza y el evento queda fuera de la consideración de la ubicación epicentral. Hay una serie de factores por los cuales la acumulación de datos y por ende el intercambio de información, deja bastante que desear.

El caso de la sismología, se asemeja un poco al caso de la meteorología, en que nadie se siente propietario exclusivo de los datos sismilógicos. No es como el caso que se mencionó aquí de la gravimetría, donde hay un problema de retener datos por las

significancias que puedan tener desde el punto de vista nacional. En la sismología, todo lo contrario, creo que hay una gran apertura en el intercambio de datos, porque es una evidente tarea cooperativa entre naciones.

Yo he mencionado algunos de los problemas que tenemos, con respecto a los centros mundiales, la carencia de datos que tienen y las razones para ello.

Hay otro problema en el intercambio de datos. Es en relación con las redes de comunicaciones no existentes, en el sentido de que no están funcionando 24 horas al día y a disponibilidad de la comunidad de los sismólogos. Lamentablemente los eventos sísmicos no ocurren siempre en las horas y los días de trabajo, ocurren en cualquer hora, día y noche.

También tenemos el problema de la comunicación con los observatorios ubicados en lugares remotos, lugares no atendidos permanentemente por personal.

En general los servicios sismológicos se caracterizan por carecer de presupuestos operativos adecuados, sin embargo, hemos estado subsanando algo la falta de comunicación a traves de la radio de alta frecuencia.

El flujo de intercambio de datos también enfrenta otro problema cuando uno necesita datos de los centros mundiales. Hemos escuchado de parte de la Dra. Shea que el centro mundial canjea datos, pero si el centro mundial no recibe muchos datos de latinoamérica, no puede haber tal canje y evidentemente habrá entonces un costo para los investigadores que solicitan datos.

Hay una disparidad también en la producción de información desde el punto de vista de boletines, que son sumamente útiles. Existen aquellos que consignan aún el más pequeño evento local de todas las estaciones que son operadas.

Esto es muy valioso, ya que de esta manera queda consignado en alguna parte de que ha existido un evento en el dismograma y se puede recurrir nuevamente a esa fuente. Pero por otra parte hay estaciones que no producen boletines; es prácticamente haber operado una estación y haber obtenido un sismograma para luego enterrar el dato.

La situación actual es de que existe una incipiente infraestructura a nivel de intercambio de información y un creciente empuje hacia reflotar información escondida. La labor que se ha hecho ha tenido la virtud de crear lazos horizontales entre los países de la región para el intercambio de datos y eso es ciertamente algo muy positivo. Se ha establecido y está en funcionamiento una red, no de 24 horas al día, pero por lo menos una red de comunicación diaria. Hay equipos para microfilm, y copia de sismogramas que se pueden enviar a los distintos lugares donde se soliciten. Existe en el centro regional en Lima una cantidad limitada de copias de sismogramas obtenidos de NOA. Hay el ofrecimiento del Centro Internacional de Sismología en Londres, para procesar los nuevos eventos que se puedan encontrar y volver a difundirlos.

Hay bastante labor que realizar en este campo, yo creo que habría que analizar muy cuidadosamente la razón de ser de un centro, de un sistema latinoamericano sismológico en cuanto a su dimensionamiento, habría que empezar obviamente por los requerimientos de los usuarios para no sobredimensionar nuestro pensamiento en este caso.

No he mencionado el caso de tsunamis. El Dr. Kausel habló de la necesidad de información muy rápida también en este aspecto, sobre todo de aquellos tsunamis originados por sismos cercanos a las proprias costas del país, pero eso es otro tipo de problema de intercambio de datos, que es muy específico.

Hay otro tipo de datos que antes se consideraba como propios de una área reservada, porque se trataba de datos sísmicos que provienen de los trabajos en el mar, explosiones sísmicas. No en épocas recientes, pero en épocas anteriores, se solía acumular una gran cantidad de información que luego no era distribuida, no habia intercambio de información ni en el propio país y menos con la región. Hoy en día sí hay posibilidad de intercambio pero no hay un sistema que lo permita. No se pone esta información a disposición de los países y a veces aquellos no conocen que ha habido un proyecto Nariño en Colombia, o que ha habido un proyecto en el sur de Perú. Así se desarrollan estudios que significan una acumulación de datos que serían interesantes para muchos otros.

Finalmente, el caso de la información que proviene de los acelerogramas es decir, instrumentos que registran movimientos fuertes. Es también otra área que requeriría un poquito más de atención. En primer lugar, habría que pensar en la necesidad de tener una facilidad en América Latina para la digitalización de los datos. Lamentablemente, sucede que la digitalización que se produce en NOA, por ejemplo, no es comparable con la que se produce en un centro de Japón, o la que hemos hecho en San Juan, Argentina, y si volvemos a reconstruir, de los datos digitales, el acelerograma original, producimos tres distintos acelerogramas. Hay algo que aparentemente no está todavía solucionado en la técnica de digitalización, pero en general, los acelerógrafos que funcionan en muchos de nuestros países producen registros que son enviados a NOA, entidad que hace este trabajo y lo pone a disposición del usuario. Este caso de la información de acelerógrafos, es un caso de una aplicación práctica muy importante dado que es la materia prima de mayor interés para el ingeniero estructural que tiene la responsabilidad de diseñar las construcciones asísmicas. En muchos países, el Perú uno de ellos, se ha usado el registro del acelerógrafo de California para el diseño de edificios. Obviamente es una buena aproximación, pero no se adecua realmente a las condiciones propias del país.

De esta manera he tratado de plantear el estado del intercambio de datos en el campo de la sismología.

Discusión :

Ing. R. Salgueiro :

El Dr. Giesecke acaba de informarnos acerca de la naturaleza de la información sismológica que actualmente maneja el CERESIS.

Con muchos esfuerzos, los países sudamericanos han establecido y organizado esta institución que tiene ya una década de existencia.

Nos hace una semblanza real de las dificultades que encuentra en lo que se refiere a la operación para cumplir los objetivos primarios para los que fué constituída esta institución.

Creo que es necesario crear el sistema de información latinoamericano de sismología que llamamos SILAS, de tal manera que se pueda integrar toda la información de carácter sísmico. Para ello será necesario un estudio técnico bien detallado, que sea encausado de tal manera que plantee sus objetivos y metas, para que, en mediano o largo plazo, pudiera realmente consumarse la constitución de un sistema informativo real, adecuado y ajustado a los requerimientos de los países latinoamericanos.

El Dr. Giesecke nos ha hablado sobre la distinta característica de la naturaleza de esta información. Por

ejemplo, en la última parte de su exposición se refirió a la información de los acelerógrafos, pues creo firmemente que si CERESIS recibe un apoyo a nivel internacional realmente adecuado, como resultado del apoyo que cada uno de ustedes exponga ante las autoridades de gobierno de sus países, es posible lograr la consumación de ese objetivo.

Quisiera que en principio, como resultado de esta reunión, podamos redactar una resolución en la cual se encarge a CERESIS un estudio bien meditado de la situación, y en base a ello diseñe el sistema de información que fuese el más adecuado para que sea manejado por esta institución.

No sé si los recursos humanos y los medios físicos de que actualmente dispone CERESIS, serán suficientes para realizar la primera fase de estudios, y luego conseguir los medios económicos necesarios para poder hacer de este centro una institución realmente representativa dentro del esquema mundial.

Padre J. E. Ramírez:

Yo quisiera hacer constar de que Alberto Giesecke ha mostrado siempre un interés, una constancia y un entusiasmo extraordinario paraque en Sudamérica haya intercambio de datos sísmicos, y si algo se ha realizado, sin duda que se debe a él.

De manera que yo aprovecho esta ocasión para felicitarlo a él por ese hecho y por su conferencia.

El siguiente expositor es el Sr. R. Geller, asociado al Sr. P. J. Winter, que hablará sobre el **SILAG.**

Mr. R. Geller:

A few general comments describing the development of the gravity survey data existing now in Latin America might help define the current need for a related information system, prerequisite to the production of a coherent series of gravity maps. In contrast to the apparent design followed in Canada, gravity in Latin America grew in a more random manner.

Almost all of the existing measurements were made since 1950. Twenty-five years ago, there were available a scattered distribution of pendulum determinations, limited exploration surveys, traverses observed with the cumbersome instruments of that time and the first measurements made with the modern portable relative gravity meters.

During the 1950's, as the Worden and similar instruments came into use, national gravity surveys were initiated by most Latin American countries in accordance with the recommendations by PAIGH, justified as much by geodetic as geological applications.

National cartographic agencies, in most cases, assumed responsibility for national gravity surveys together with a few universities and scientific institutions. During this period, networks of gravity traverses began to evolve, usually from a pendulum base as origin and provisional datum, following the scheme of the monumented geodetic levelling concurrently being accomplished for topographic mapping. The expense of survey control could not be justified solely for gravity mapping. Topographic mapping and mapping control were emphasized in the developed and populated areas and this circumstance continues to limit the distribution of gravity values in Latin America. The lack of horizontal control even where precise levels have been run continues to delay the reduction of some gravity data. Exploration gravity surveys were most often remote from geodetic control and were related to arbitrary mapping and gravity datums. The relative precision of the gravity surveys completed during the 1950's was very good and measurements were made with the confidence that absolute standards would eventually be developed to permit integration of the data within a regional or world system. Beginning about 1960, relative gravity meters with much improved drift characteristics and range made possible the observation of coherent national and international gravity reference station networks. A regional network was extended through Central and South America during 1961 and 1962. North-south calibration lines were observed with groups of instruments during 1963 and 1965 in the west from Alaska through Central America to Tierra Del Fuego and from eastern Canada through the Antilles to Buenos Aires, Argentina. By 1970, direct ties had been made from South America to Africa and Europe and national gravity reference networks were largely adequate for control of existing local survey data. Coherence had been achieved by inter-comparison of instruments. The construction of accurate semi-portable absolute instruments by 1969 established the absolute datum and scale for adjustment of the World Gravity Standardization Net, adopted in 1971 by the International Union of Geodesy and Geophysics. Over 100 stations of the world net are included within Latin America.

In 1971, it was evident that several hundred additional base ties had been made in Latin America with a precision comparable with the world net. About 70,000 field stations had been observed over monumented control points in addition to exploration surveys and the bulk of these data remained in an intermediate stage of computation. The PAIGH Commission for Geophysics suggested the unifying concept of a Latin American gravity network. A work group was formed during 1971 within the Commission for Geophysics for the purpose of organizing the Latin American gravity information system called SILAG. Individual tasks were identified and defined. The first of these is the collection and adjustment, within the framework of IGSN71, of all precise base ties from Latin America. The Canadian delegation for PAIGH will soon publish and distribute the catalogue of values and descriptions for the Latin American Gravity Standardization Net, by which absolute standards for gravity datum and scale will have been extended to all of Latin America.

One of the tasks remaining in 1976 is consideration of a standard approach to organization, automation, computation, storage and retrieval of the various categories of accumulated gravity survey data adjusted to the standard gravity values. When final values are available in a convenient form, a coherent series of gravity maps and other useful presentations can be prepared. The cooperation of geologists and geophysicists with the cartographers is necessary for review and editing prior to publication. With reasonable success, 10 to 15 gravity anomaly charts will be published at a scale of 1:500,000 — 1:1,000,000 during the next two to three years. The present status of gravity data in each country ranges from the preliminary stages of organization to published final values and charts, most of which require adjustment and revision to the standard system. There are to my knowledge 19 LaCoste and Romberg and 12 Worden gravity meters now being used in Latin America producing from 5 — 7,000 new stations each year, exclusive of commercial surveys. Future extension of surveys will be limited by the production of large scale topographic maps and monumented geodetic control.

Mr. P. J. Winter:

The compilation and adjustment of a unified gravity reference network for Latin America began at the Earth Physics Branch in January 1973. Observational data forwarded to Canada through IAGS, Panama were reduced and the results of a preliminary adjustment were presented to the Geophysical Commission of PAIGH at the Panama meeting in April 1973. Since that time many additional data have been received and incorporated into the network. The bulk of the effort during the past year has been concentrated on the compilation of the description of the reference stations in the network. With the exception of the descriptions for Panama this work is essentially complete. The compiled descriptions have been forwarded through IAGS, Panama to the various national agencies concerned for final verification before we send them to press. A number of agencies has now returned the updated material.

The Latin America Gravity Standardization Net presently spans some 20 countries and consists of 7,800 gravimeter connections between 1,005 reference stations, 280 of which are common to the IGSN71. The results of the adjustment and the station descriptions will be available for distribution in the next few months. Complete documentation of the adjustment will be presented at the PAIGH meeting in Quito next year.

National networks

Fig. 1 shows the national networks in Central America, including the Dominican Republic. There is also a comprehensive network of about 250 stations in Mexico which is not shown in the diagram.

Fig. 2 indicates the national networks in South America (the large dots represent IGSN71 stations and the small ones the national network stations). You will note that we have not included the national network for Brazil. Although we were aware of the existence of national data in Brazil we were unable to incorporate it in the adjustment since we did not have the raw gravity readings available. Discussions are currently underway with the National Observatory and the University of Parana with a view of future development of the network and its incorporation into the Latin American Gravity Standardization Net.

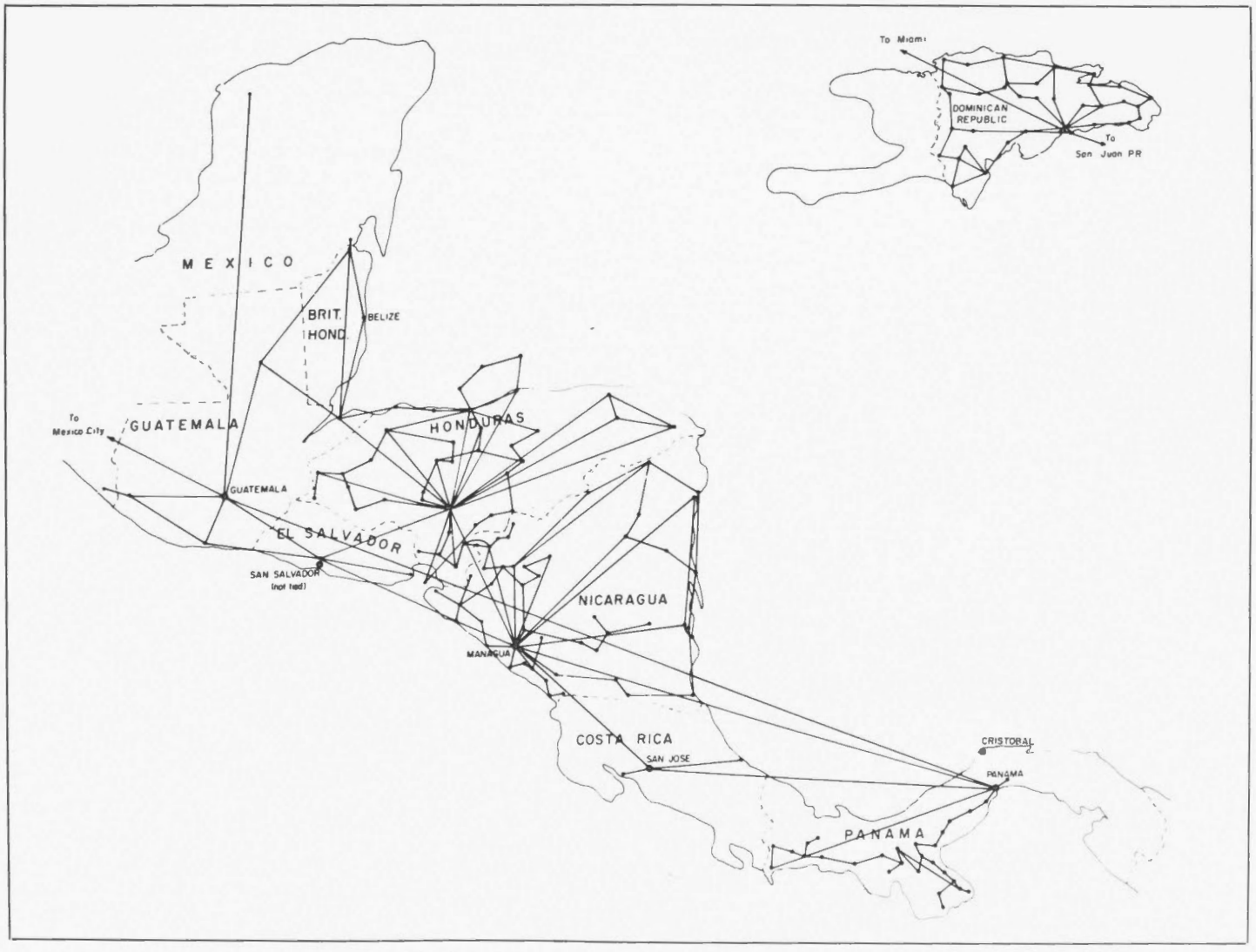

Figure 1. National gravity networks in Central America.

Figure 2. National gravity networks in South America.

Station description booklets

The descriptions of the gravity stations will be compiled into sets for each country. Loose leaf binders which will hold up to 250 descriptions will be available. At the front of each of these sets there will be a computer print-out of the base stations contained therein. This listing will be in two parts. The first part will be a listing of the bases placed in alphabetical order and the second will be a duplicate listing indicating the numerical sequence of the bases. Fig. 3 shows part of the listing for Argentina, as an example. The listings will be followed by network diagram maps and then the station descriptions in alphabetical sequence. The descriptions will be in two formats — one being the official stations in IGSN71 (Fig. 4) and the other for the remaining national network stations. Since the IGSN71 bases are situated throughout the world and many languages are involved, the text and reference material are usually given only in English. However, for the purpose of the LAGSN publication we have added a text in Spanish or Portugese as appropriate.

ARGENTINA (LATIN AMERICAN NET) 21/09/76 PAGE 1

EPB NO.	IGSN NO.	NAME	CNTRY/ PROV	IGSN G-VALUE	LAGN G-VALUE	EGM EST	S LATITUDE	LONGITUDE	A F	ELEV (M)	A F	DESCRIPTION	STAT
9356-68		ANATUYA	ARG		979186.17		3 28 27.00	62 50.00	3	107.00	3	AIR STATION HANGAR	
9364-68		ASUNCION	ARG		978972.81		3 25 15.50	57 31.30	6	25.00	5	MARBOLA MONUMENT	
9304-68		BAHIA BLANCA	ARG		980056.20		3 30 46.00	62 10.00	3	60.00	2	CYE ESPONA AIRPORT	
9305-68	43982K	BAHIA BLANCA	ARG	980052.78	980052.81		3 30 43.00	62 11.00	3	22.01	2	AIRPORT PORCH	
9277-50	43982L	BAHIA BLANCA	ARG/BA	980052.91	980052.92		3 30 43.00	62 11.00		22.00		AIRPORT GPS BLDG	
9673-63		BAHIA BLANCA ARGENTI	ARG/BA		980052.75		3 30 43.00	62 11.00	7	22.00	5	AIRPORT MAIN PORCH	(INDEX)
9349-68		BELL VILLE	ARG		979499.43		3 32 40.00	62 41.00	3	131.00	3	AIRPORT OFFICE	
9271-50	43848M	BUENOS AIRES	ARG/BA	979689.35	979689.36		3 34 39.00	58 37.20	6	30.00	5	AEROPARQUE	(OUD)
9269-50	43848B	BUENOS AIRES	ARG/BA		979687.92		3 34 36.40	58 31.00	6	9.40	1	IGN SERVICIO HORA	(INDEX)
9270-50	43848C	BUENOS AIRES	ARG/BA	979691.16	979691.13		3 34 35.00	58 29.00	7	25.00	1	SERVICIO MET.NAC.	
9665-63	43848K	BUENOS AIRES	ARG/BA	979716.75	979716.74		3 34 40.00	58 33.00	7	21.00	5	EZEIZA APT ADMIN BDG	
9667-63	43848J	BUENOS AIRES	ARG/BA	979718.05	979718.06		3 34 51.00	58 32.00	7	16.40	4	EZEIZA APT BASEMENT	
9367-50	43848N	BUENOS AIRES	ARG/BA		979688.61		3 34 39.00	58 37.00	7	6.00	5	OBSOLETE	(INDEX)
9669-63	43848L	BUENOS AIRES	ARG/BA	979688.37	979688.35		3 34 39.00	58 37.20	6	5.00	6	AEROPARQUE ROOM39	
9666-63	43848A	BUENOS AIRES	ARG/BA	979690.03	979690.02		3 34 34.40	58 31.10	6	9.00	5	IGN BASEUB BASEMENT	
9360-68		CAMPO GALLO	ARG		979011.06		3 26 35.00	62 52.00	3	190.00	3	AIR STATION YPF	
9689-63	43858J	CANUELAS	ARG/BA	979735.29	979735.29		3 35 3.33	58 48.33		31.60		CITY HALL	
9674-63	47503K	CARMEN DE PATAGONES	ARG/BA	980224.72	980224.72		3 40 40.00	63 0.00	3	30.00	2	AIRPORT RADIO IAGB	
9357-68		CATAMARCA	ARG		979019.05		3 28 28.00	65 47.00	3	536.00	3	AIRPORT GALLERY BUIL	
9351-68		CERES	ARG		979313.26		3 29 53.00	61 57.00	3	87.00	3	AIRPORT RADIO LIGHT	
9346-68		CHAMICAL	ARG		979212.90		3 30 22.00	66 10.00	3	466.00	3	AIR FORCE STATION	
9355-68		CHARATA	ARG		979098.80		3 27 13.00	61 12.00	3	906.00	3	AIRPORT OFFICE	
9308-68		CHOELE-CHOEL	ARG		980065.57		3 39 16.00	65 39.00	3	195.00	2	AIRPORT OFFICE CLUB	
9362-68		COLONIA CASTELLI	ARG		979003.89		3 25 57.00	60 37.00	3	189.00	3	SCHOOL HALL	
9326-68		COLONIA LAS HERAS	ARG		980662.24		3 44 43.00	68 57.00	3	329.00	3	AIRPORT HANGAR OFF.	
9316-68		COLONIA SARMIENTO	ARG		980590.51		3 45 35.00	69 4.00	3	260.00	3	AIRPORT OFF FLIGHT	

Figure 3. Sample listing of principal facts.

STATION NO. 40345 K

IGSN STATION DESCRIPTION

QUAD. 3 DEG.SQ. 24065

Station Name SALTA
Country ARGENTINA
Other Designation UW: WA 6012
EPB: 9672-63
National Contact Agency
Access Restrictions

The station is located on the mosaic tile floor of the porch of the Salta airport terminal. It was 0.30 m. below the Instituto de Geodesia (U.N.B.A.) BM which was in the wall 0.40m from the front of the building. The BM is destroyed but the floor level remains unchanged.

La estación está situada en el suelo de mosaico del porche de la terminal del aeropuerto de Salta. Está 0.3 m debajo de la cota de referencia del Instituto de Geodesia (U.N.B.A) que se encontro en la pared, a 0.4 m del frente del edificio. El BM está destruido pero el nivel del suelo está inalterado.

Figure 4. Sample IGSN71 station description.

The second format is for the remaining LAGSN base descriptions as shown in Fig. 5. These have been prepared in English and also in the language of the nation concerned, i.e., either Spanish or Portugese. They contain a verbal text, location sketch and where available two photographs, one being a distant view and the other a close-up. Note that no numeric information appears on the station descriptions. All updates and coordinates, elevations, etc., will be made in the control station data base and new print-outs provided on request to the distributing agency.

Data recording

Agencies wishing to contribute new data to the data bank are requested to use the coding sheets in the following format.

Base station card 1 (Fig. 6)

This card contains the information pertaining to the station identity, elevation, coordinates, preliminary gravity value and the date/time of establishment.

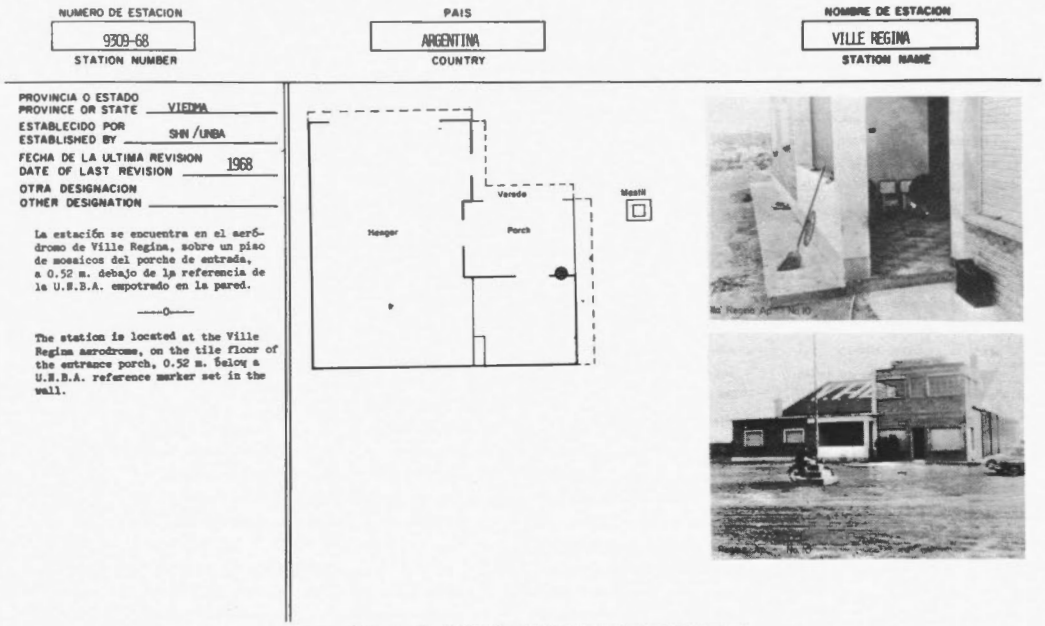

Figure 5. Sample LAGSN station description.

ESTACION REFERENCIA DE GRAVEDAD (1)

AGENCIA _____ OBSERVADOR _____

REF.	NUMERO TEMPORAL	NUMERO RELAG	CLASE	ELEVACION (M)	F.P.A.	F.D.A.	F.O.A.	LATITUD O UTMN	LONGITUD O UTME	ZONA	CUAD	F.P.C.	F.O.C.	VALOR PRELIMINAR DE G	CORR. TERR.	F.P.C.T.	ORIGEN	PROY.	FECHA AN.	ME.	DI.	OBSERVACIONES
01																						
02																						
03																						
04																						
05																						
06																						
07																						
08																						
09																						
10																						
11																						
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15																						
16																						
17																						
18																						
19																						
20																						
21																						
22																						
23																						
24																						
25																						

Figure 6. Base station card 1.

ESTACION REFERENCIA DE GRAVEDAD (2)

REF.	NOMBRE DE LA ESTACION	UBICACION	PAIS	ESTADO/ PROVINCIA	PAIS/EST CIF	CROQUIS	FOTO.	DESC. VER.
0.1								
0.2								
0.3								
0.4								
0.5								
0.6								
0.7								
0.8								
0.9								
1.0								
1.1								
1.2								
1.3								
1.4								
1.5								
1.6								
1.7								
1.8								
1.9								
2.0								
2.1								
2.2								
2.3								
2.4								
2.5								

Figure 7. Base station card 2.

Card 2 (Fig. 7)

This contains the descriptive location information.

Observation form (Fig. 8)

This form records the station identity, date/time of the observation, the original instrument reading and time and the source information.

Recommendations regarding future plans

In the case of new observations the actual readings, not readings converted to milligal values, which have been observed with LaCoste and Romberg gravimeters and recorded on the coding sheets previously described should be forwarded to the agency responsible for the maintenance of LAGSN.

It is extremely desirable that one particular agency be responsible for the collection of data, preparation and dissemination of adjusted gravity data, base station descriptions and related material. Networks of any size deteriorate very quickly if not maintained. It is my hope that such an agency will be appointed.

OBSERVACIONES DE RED GRAVIMETRICA
(LACOSTE & ROMBERG)

AGENCIA _____ OBSERVADOR _____

NUMERO TEMPORAL	NUMERO RELAG	FECHA AN.	FECHA ME.	FECHA DI.	GMT HO.	GMT MI.	LECTURA	TPT.	ORIG.	PROY.	COMENTOS

Figure 8. Observation form.

Padre J. E. Ramírez:

Muchas gracias Sr. Geller y Sr. Winter. Nuestro siguiente expositor es el Ing. A. Fonseca quién nos presentará su papel que se titula **"Estudios de Geofísica en Venezuela".**

Ing. A. Fonseca:

Voy a presentarles un informe que hemos preparado el Ing. Graterol y yo, sobre investigaciones gravimétricas en la República de Venezuela.

La historia de los levantamientos gravimétricos en la República de Venezuela comienza el mes de abril de 1949 cuando el "U.S. Coast and Geodetic Survey" procedió a efectuar las mediciones pendulares de Caracas y Barcelona. Estas mediciones se efectuaron en péndulos Brown, obteniéndose los valores de 978161.7 mgal y 978066.4 mgal para Barcelona y Caracas respectivamente.

Posteriormente a estos levantamientos la Dirección de Cartografía Nacional del Ministerio de Obras Públicas y el Servicio Geodésico Interamericano, decidieron establecer en nuestro país el "Datum Geodésico — de Control Horizontal de la Red de Triangulación de Primer Orden" en el punto La Canoa, ubicando este último al sur del Estado Anzoátegui. En vista de la importancia de este punto el mismo año de 1949 se inició el levantamiento gravimétrico a sus alrededores. La investigación consistió en el levantamiento de 2508 estaciones y tuvo su apoyo en la estación péndular de Barcelona. Las estaciones se ubicaron en áreas con radios de 25, 75, 150 y 250 km. Se elaboraron cartas de anomalías de aire libre a escala 1:100.000 y una global a escala 1:250.000. Se calcularon los efectos en las componentes de la desviación de la vértical por aumento del radio en la Canoa.

El enlace de Venezuela a la Red Gravimétrica Mundial fue efectuado por pimera vez por el Sr. Norman C. Harding, con trabajos realizados entre el 5 y 9 de agosto de 1949 de acuerdo al proyecto del Dr. G. Woollard del año 1940.

Durante el periodo comprendido entre agosto a diciembre — de 1958 (Año Geofísico Internacional) se estableció una estación péndular en Caracas, ubicada en el Observatorio Cogigal. Este trabajo se hizo de acuerdo a un programa propuesto por el Dr. G. Woollard y el Sr. Browne en la conferencia de la IUGG en 1957 llevada a cabo en Toronto, Canadá. El trabajo lo ejecutó el Sr. J. F. Jackson, utilizando péndulos Cambridge. Woollard y Rose, también midieron pero usando péndulos Gulf y se obtuvo un valor de 978039.8 mgal.

En el año 1960 se efectuó el Proyecto 54-AFS-50 del IAGS utilizando dos gravímetros "Worden Master". Este proyecto permitió obtener los valores de gravedad de estaciones ubicads en los aeropuertos de las Cuidades de Maracaibo, Maiquetia, Porlamar, Maturín, Cuidad Bolívar y Guasipati.

A partir de 1970 comienzan en una forma planificada y sistemática las investigaciones gravimétricas en Venezuela con el proyecto de "La Red Gravimétrica Nacional de Estaciones Base" organizado por la Dirección de Cartografía Nacional y el Servicio Geodésico Interamericano.

Recientemente después del año 1972 el Ministerio de Minas e Hidrocarburos a través de la Dirección de Geología, con la colaboración de la Universidad de Princeton, ha efectuado una recopilación de toda la información gravimétrica, no solo de las mencionadas, sino también la de las compañías petroleras que han operado en el país, lo cual ha dado como resultado la elaboración de las cartas de anomalía de Bouguer de la República de Venezuela a escala 1:500.000 seguidamente se detallan estos últimos trabajos:

La Red Gravimetrica Nacional de Estaciones Base

Tal como se mencionó anteriormente este programa comenzó en 1970 y se proyectó después de efectuar un análisis de los itinerarios de las líneas Aereas Nacionales que operaban en Venezuela para esa fecha. El proyecto se llevó a cabo bajo los auspicios de la Dirección de Cartografía Nacional del Ministerio de Obras Públicas y el Servicio Geodésico Interamericano.

Las observaciones se hicieron siguiendo los métodos de escalera y secuencia de escalera modificada, utilizando 3 gravimétros La Coste-Romberg, modelo g. Se utilizó la estación fundamental Santa Inés como datum y cumpliendo que las estaciones tuviesen una exactitud de +0.05 mgal con respecto a la base escogida como origen.

Se realizaron 30 circuítos, mediante los cuales se logró constituír la red gravimétrica nacional 58 estaciones con 390 observaciones.

Los cálculos preliminares de reducción y ajuste fueron hechos por USATOPOCOM utilizando UNIVAC 1108, programas GRASS, correcciones por marea y ecuaciones de mínimos cuadros lineales para corregir desviaciones en observaciones y circuítos donde fue necesario. La red se ajustó por el método de mínimo cuadrados con condiciones a escala y ecuaciones desconocidas obteniéndose los siguientes resultados:

Error de una observación sencilla	±0.029 mgal
Error de estación standard promedio propagada	±0.021 mgal
Error de estación máxima standard propagada	±0.028 mgal

Los factores de escala utilizados fueron:

LCR N° 50	1.000310	(1963)
LCR N° 56	1.000527	(1964)
LCR N° 57	1.000387	(1954)

y las correcciones a los factores de escala de los gravímetros por ajustes resultaron:

LCR N° 50	0.000053	±	0.000036
LCR N° 56	0.000020	±	0.000025
LCR N° 57	0.000074	±	0.000025

Los resultados del programa "Red Gravimétrica Nacional de Estaciones Base" dieron como secuencia el establecimiento de estaciones de gravedad en los principales aeropuertos del país.

Posteriormente fue hecho un segundo ajuste provisional por la Division de Gravimetría y Geodinamica del Departamento de Física de la Tierra. Energía, Minas y Recursos de Ottawa, Canada, institución encargada actualmente del banco de datos gravimétricos de Latinoamerica en programa SILAG del IPGH. Esta red está referida a la Red Standard Internacional de Gravedad 1971 (IGSN 71) adoptada por la Unión Internacional de Geodesia y Geofísica en Moscú.

El ajuste definitivo será posible al disponer de las conexiones entre los países y de la cobertura de todos los países latinoamericanos.

En nuestro país ya se realizaron unas conexiones que hacian falta entre puntos de la red de estaciones base utilizando tres gravimétros LaCoste y Romberg, y bajo la recomendación del grupo de SILAG en la reunión de gravimetria el 27 de noviembre en Panamá. Se hizo diligencias para hacer los enlaces de las redes

de Colombia y Venezuela pero no fue posible ejecutar tal proyecto. También se cumplio en parte con la recomendación N° 6 ya fue posible incorporar los levantamientos gravimétricos realizados en el Mar Caribe por las Empresas Petroleras, en la preparación de las cartas de anomalías de Bouguer aunque no se ha hecho el enlace físico con los levantamientos del continente.

El programa de la Red Gravimétrica Nacional de Estación Base, sentó las condiciones para el comienzo de levantamientos gravimétricos de relleno, las cuales servirían para la elaboración definitiva de las cartas gravimétricas de anomalías de aire libre y Bouguer para la República de Venezuela.

Estos levantamientos han sido propuestos como para fines geodésicos (Fonseca, 1975) y seguidamente se detallan sus principales características.

Levantamientos gravimetricos con fines geodesicos

Estos levantamientos son planificados y llevados a cabo por el Departamento de Control Vertical y Geofísica, de la Division de Geodesia de la Dirección de Cartografía Nacional del Ministerio de Obras Pública.

Las estaciones gravimétricas de estos levantamientos coinciden con los puntos de nivelación de primer orden de la Cartografía Nacional. Se utilizan puntos de la Red Gravimétrica Nacional de Estaciones Base para el inicio y final de los trayectos y los levantamientos se hacen empleando el método de escalera. El intervalo entre estaciones es de 4 km y poseen cotas o alturas de primer order. Las observaciones se corrigen por marea y deriva y las diferencias de gravedad observada entre ida y vuelta no deben ser mayores de ± 0.05 mgal. Se utilizan gravímetros La Coste y Romberg (Fonseca, 1975). Con esta información se ha preparado la carta de anomalía de aire libre a escala 1:1000.000 y con curvas a intervalos de 20 mgal.

Levantamientos con apoyo en la Red Gravimetrica Nacional de Estaciones Base

A partir del año 1971 y con el objetivo de cubrir sistemáticamente nuestro país con una densificación de estaciones que permitiese la obtención definitiva de cartas de anomalías de Bouguer. El Ministerio de Minas e Hidrocarburos a través de la Dirección de Geología, con la colaboración de la Universidad de Princeton, ha venido efectuando levantamientos regionales utilizando un método de trabajo similar al empleado por el U.S. Geological Survey en el Estado de California.

Las estaciones de gravedad se proyectan de manera que el inicio y final de los trayectos sea un punto de la Red Gravimétrica Nacional de Estaciones Base. Las estaciones se ubican a lo largo de las vías de comunicación disponibles, utilizando el apoyo cartográfico de las cartas 1:100.000 de la Cartografía Nacional. Se utilizan gravímetros La Coste y Romberg y las cotas de las estaciones se obtienen barométricamente. Las mediciones se hacen en un solo sentido y solo se hacen correcciones por deriva.

Todo el procesamiento de oficina de dichas estaciones se hace empleando el sistema SPDGM, (Graterol, 1972) obteniendose valores de anomalía de aire libre y anomalía de Bouguer para cuatro densidades diferentes.

El sistema SPDGM acepta también todas las estaciones levantadas por la Dirección de Cartografía Nacional, Universidad de Princeton y compañías petroleras, las cuales pasan a una cinta magnética donde son ordenadas y almacenadas. Se pueden obtener listados de estaciones donde se muestran las características principales de las mismas, solo de aquella zona del país que sea de interés.

Seguidamente se enumeran los levantamientos gravimétricos llevados a cabo siguiendo este procedimiento; también se incluyen los levantamientos llevados a cabo por la Corporación Venezolana de Petróleo.

1971 1974 Levantamientos gravimétricos en la región central y oriental de Venezuela
W. Bonini, C. Acker y G. Buzman
Universidad de Princeton

1971 1976
1. Levantamientos gravimétricos en la región central de Venezuela
V. Graterol, J. Campero, J. Pérez R. y N. Rodríguez
Ministerio de Minas e Hidrocarburos y Ministerio de Obras Públicas
2. Levantamiento gravimétrico en la región occidental de Venezuela
V. Graterol, J. Pérez R. y A. Azavache, F. Fernández, I. Rodríguez, A. Fonseca y J. Campero
Ministerio de Minas e Hidrocarburos y Ministerio de Obras Pública
3. Levantamientos gravimétricos en la región oriental de Venezuela
J. Pérez R. y Victor Graterol
4. Levantamientos gravimétricos en el Estado Bolívar — Venezuela
V. Graterol y J. Pérez R.

1971 1975 Corporación Venezolana de Petróleo
1. Levantamiento al este del delta del Río Orinoco
2. Levantamiento al este de la Isla de Margarita
3. Levantamiento de la Ensenada de Barcelona, Golfo de Paria y Golfo Triste.
4. Levantamiento del Golfo de Venezuela y Lago de Maracaibo.

Elaboracion de las cartas de anomalias de aire libre y Bouguer de la República de Venezuela

Tal como se mencionó al comienzo de este trabajo. El Ministerio de Minas e Hidrocarburos, a través de la Dirección de Geología, utilizando toda la información gravimétrica mencionada efectuó una primera compilación, la cual ha dado como resultado la obtención de la carta de gravimétrica de anomalía de Bouguer de Venezuela a escala 1:500.000 y la Dirección de Cartografía Nacional del Ministerio de Obras Públicas, preparó la carta gravimétrica de anomalías de aire libre a escala 1:1.000.000.

La compilación para preparar la carta de Bouguer, fué ejecutada por el Ing. Victor Graterol, la Geol. Clara Pimstein de Gaete y el Prof. William Bonini y arrojó los siguientes resultados:

1. Se preparó un mapa de anomalía de Bouguer a escala 1:500.000 con contornos cada 10 mgal, el cual no muestra ni ubicación ni valores de las estaciones. Dicho mapa será incluído en el mapa geológico estructural de Venezuela actualmente en su última fase de impresión.

2. Se preparó un mapa de anomalía de Bouguer a escala 1:1.000.000 el cual será publicado posteriormente por la Universidad de Princeton y el Ministerio de Minas e Hidrocarburos.

3. Se preparon cartas de anomalía de Bouguer, a escala 1:500.000, las cuales muestran ubicación y valores de las es-

taciones y los contornos cada 5 mgal. Estás cartas serán publicadas en forma impresa por la Dirección de Cartografía Nacional del Ministerio de Obras Públicas, a partir del año 1976.

La compilación para preparar la carta de anomalía de aire libre a escala 1:1.000.000 fué realizada por el Ing. Angel Fonseca, utilizando programa GEOFI del Centro de Computación del M.O.P.

Conclusiones

Se ha presentado un resumen de los estudios e investigaciones gravimétricas en Venezuela desde 1949 hasta 1976, los cuales han hecho posible despues de haber efectuado la compilación de la misma, la obtención de la carta de anomalía de Bouguer de nuestro país a escala 1:500.000.

La carta de anomalía de Bouguer de la República de Venezuela a escala 1:500.000, será publicada en hojas de acuerdo a las especificaciones cartográficas del país. Estas hojas mostrarán la ubicación y valor de anomalía de Bouguer para una densidad de 2.67 g/cm^3, de cada una de las estaciones, la publicación será en forma impresa y podrán ser adquiridas a partir del año 1976 en la Dirección de Cartografía Nacional del Ministerio de Obras Públicas.

La compilación efectuada cubre el área comprendida entre los 8° y 13° de latitud norte y 60° a 73° de longitud oeste. La carta de anomalía de Bouguer obtenida muestra zonas donde el intervalo entre estaciones es mayor de 8 km. Es precisamente en estas áreas donde se necesita con urgencia proyectar trabajos gravimétricos que permitan efectuar una correlación definitiva de los contornos gravimétricos.

Planes a desarrollar

1. Metas cuantificables a obtener mediante convenio: Dirección de Cartografía del M.O.P. y la Escuela de Geodesia de la Universidad del Zulia
   - 1.1. Elaborar carta del geoide en Venezuela
   - 1.2. Determinación de alturas absolutas en el país
   - 1.3. Estudio de variaciones seculares de la gravedad
   - 1.4. Determinación de espesores de corteza en diversas regiones del país: sistemas montañoso de los Andes, del caribe, macizo guayanes, etc.
   - 1.5. Estudios topográficos-isostáticos
   - 1.6. Determinación de espesores de sedimentos en cuidades
   - 1.7. Predicciones gravimétricas en zonas montañosas
   - 1.8. Estudios de marea terrestre
2. Metas cuantificables a obtener mediante convenio: Dirección de Geología del M.M.H., Dirección de Cartografía del M.O.P. y Universidad de Princeton
   - 2.1. Preparación de cartas de anomalías de Bouguer del sur de Venezuela
   - 2.2. Interpretación de anomalía gravimétricas
   - 2.3. Planificar proyectos que no permitan duplicidad
   - 2.4. Edición de cartas de anomalías de Bouguer a escala 1:500.000 de acuerdo a indice de cartas proyección conico-secante.

Geomagnetismo en Venezuela, preparado por el Ing. A. Fonseca y el Sr. M. A. López Mussa.

Evolución histórica

La Dirección de Cartografía Nacional del Ministerio de Obras Públicas a través de su División de Geodesia, se ha encargado desde el año 1950 de realizar las mediciones geomagnéticas en el país con el propósito de elaborar cartas magnéticas, que han servido de apoyo a estudios detallados y preparación de otras cartas. Se han establecido estaciones magnéticas en terrenos que corresponden a aeropuertos del país y en algunas se han medido todos los elementos del campo magnético y en otras solo la declinación. Con esta información se ha venido preparando desde el año 1955 con intervalo de cinco años las cartas isogónicas, isodinámicas e isoclínicas para Venezuela.

En el año 1957 el Ministerio de Obras Públicas adquirió instrumentos geomagnéticos para el Observatorio Cagigal con el propósito de que se instalará un observatorio geomagnético. Se hizo estudios de sitios y finalmente se recomendó Araira como un lugar tranquilo sin anomalías y disturbios magnéticos; donde se instaló un variografo en febrero del año 1964; con un buen funcionamiento y obtención satisfactoria de registros; pero surgieron inconvenientes ya que no fué posible adquirir los terrenos; razón por la cual fué trasladada a la Hacienda Sorocaima después de estudios de sitios en diversos lugares y donde funcionó por un año ya que posteriormente la zona se hizo inapropiada. Finalmente el variografo se dañó y no continúo funcionando.

En el año 1975 la Dirección de Cartografía Nacional adquirió un magnetometro Geometrics G-826 para estación base, con el cual se estan logrando magnetogramas con registros de la intensidad total del campo magnético en diversos lugares del país y también un magnetometro Scintrex M F03 donde se registran las tres componentes del campo magnético; dichos proyectos han continuado durante el año 1976.

A partir de julio del año 1976 se comenzaron las diligencias respecto a la escogencia y ensayos de sitios en el Edo. Aragua para establecer definitivamente en el país un efectivo observatorio magnético. Actualmente se ensaya en un lugar denominado Pozo Hondo perteneciente al Dtto. Zamora de Villa de Cura, ya que la Dirección de Cartografía Nacional del M.O.P. y el Observatorio Cagigal de la Comandancia de la Marina del Ministerio de la Defensa, aspiran que empiece la construcción de instalaciones, montajes de equipo y funcionamiento a partir del próximo año.

Instrumental y calibracion

Para realizar las mediciones con las cuales se obtienen la declinación magnética, intensidad horizontal e inclinación magnética se ha utilizado un magnetometro Ruska, un inductor terrestre Ruska, un galvanometro y accesorios; instrumental que ha sido calibrado en el Observatorio San Juan de Puerto Rico en tres oportunidades: mayo 1951, junio 1954 y agosto 1963. Se tiene previsto una nueva calibración a final del presente año o comienzo del próximo en el Observatorio Magnético de Huancayo, Perú.

Para el observatorio magnético que se aspira su funcionamiento a partir del próximo año se posee: una estación de variometros geomagnéticos según Eschenghagen compuesta por un variometro para intensidad horizontal, un variometro para la declinación y un variometro para la intensidad vertical; equipo para instalar los variometros; bobinas para determinar el valor de escala y registradores. Un teodolito geomagnético normal según Schmidt marca Askania con sus accesorios. Un gran inclinatorio rotatorio y un variografo geomagnético marca Askania.

Además se posee un magnetometro protonico registrador G-826 para estación base, movil o levantamiento de campo y magnetometro descriminador de Flujo.

Cartografía magnética

El valor más antiguo que se tiene de la declinación magnética en Venezuela, fué interpolado del mapa isogónico del astronomo Halley publicado en el año 1700, el Dr. Felipe Aguerrevere en su estudio Declinación Magnética de Venezuela desde 1700, dió para ese año 7° 44′ 2 (A. Romero, 1961).

Lamentablemente en el país no ha existido un observatorio magnético y por ello los valores de declinación, intensidad horizontal e inclinación no han sido corregidos por variación diurna, la variación secular se ha determinado con las reocupaciones de estaciones seleccionadas; lo cual no es exacto y por supuesto tampoco lo será la reducción a la epoca de los elementos por representar. Se empezó la preparación sistemática de las cartas magnéticas en el año 1955 con una carta isogónica. Ya para el año 1960 se habían establecido setenta y nueve estaciones y por ello el Dr. Adolfo Cosme Romero, preparó los tres mapas isomagnéticos: isogónico, isodinámico e isoclinico de Venezuela a escala de 1:4.000.000.

Posteriormente se han venido preparando cartas isogónicas para 1965, 1970 y 1975 de nuevo se han preparado las tres cartas magnéticas (López M., E. Lugo y A. Fonseca), las cuales fueron editadas por la Dirección de Cartografía Nacional.

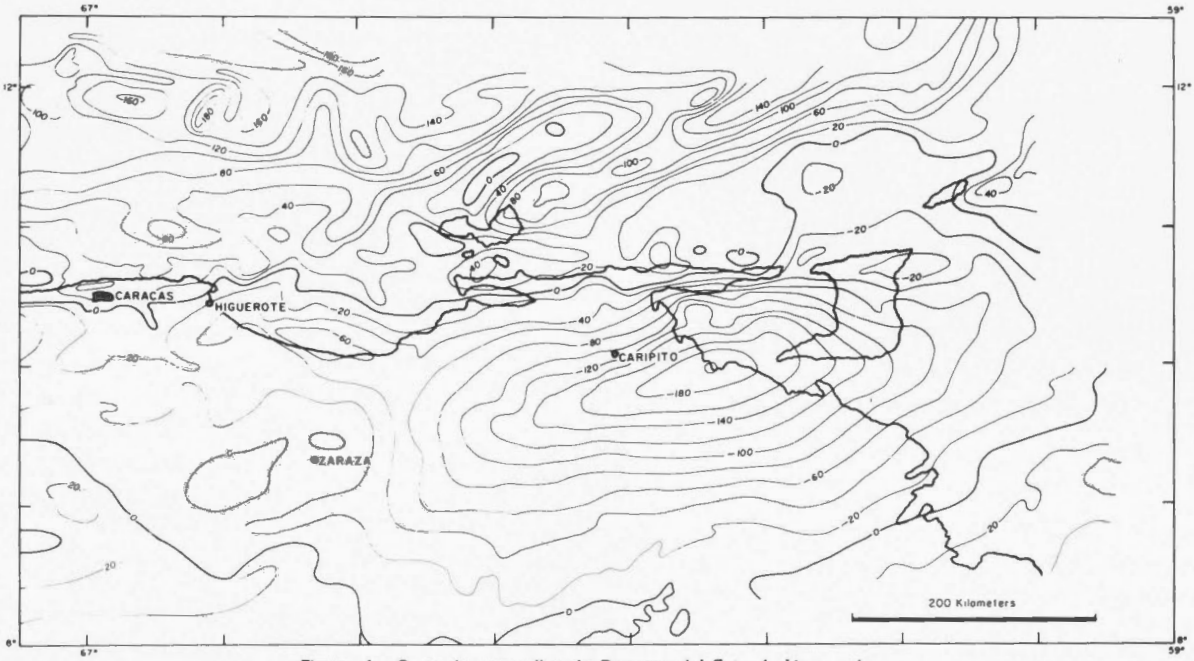

Figura 1. Carta de anomalias de Bouguer del Este de Venezuela.

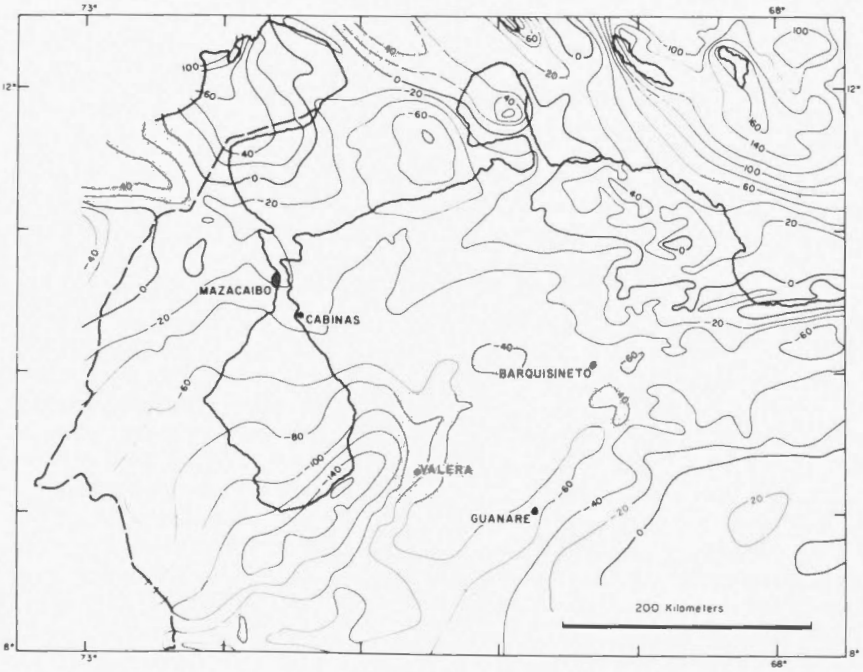

Figura 2. Carta de anomalias de Bouguer del Occidente de Venezuela.

Levantamientos aeromagnéticos

En el período 1959-1960 se ejecutaron levantamientos aeromagnéticos y radimetricos de detalle al sur del Río Orinoco con excepción del Distrito Cedeño bajo la responsabilidad y supervisión de la División de Recursos Minerales de la Dirección de Geología del M.M.H. También se hizo vuelo de reconocimiento magnético y radimetrico al sur del paralelo 6 en el Edo. Bolívar y se acaba de concluir un levantamiento aeromagnético en la Serranía de Perija en cual fué ordenado por Corpozulia y asesorado por la División de Recursos Minerales.

En el período 1975-1976 se realizó el levantamiento y estudio de aproximadamente 30.000 km² en la Faja Petrolífera del Orinoco.

Se han realizado levantamientos magnéticos locales en la Zona Central, Andes, Guayana y Carúpano.

Sismología en Venezuela, hecho por E. Gajardo y el Ing. A. Fonseca.

La Red Sismologica Nacional actualmente está constituida por 7 estaciones sismologicas distribuidas en el país. Caracas ubicada en el Instituto Sismologico del Observatorio Cagigal con sismómetros período largo y período corto las 3 componentes, Lagunillas (Edo, Zulia) con un sismometro vertical período corto. Cumana (Edo. Sucre) con sismometros Sprengnether período corto, las 3 componentes ya que los galvanometros para períodos largos necesitan reparación, Merida y Santo Comingo (Edo. Mérida), El Tocuyo (Edo. Lara), con un sismometro vertical período corto y una estación telemétrica denominada La Siria (Edo. Miranda). En seis de las estaciones existen acelerografos. De estas estaciones tres son operadas por el Instituto Sismológico del Observatorio Cagigal, Ministerio de la Defensa y las otras cuatro por el Departamento de Control Vertical y Geofísica de la Dirección de Cartografía Nacional del Ministerio de Obras Públicas. La interpretación de sismogramas es realzada en cada estación y suministrada diariamente por radio al Instituto Sismológico, centro de procesamiento y almacenamiento de la información.

El Instituto Sismológico publica mensualmente Boletines Sismicos y ha preparado Carta Sísmica de Venezuela además de haber realizado varios trabajos. Gunter Fidler y Javier Aparicio.

A raíz del terremoto del 29 de julio de 1967 se crearon comisiones con el propósito de evaluar los daños ocasionados por el terremoto. La Comisión Presidencial del Sismo y la Oficina Técnica Especial del Sismo (OTES) ambas instituciones están terminando sus labores ya que editan actualmente su informe final.

Desde el 27 de julio de 1972 se crea La Fundación Venezolana de Investigaciones Sismológicas, la cual centralizará las investigaciones sismológicas de ingeniería sísmica y de ciencias de la tierra, especialmente en relación con la sismotectónica, que se realicen en Venezuela.

Con este objeto se preparó el plan básico para las Investigaciones Sísmicas en Venezuela, el cual fue presentado en la Seccional Nacional del IPGH, a comienzos del año 1975.

En la actualidad se encuentra en ejecución la etapa de diseño y especificaciones del citado plan básico, la cual comprende dos proyectos que se tramitan en la Organización de Estados Americanos (OEA), denominados "Evaluación de Riesgo Sísmico" y "Protección de Riesgo Sísmico Andino" y dos convenios de trabajo, uno con el Servicio Geológico de los Estados Unidos y otro con el Observatorio Lamont Doherty de la Universidad de Columbia.

a) Proyecto de Evaluación del Riesgo Sísmico, para el proyecto, diseño y especificaciones de la Red Sismológica Nacional Telemétrica (RESNAC). Este proyecto multinacional se realizará en colaboración entre la Universidad Nacional Autónoma de México y FUNVISIS, coordinado por el Ing. Enrique Gajardo W.
b) Proyecto de Protección del Riesgo Sísmico Andina (PROSISAN), acordado en la V Reunión del Centro Regional de Sismología para América del Sur (CERESIS) como una acción combinada Chile, Perú, Ecuador, Colombia y Venezuela.
c) Convenio con el Servicio Geológico de los Estados Unidos (USGS) tendiente a optimizar la Red Sismológica Nacional Telemétrica (RESNAC) y la formación de personal especializado para la red y para las investigaciones futuras con los datos de la red.
d) Convenio con la Universidad de Colombia, Observatorio Lamont-Doherty, para la realización de un estudio de microtremblores en el sistema de fallas de Boconó.

Todos estos proyectos son tramitados a través de CORDIPLAN, la oficina estatal de planificación nacional.

Simultáneamente se está comenzando la etapa de construcción — de la infraestructura necesaria para las investigaciones sísmicas, comprendiendo tres aspectos principales.

a) Red Sismológica Nacional de Apertura Continental (Telemétrica), la cual comprenderá alrededor de 45 estaciones sismológicas, dotadas de una a seis componentes según el caso, y una super-estación (Array Sismológico) con treinta sensores. Los datos recogidos por las estaciones serán enviados automáticamente a la central de Caracas en la cual serán procesados por medio de computadoras.
b) Red de Acelerógrafos y Sismoscopios. Consistente en la instrumentalización de las obras civiles de infraestructura nacional y de las zonas urbanas, con el fin de conocer datos de la repuesta del suelo aplicables a los proyectos de ingeniería y ubanismo.
c) Centro de Documentación e Información Básica en Sismología e Ingeniería Sísmica. Dotado de una adecuada infraestructura — de microfilms, duplicación y lectura de información que funcionará como biblioteca especializada y como banco de datos — para apoyar la investigación y la docencia.

Complementariamente se realizan algunas investigaciones básicas para apoyar estos proyectos, algunas desarrolladas por el personal de FUNVISIS y otras por estudiantes de ingeniería geofísica, quienes optan el título de Ingenieros, dentro de un programa combinado entre FUNVISIS y la Universidad Central de Venezuela.

Investigaciones actualmente en ejecución en FUNVISIS:

a) Estudios sismotectónicos de la región oriental de Venezuela. Responsable: Geo. Claudio Gallardo L.
b) Riesgo sísmico en la región norcentral de Venezuela. Responsable: Ing. Jairo Larotta S.
c) Determinación del potencial de sismicidad inducida por presas. Responsable: Ing. Enrique Gajardo W.

Investigaciones con carácter de tésis de grado, dentro del programa FUNVISIS (UCV):

d) Análisis espacial de la sismicidad de los Andes de Venezuela. Responsable: Geo. Claudio Gallardo L.
e) Estudio del Sismo del 12 de junio de 1974, en Carúpano; y su relación con la tectónica del área. Responsable: Ing. Enrique Gajardo W.

f) Determinación de la profundidad de la corteza de la región de Caracas. Responsable: Ing. Enrique Gajardo W.

g) Estudio del potencial de sismicidad inducida en la presa de Yacambú. Responsable: Ing. Enrique Gajardo W.

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Padre J. E. Ramírez:

El siguiente en la lista de hoy es el Dr. Feininger que va a hablar sobre el **"mapa gravimétrico del Ecuador".**

Dr. T. Feininger:

The simple Bouguer gravity anomaly map of Ecuador was compiled from data taken at more than 14,000 gravity stations between about 1935 and 1975. About 76% of the readings were taken before the Second World War by oil companies during petroleum exploration both to the east and west of the Andes. Twenty per cent of the readings were taken between 1966 and 1970 by personnel of the Instituto Geográfico Militar (IGM) and the Inter-American Geodetic Survey (IAGS) on benchmarks of 1st and 2nd order level lines throughout continental Ecuador (Mora, 1973). Nearly 4% were taken during 1974 and 1975 by my assistant, Sr. Alfonso Crespo J., and myself chiefly on benchmarks established by the IGM after 1970. Fifty readings (0.3%) were taken by Case *et al.* (1973) on the Galápagos Islands in the eastern Pacific Ocean.

The map is uniformly tied to the value 977,270.32 mgal (adjusted to the new basic value of gravity at Potsdam) as the absolute attraction of gravity on the floor of Quito's Mariscal Sucre International Airport at the gate used for the departure of international passengers prior to December 1976. The site is not monumented. The theoretical attraction of gravity at sea level by latitude was taken from the Coast and Geodetic Survey (1942) tables. Conversion of the simple Bouguer gravity anomaly map of Ecuador (Feininger, 1976) to tie with the 1967 Geodetic Reference System (International Association of Geodesy, 1971), now preferred by most geophysicists, would result in simple Bouguer anomalies uniformly about 17.1 mgals more positive throughout Ecuador. A density factor of 2.67 g/cm^3 was applied, and no terrain corrections were made in preparing the map. The contour interval of the published map is 10 mgals whereas on the reduced version shown in Fig. 1 it is 50 mgal.

Bouguer gravity field of Ecuador

As the Bouguer gravity field of Ecuador corresponds closely to the physiographic provinces of the country, it is convenient to describe the field of each province separately. I shall do so from east to west.

The Oriente.

This physiographic province consists of the upper Amazon basin within Ecuador. It lies east of the Andes and is drained chiefly to the south and southeast by large consequent rivers. Simple Bouguer anomalies over the Oriente are negative and range from between −100 and −150 mgal at the base of the Andes or their adjacent foothills to between 0 and −10 mgal at the eastern limit of data. The gravity field is not smooth, but is characterized by broad closed highs and lows from 3 to 30 km across with amplitudes from 10 to 40 mgal. Most of these are too weak to appear on the simplified reduction of Fig. 1.

The Sierra.

The Andean Cordillera and its foothills (nearly continuous in the east and present in the west only in the south) constitute the Sierra. The highest peaks of the Andes generally exceed 4,500 m from the Colombian border to latitude 2° 30′ S, whereas farther south few peaks exceed 4,000 m. The Sierra and its eastern foothills are characterized by strong negative simple Bouguer anomalies. Along the length of the Sierra, minimum values increase progressively southward from −230 mgal on the Colombian border, to −292 mgal (the most negative value in the country) at Latacunga, 80 km south of Quito. Farther south, negative values decrease somewhat and constitute a series of closed lows of lesser intensity with minimum values of −270 mgal at Cuenca and −250 mgal 80 km farther to the south southwest. At the southern limit of data, minimum values are 10 mgal less negative than the most negative values on the Colombian border in the north.

The Costa.

The north-south strip of land from 25 to 200 km wide that lies between the Sierra and the Pacific coast constitutes the Costa. The total relief of the simple Bouguer gravity field over the Costa is more than 300 mgal, far exceeding the relief of the gravity field over any of the other physiographic provinces of the country. The Costa is dominated by a broad belt of positive anomalies that enters the country from Colombia, crosses the northern two thirds of the Costa, and goes out to sea in the Gulf of Guayaquil. Anomalies 45 km north-northwest of Guayaquil exceed +162 mgal. These are the most positive in Ecuador, and may be the most positive on the entire South American continent (Ing. Julio Monges C., oral commun., 1975). The belt of positive anomalies is interrupted by four areas of negative anomalies, the strongest of which lies 55 km south of Guayaquil and has values to −150 mgal.

The Galápagos Islands.

This oceanic archipelago consists of 14 major volcanic islands and numerous lesser ones clustered in the eastern Pacific

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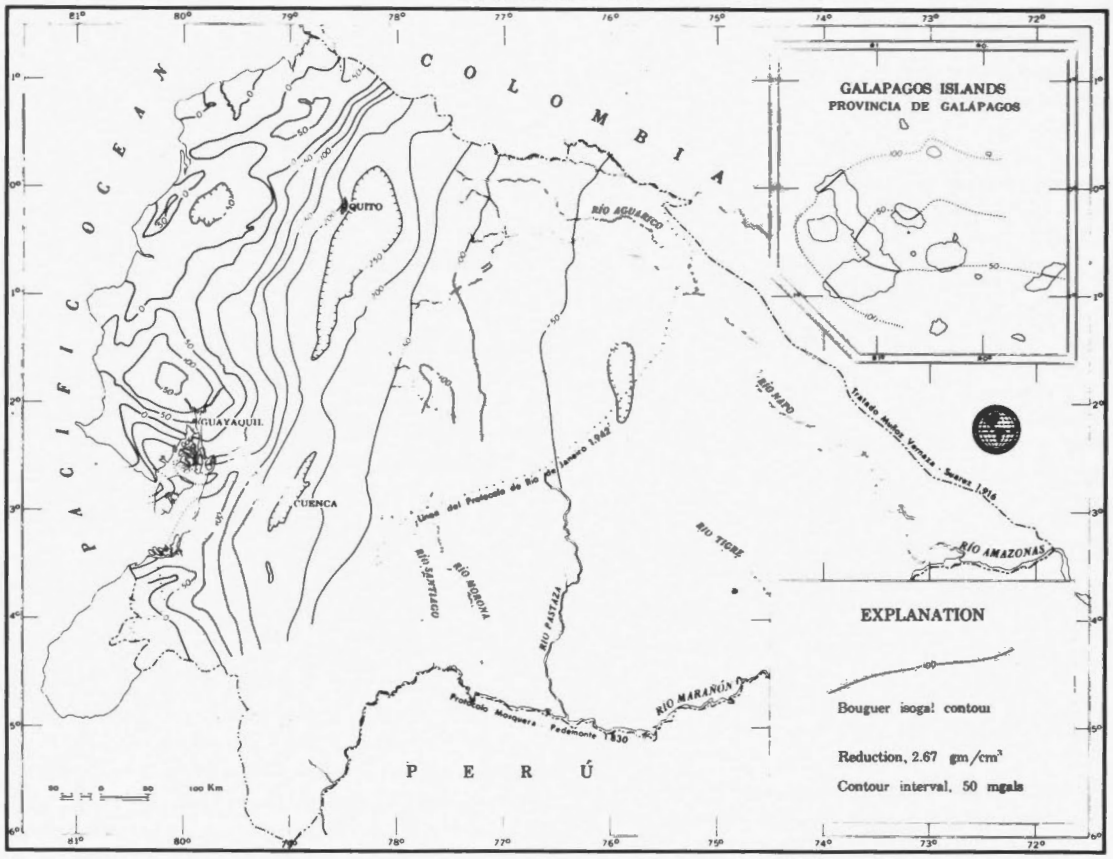

Figure 1. Synoptic reduction of the simple Bouguer gravity anomaly map of Ecuador.

Ocean about 1,300 km due west of Quito and 1,000 km off the coast of continental Ecuador. Bouguer anomalies are positive throughout the Galápagos Islands. They are least positive over the centre of the archipelago (values as low as +22 mgal), and increase progressively toward the periphery, where locally they exceed +100 mgal.

Crustal Structure of Ecuador

Two features dominate the simple Bouguer gravity field of Ecuador: the remarkable positive anomalies of the Costa (in part greater than +160 mgal), and the great belt of strong negative anomalies coincident with the Sierra.

North of the latitude of Guayaquil, the western base of the Andes follows roughly the boundary between the negative anomalies of the Sierra and the positive anomalies of the Costa. This boundary coincides with the eastern edge of the West Colombian Gravity High, which is taken by Case *et al.* (1971) and Case *et al.* (1973) to signal the boundary in Colombia between oceanic crust to the west and continental crust to the east. This interpretation appears equally valid in Ecuador. The strong positive anomalies of the Costa are coincident with areas where the Piñón Formation of Cretaceous age (Servicio Nacional de Geología y Minería, 1969; Goossens and Rose, 1973) crops out or is veneered only thinly by younger sedimentary rocks. The Piñón consists of basalt (commonly pillowed), diabase, and more rarely, gabbro and peridotite. The chemical composition, lithology, and structure of the formation all point to its oceanic origin and I suggest that the Piñón of the Costa is a remnant of ocean floor of Cretaceous age. This remnant was preserved and now crops out owing to its having been isolated by a westward jump of the continental border subduction zone in Early Tertiary time; from a previous trench located at the site of the actual Western Cordillera of the Andes to the present trench off the coast of Ecuador (Feininger, 1975). The strictly oceanic nature of the Piñón of the Costa is made evident by the great extent and large magnitudes of the positive anomalies over its outcrops. Clearly, continental rocks nowhere underlie this formation. The areas of negative anomalies over the Costa coincide with deep basins of sedimentary rocks mostly of Miocene age or younger.

The belt of negative simple Bouguer anomalies over the Andean Cordillera reflects the root of low-density rock of these mountains. As the width of the Cordillera in Ecuador is uniform, about 140 km, longitudinal changes in the strength of the anomalies are taken to reflect chiefly the depth of the Andean root. Accepting this simple interpretation, the root of the Andean Cordillera deepens progressively from the Colombian border to Latacunga, where it achieves its maximum depth in Ecuador. Southward it shallows slightly, and thence maintains a broadly uniform depth from the vicinity of Riobamba (165 km south of Quito) to the Peruvian frontier. The small area of weak positive anomalies over the western foothills in the south coincides with a thin belt of amphibolite.

The gentle gradient of the gravity field over the Oriente eastward from the Andes may be caused by a gradual thickening of the continental crust from east to west. This postulated crustal

thickening may be the result of granite emplacement at depth by magmas derived in the subjacent Benioff zone, the stacking of eastward-directed thrust sheets in the eastern Andean foothills, or a combination of the two processes. The closed highs and lows of the gravity field east of the Andes reflect the enormous variety of the basement rocks that underlie the Oriente, and do not correlate with the superjacent, little-disturbed, oil-bearing Cretaceous and Tertiary sedimentary rocks.

The positive simple Bouguer anomalies that dominate the Galápagos Islands attest to the oceanic character of the archipelago. The residual low over the centre of the archipelago could be the result of thermal expansion caused by the active Galápagos hot spot (Case *et al.* 1973), the normal consequence of the isostatic load imposed by the islands' volcanic edifices (Watts and Cochran, 1974), or a combination of the two effects.

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Padre J. E. Ramírez:

Muchas gracias Dr. Feininger. Nuestro siguiente en la lista de hoy es el Señor L. M. Sebert que va hablar sobre **"Cartographic projects pertinent to Latin American geophysical investigations".**

Mr. L. M. Sebert:

Cartography is one of the important services that supports geophysics, so I believe it is quite appropriate to talk to you this afternoon in general on cartographic activity in Latin America, and in particular on those PAIGH projects that are pertinent to Latin American geophysical investigation. I was delighted to hear the Resolutions Steering Committee appointed on Monday because that gives me an opportunity to suggest two resolutions, which I will do at the end of my paper. You possibly will consider my resolutions trivial, but I assure you they will help materially in the work of my PAIGH Committee, which is the Special Maps Committee of the Cartography Commission.

During my talk you will find that I use a very broad interpretation of the term "geophysical investigation". There appears to be a continuum of cartographic activity starting with purely geophysical mapping such as geomagnetic and gravity maps, but continuing through maps of bedrock geology, geomorphology, soils maps, hydrological maps, land use maps and potential land use maps, to name just a few. In some of the types listed, geophysical investigations provide the major input to the theme of the map. In others, geophysics is an important but relatively minor aspect of the map content. For example, potential land use maps may not strike you as being the result of geophysical surveys, but in arid regions the search for water may be aided by such surveys. It follows that if sufficient water is located there is often a marked change in the potential of the land for certain forms of agriculture.

So, having broadened my field to include a rather wide range of thematic maps, let me broaden it still more. We cannot talk about thematic mapping without at least a passing reference to topographic mapping which provides the base for all mapping activity. Fortunately all member states of PAIGH have good topographic mapping agencies. Much of the credit for this goes to the work of the Inter-American Geodetic Survey of the United States Army. In the years immediately following World War II this agency introduced modern surveying and photogrammetric mapping methods and equipment into Latin America. This was of course enlightened self-interest, but this should not detract one iota from this valuable gift to the Latin American scientific and technical community.

But, let us return to thematic maps which is the role of my Committee, the Special Maps Committee. The term "thematic map" is quite new in the mapping vocabulary. Arthur Robinson, the famous American cartographer, points out in his new text, "The Nature of Maps" that the German cartographer N. Creutzberg invented the term in 1953. Since then it has completely replaced such vague terms as special maps and topical maps. (As an aside I might mention that I think it is now time to change the name of my PAIGH Committee from the Special Maps Committee to the Thematic Maps Committee.)

Although the term thematic mapping is new, thematic maps as such have a very long history. Some of the oldest forms of thematic mapping are in fact geophysical in nature. In 1686 Edmond Halley, the famous astronomer, published a map of the world showing the prevailing winds of the world, and in 1700 he produced a map showing variations of the compass throughout the world. In 1815 William Smith published a map titled "The Strata of England" which is generally accepted as being the first geological map in the modern sense of the term.

The geological surveys of the member states of PAIGH have long been very active in the cartographic field because geological maps are essential to the reporting of geological surveys. Because the material benefits of geological surveys are often both immediate and substantial, such surveys need little justification, especially if there is any evidence that the region under investigation might contain oil or mineral deposits.

Some other forms of geophysical investigation are becoming almost as attractive. Over the centuries most of the more obvious deposits of valuable minerals have been found and exploited. To-

day the use of geophysical techniques is the normal method of exploration. This is so true in Canada that the lone prospector with his canoe, tent, shovel and hammer, has virtually disappeared from the scene. He has been replaced by large helicopter transported teams armed with aeromagnetic, gravity and other maps and carrying a wide range of electronic prospecting instruments. Results have proven the efficiency of such teams.

There really are very few cartographic problems in preparing geophysical maps provided that a good topographic base exists and the geophysical data are acquired in a systematic fashion. Gathering data by airborne sensing is now commonplace, and I am sure you are all well acquainted with such cartographic products as aeromagnetic and gravity anomaly maps. Some of the newer remote sensors are quite promising, and in this field my committee in PAIGH and the Canadian Government are cooperating in organizing a number of test flights in Guatemala, Columbia and Chile between January 6 and January 24, 1977. The Canadian plane that will make these flights will be equipped with the latest thermal and infrared sensors that we have. We hope to use this data, with a minimum of ground-truth surveys to produce data suitable for incorporation in hydrological and soils mapping, and possibly other thematic maps. This plane is at present in Ottawa, and if any of you would be interested in seeing the remote sensing equipment I will arrange a visit tomorrow during the lunch hour.

Soil maps and hydrological maps are closely related to geological maps and very often the survey of one greatly assists the survey of the other. And, as I mentioned earlier, all are based on topographic maps. This interdependency argues strongly in favour of an integrated survey approach such as that being carried out by CENTENAL in Mexico. I think I can presume that you all are aware of the activities of that remarkable agency. If you are not, I would recommend that you arrange for a technical visit when you are next in Mexico.

The maps I have mentioned so far are generally at relatively large scales of 1:50,000 for topographical, geological, soils and land use and 1:250,000 for hydrological maps both surface and subterranean. PAIGH gives a modest support to such work in the member states by providing for an exchange of information on new developments, both within the PAIGH family and in the world at large. As you all well know, there have been great advances in recent years in instrumentation and techniques for gathering geophysical data. There have been equal advances in methods for improving the production of topographic and thematic maps. I believe PAIGH has been quite successful in passing this information along both by seminars and by technical publications.

PAIGH does relatively little mapping on its own, but there are two projects in my committee that I would like to mention. The first is the production of a geological base map for South America at a scale of 1:2,500,000. This project, when completed, will cover the land area and the continental shelf of South America on seven sheets. Eleven PAIGH member states are involved in this project, and at the present moment I have 11 different ideas as to what a base map at this scale should contain. However, I expect to work this out to the satisfaction of all in the near future.

The other project is rather sad. As many of you know, the existing 1:5,000,000 tectonic map of South America is very much out of date. It was drawn many years ago, long before the present plate tectonic hypothesis was evolved, and hence it is seriously behind the times. A new map was produced in 1973 by Dr. Cecelia Bellizzia of Venezuela with the active cooperation of Professor Almeida of Brazil. UNESCO has promised about half the funds necessary for the publication of this map, and it was my hope that my committee (Special Maps) could acquire about $20,000 from PAIGH to get this valuable map printed. Unfortunately both Dr. Tanner and I have been unable to generate any enthusiasm for the project in PAIGH Directing Council.

I know I am preaching to the converted, I don't need to explain to you the value of an updated small-scale tectonic map of South America. But some of the arguments that you might use, if you were to join the cause, is to point out the value in teaching and in the education of influencial lay people about the motion of the earth's crust and the consequent need for increased funds for seismic and volcanic investigation and prediction.

There is a second point in which I would like to enlist your support. One of the major difficulties in publishing small scale thematic maps in Latin America, is the depiction of national boundaries. As you know, these boundaries are necessary on small scale maps for the location of phenomena. We all know where the defacto boundaries are. On scientific maps with a suitable disclaimer note, the depiction of defacto boundaries would have no effect on a future boundary settlement. We have already, in my committee, published one map of South America using the United Nations depiction of boundaries and disclaimer note with no unfortunate repercussions. I trust by using the same formula, my geological base map will be allowed to see the light of day. I hope you will support this plan.

I would like to close my talk with a brief résumé of the work of my committee in PAIGH (i.e. the Special Maps Committee). The members of my committee, one or two per member country exchange information on the progress of thematic mapping in each member state. I encourage the writing of technical articles for the PAIGH journal, Revista Cartografica. These articles cover thematic mapping techniques and map content. We have very recently published a text "Thematic Mapping — Symbols and Specifications" which I consider a most useful work. The distribution of this text is now underway and I would encourage you to have reviews of it published in your country so that those interested in the subject may learn of its existence.

I have mentioned our efforts in publishing small scale thematic maps. One of the regulations of PAIGH stipulates that special projects must benefit more than one member state; and this regulation tends to direct us toward scales smaller than 1:1,000,000. As I mentioned, we have a project underway to produce a new geological base map of South America at 1:2,500,000.

My committee has taken on the responsibility for encouraging the formation and growth of map libraries in PAIGH. It is difficult, if not impossible, to encourage the production of thematic maps if there is no place for the cartographers concerned to study the work of other agencies. A good map library, well housed, well stocked and well used, is essential to any national program of thematic mapping. My committee has prepared a "Manual for Small Map Libraries" which will be published shortly in Revista Cartografica. It has been translated into Spanish and I believe if any of you wanted a xerox copy of the manuscript you could get it from the Secretary-General, Ing. Sáenz.

Finally, my committee is responsible for encouraging work in the publication of national and regional atlases. Atlases are today largely composed of thematic maps at very small scales, and hence

the study of their production comes logically to my committee. We have several "survey" projects underway at present which are gathering information prior to a PAIGH Symposium on National and Regional Atlases which will be held in about two years' time.

Now, as I mentioned at the beginning of my talk, I would like to suggest two subjects which I think might form the bases of worthwhile resolutions.

1. I think the tectonic map of South America at a scale of 1:5,000,000 which is at present in manuscript form should be published and should receive PAIGH support in this regard. I would like to see a resolution to this effect.
2. I believe that well organized map libraries are essential both to the teaching of advanced cartography and in the design of new forms of thematic maps. Therefore, I recommend a resolution urging all delegates to support the formation and growth of map libraries in universities and cartographic agencies.

Padre J. E. Ramírez:

Muchas gracias Señor Sebert. Nuestro siguiente en la lista de hoy es el Sr. James N. Jordan que va hablar sobre **"Where are we headed in seismic data exchange?"**

Mr. J. N. Jordan:

Fig. 1 shows the Chinese instrument alleged to be the granddaddy of earthquake recordings. The Chinese catalog, going back about 3,000 years, is good evidence that there has long been a desire to document and exchange data on earthquakes. More recent manifestations of this desire to share in and cooperate among earthquake research groups are the improved global seismicity studies. The increased number of stations and seismological investigations of the International Geophysical Year (IGY), and several years later the World Wide Standardized Seismograph Network (WWSSN), provided the seismic data to outline the plates of the new tectonics.

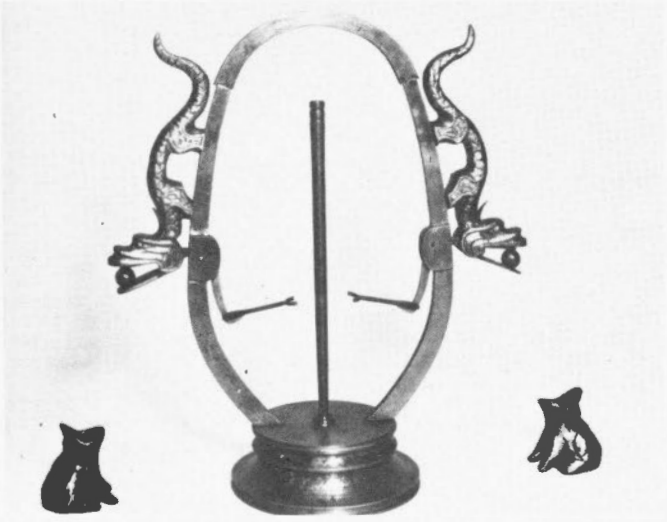

Figure 1. Chinese seismoscope.

Another cooperative venture that was started with minimal facilities but represents a broad based effort on the part of many is the International Tsunami Warning System (ITWS). Though there have been deaths and property losses since the system was started in 1946, there is no doubt that this International Oceanographic Commission (IOC) sponsored effort has been and will continue to be beneficial. Fig. 2 shows the principal tsunamigenic zones and also the tide stations and seismograph stations of the ITWS. This loosely structured multi-national cooperative effort is unique in terms of a high-return, low-cost operational system. It has an intergovernmental superstructure but the real key to its successful operation, in my opinion, are the dedicated individuals that see the need and actively participate in the ITWS.

This increased number of quality seismographs, facilities and workers, coupled with the recent earthquake disasters (Chile, 1960; Alaska, 1964; Venezuela, 1967; San Fernando, 1971; Managua, 1972; Guatemala, 1976; and many others), have engendered programs in earthquake risk and prediction. Just a few years ago earthquake risk was represented by seismicity and zoning maps and most seismologists even refused to discuss prediction. Viable efforts in earthquake risk, prediction and tectonic studies, require not only improved data analysis and handling systems, such as those of the International Seismological Centre (ISC), National Earthquake Information Service (NEIS) and others, but also special data processing for regional and national needs. Each group or individual has different needs, but it should be obvious that data exchange on some level should be mutually beneficial.

National Earthquake Information Service seismicity studies

NEIS locates earthquakes and determines magnitudes by making use of data provided by cooperative observatories. The group also operates the U.S. Network of Seismograph Stations (Fig. 3). Some of the stations, operated by universities and other groups, as well as data reported by telephone, are used to locate large or important earthquakes as soon as possible on a 24-hour, 7-day week basis. Data are released immediately to all groups including civil defense hazards study groups. For important earthquakes, NEIS will provide timely data as requested via telephone, telex or other means. Many other stations report data to NEIS in a variety of modes. Derr *et al.* (1976) give additional detail on NEIS operations, services and products.

The Preliminary Determination of Epicentres (PDE) program is a voluntary and cost-sharing activity. The success of this global seismicity study is due to the dedicated efforts of many people all over the world. Publications of NEIS, such as the PDE and Earthquake Data Report (EDR) are provided gratuitously to contributors of data. The bulk of the data comes from U.S. Geological Survey WWSSN and similar stations (Fig. 4). The earliest received data arrive via telegraphic standard format for ease in processing (Fig. 5)*. Cutting and splicing of tapes is required. It is worthwhile to note the ease in which we acquire the Canadian data. A data file is established for us in Ottawa and the file is transferred to cassette in Golden and thence to the computer. Once in the system the data are automatically sorted and preliminary solutions are obtained. Data are continually added and deleted (either due to later arriving station data or to the publication of the associated event). During normal operations there are about 2 months of data in the system or about 120,000 determinations of phase data and slightly fewer determinations of amplitude data. Efforts are underway to improve the system and are discussed later in this report.

* The use of brand names in this report is for descriptive purposes only and in no way constitutes endorsement by the U.S. Geological Survey.

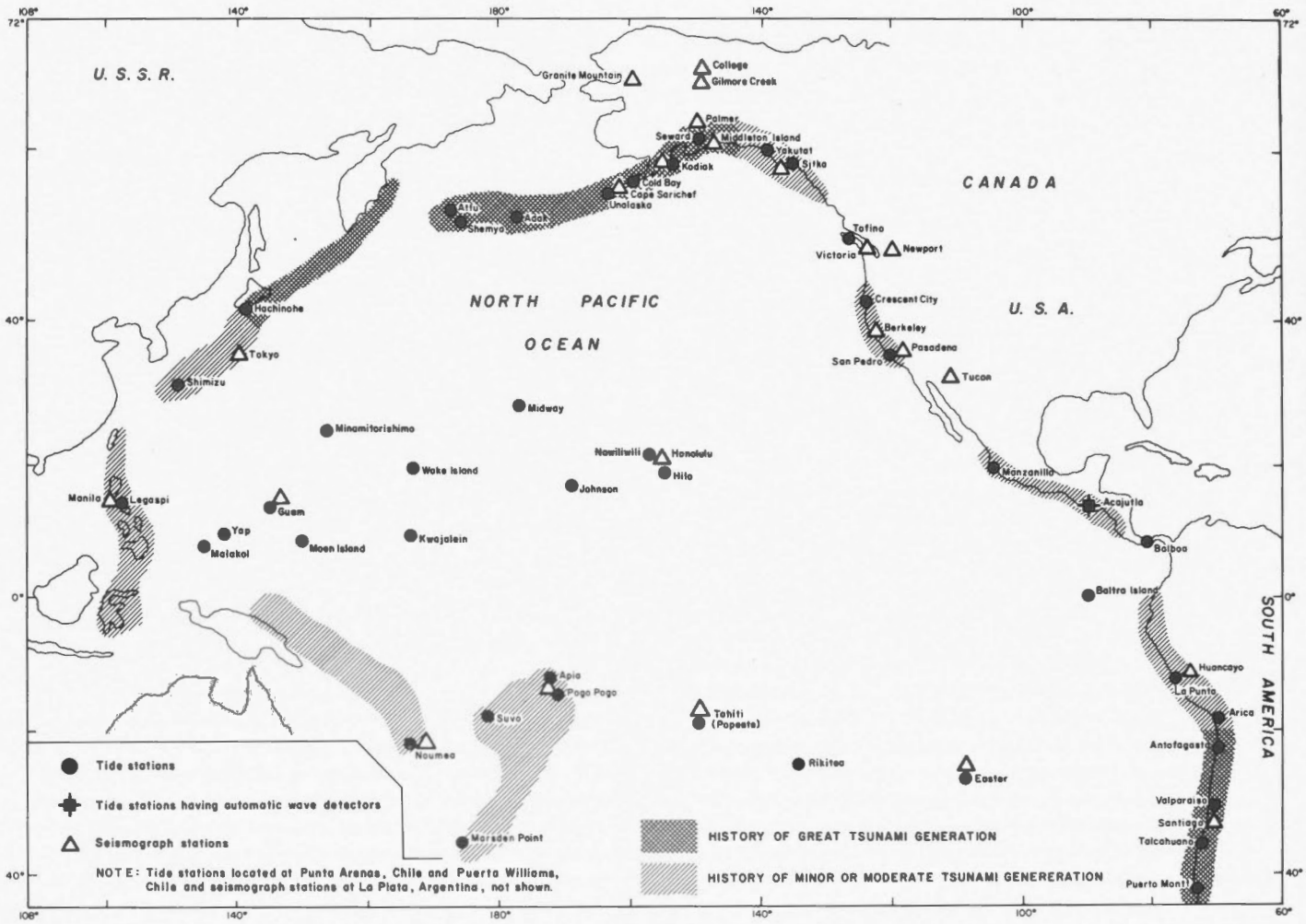

Figure 2. Tsunamigenic zones and the Tsunami warning system.

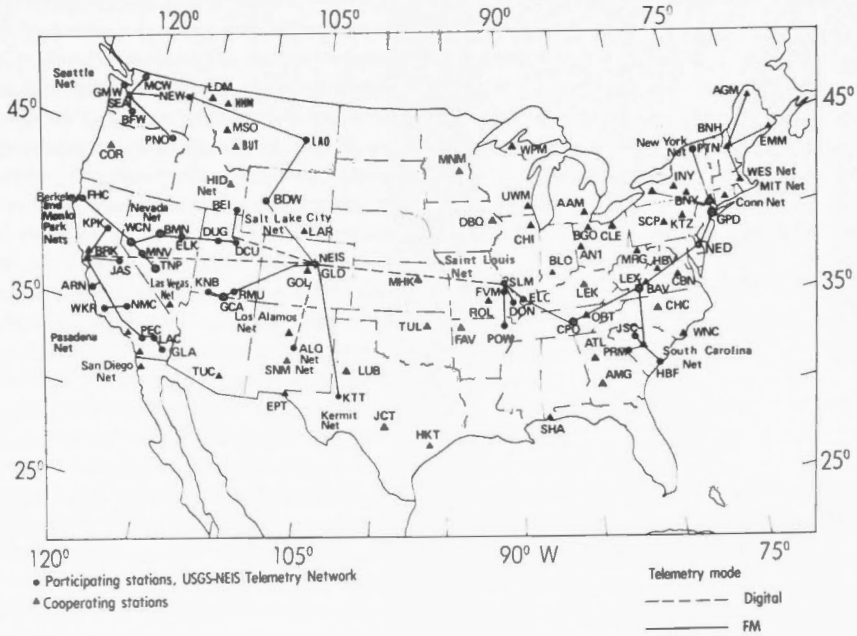

Figure 3. U.S. Network of Seismograph Stations. Station code identification can be found in seismograph stations abbreviations and coordinates. Available from NEIS-US. Geological Survey, 1977.

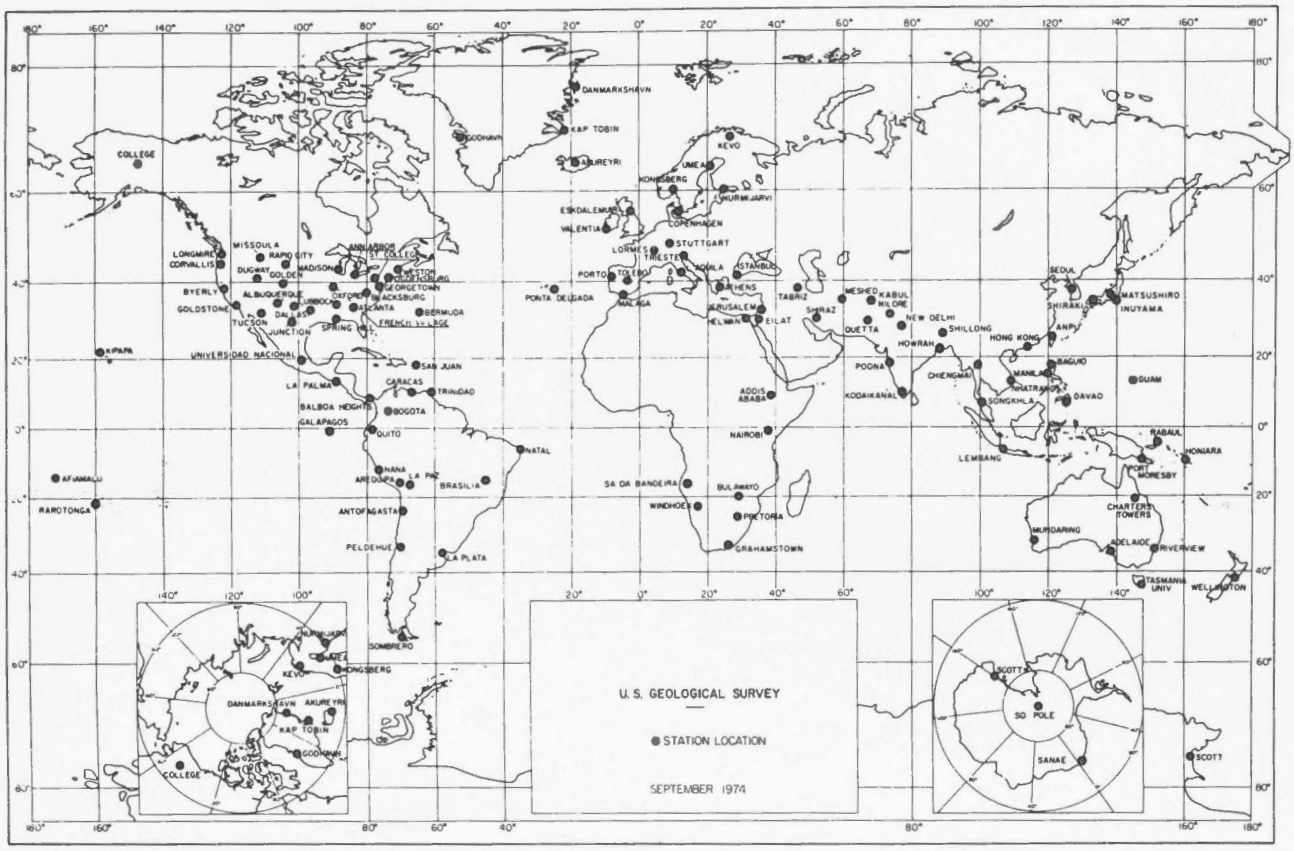

Figure 4. World-wide standardized seismograph network.

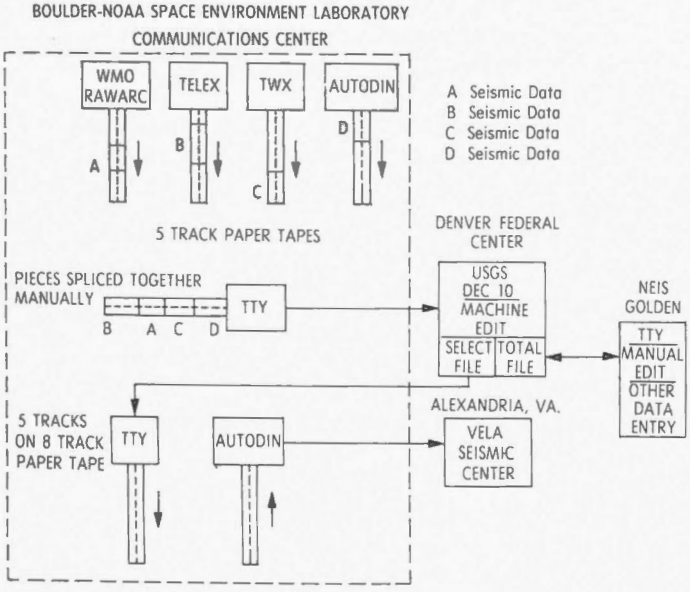

Figure 5. Current telegram processing system.

Earthquake locations in the southern hemisphere, especially South America and environs

For a variety of reasons there are some areas in the southern hemisphere where there is a paucity of seismic data and therefore NEIS can provide only fair to poor earthquake locations and magnitudes. In some areas interesting events may not be reported. Fig. 6 shows the availability of data from selected South American stations for April 1975. The data obtained by NEIS from this region are not adequate for modern seismicity studies. ISC does not add much additional information. Fig. 7 (with the knowledge of Fig. 6 showing frequency of reports) suggests a first processing of data by NEIS and that additional processing, along with additional data input, by regional or national groups, is required. This second-effort processing could be done starting with the publication of the U.S. Geological Survey extended EDR or after the ISC publish their data. Seismic risk studies require good earthquake locations and magnitude determinations. Recent studies show that location errors of 15 - 60 km and occasionally greater are common.

Recent initiatives by the Regional Centre for Seismology for South America (CERESIS) and other groups will improve seismicity studies in the region. An interim effort might be rewarding if accompanied by improved data exchanges.

Improvements

The WWSSN has been, and continues to be, quite beneficial in seismological studies. Analytical techniques by a number of groups and individuals are greatly enhanced by the use of digital techniques. A number of stations, known as Seismic Research Observatories (SRO), are now being installed (Peterson *et al.*, 1976). It is understood that in addition to the current planned network of 13 stations other SRO systems are being considered. While the SRO system greatly improves S/N (signal to noise ratio), an additional advantage is the great range of unclipped

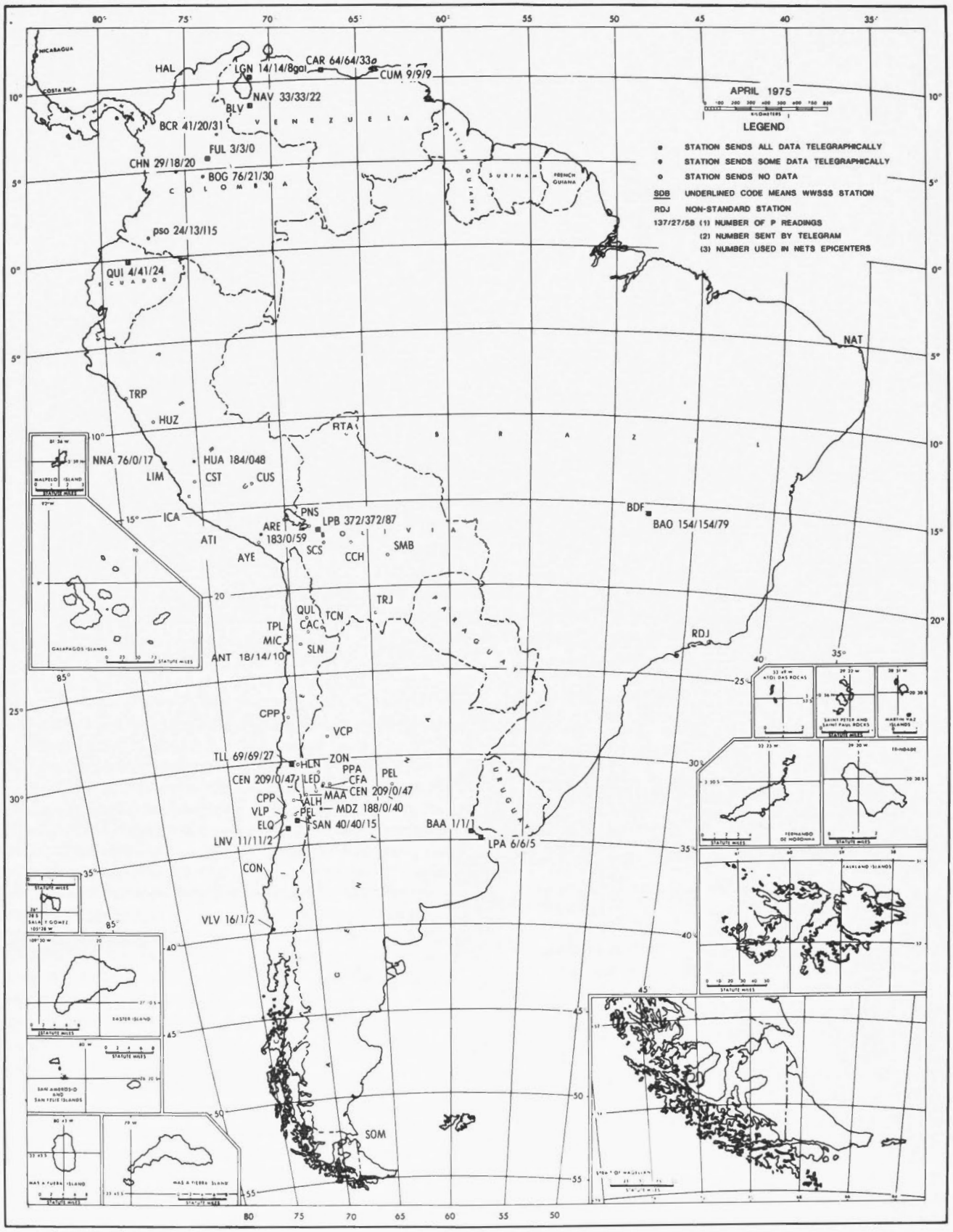

Figure 6. Seismic data reporting from South American stations April 1975. Numbers by station codes give frequency and type of reports for month indicated.

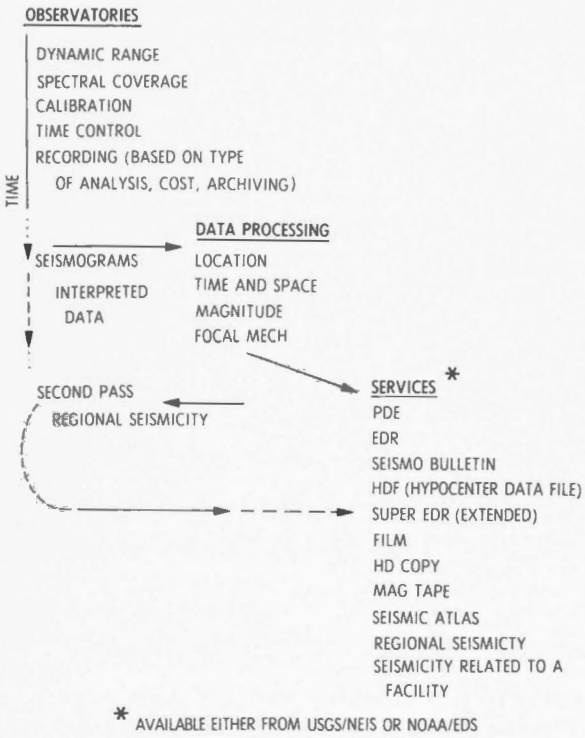

Figure 7. Observatories/Data/Services. Flow diagram giving function of each step.

recording (126 dB or 6 orders of magnitude). The conventional seismograms, SPZ (Short period vertical) and LPNEZ (long period, north-south, east-west, vertical) and magnetic digital tape records will be available. The U.S. Geological Survey is now setting up a data analysis system aimed primarily at source parameter studies and primarily making use of the SRO and other similar systems. Some of the results will become a part of the PDE program in the future. Also a number of HGLP (high gain long period) stations will be modified to record data equivalent to the SRO. Additional stations with similar capabilities may be added later.

We have discussed the great bulk of seismic data and have seen how the telegrams are processed involving human intervention (and some errors). Now plans are to use micro-processors and/or mini-computers to aid in data input and early analysis. Fig. 8 shows a plan for handling telegraphic data. This could be upgraded for computer links, e.g., to Ottawa, ARPANET, etc. The United-array data now being read onto a cassette from a London gateway host could be processed automatically. The PDP11 could be used for additional waveform analysis or files could be set up for merging P-(primary-wave) picker data and telegraphic data. The plan is to build a prototype system and in due course integrate as many of the data management and processing methods as possible. Fig. 9 shows the system for an event detector that is planned for the U.S. network.

Once the P-picker and data analysis systems are operational, it is planned to consider alternative satellite seismic data gathering systems. Either numeric or waveform analysis can be carried out in Golden or other centres with currently conceived systems. Figs. 10 and 11 show a schematic of the ground and the overall system. Current technology, assuming availability of satellite channels, appears to be a cost-effective manner for data acquisition and improved data exchanges.

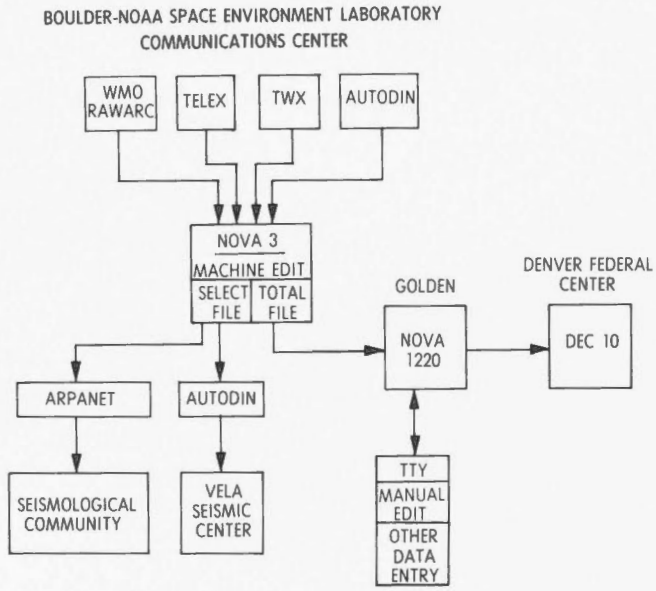

Figure 8. Proposed improved telegram processing scheme.

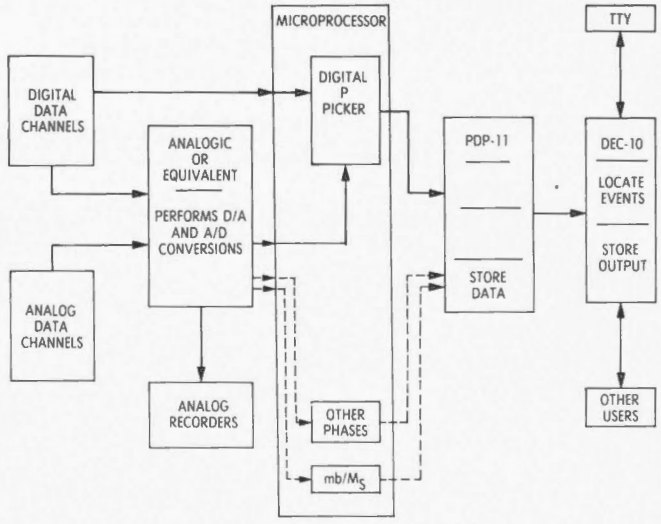

Figure 9. Scheme for an event detector for U.S. network.

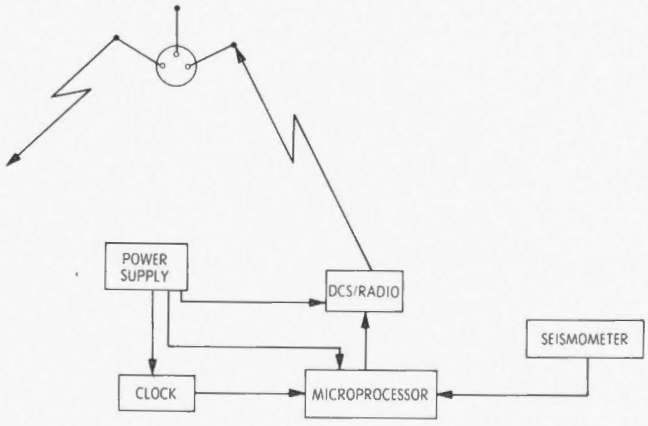

Figure 10. Ground satellite seismic recording scheme.

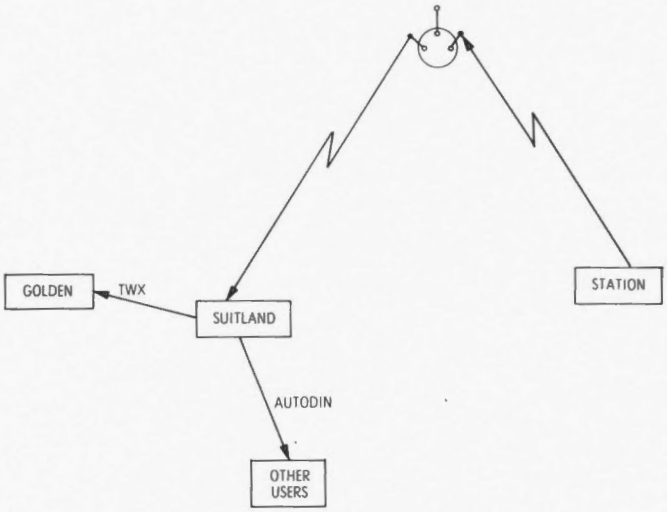

Figure 11. Overall satellite seismic recording scheme.

In this brief discussion we have commented on the very oldest seismic data system and some of the newer systems being either implemented or planned. These new systems, affording new analytical opportunities, are coming at a time when there is increased concern with earthquake hazard and prediction studies. An effective seismic data exchange system will benefit all concerned with international, regional, national or specific site aspects of the earthquake problem. NEIS looks forward to the increased challenges and welcomes the opportunity to work with other groups, particularly regional and national centers, in programs of mutual interests.

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Padre J. E. Ramírez:

Muchas gracias Señor Jordan por su conferencia tan interesante.

SEVENTH SESSION
Thursday, September 30

SEPTIÈME SÉANCE
Le jeudi 30 septembre

SEPTIMA SESION
Jueves, septiembre 30

REVIEW AND REVISION OF PROGRAMS AND PRIORITIES OF THE GEOPHYSICS COMMISSION

ÉTUDE ET REVUE DES PROGRAMMES ET DES PRIORITÉS DE LA COMMISSION GÉOPHYSIQUE

EXAMEN Y REVISION DE PROGRAMAS Y PRIORIDADES DE LA COMISION DE GEOFISICA

Chairman/Président/Presidente
DR. E. KAUSEL

Speakers/Conférenciers/Expositores

ING. V. MAZZINI
ING. A. BRUSSONI
ING. R. SALGUEIRO
ING. R. ARGENAL
ING. J. J. GUEVARA
PADRE J. E. RAMIREZ
ING. R. LLINAS
DR. L. OCOLA

Dr. E. Kausel:

Tal como habíamos indicado muy al principio de este simposio, estos dos últimos días estarán dedicados fundamentalmente a estudiar cuales deben ser las líneas troncales del programa de geofísica para el cuadrienio 1977-1981.

Habrá un exámen y revisión de los programas y prioridades de la Comisión de Geofísica. Dentro de este punto aparecen seis subtemas, ha habido algunas personas que han demostrado interés en poder dar en forma muy resumida una breve reseña de roles y prioridades que la Comisión de Geofísica debiera tener en el fomento de la investigación de América Latina.

Antes el Ing. Victor Mazzini expondrá sobre **"Un Perfil Sudamericano de Mareas Terrestres".**

Ing. V. Mazzini:

Voy a hacer un esbozo sobre el tema el perfil sudamericano de mareas gravimétricas. Quizás muchos países latinoamericanos hayan recibido una invitación del Observatorio Real de Bélgica, para cubrir con estaciones de mareas gravimétricas el único continente en que aún no se han estudiado, el sudaméricano. Como la Universidad de Tucumán tiene investigadores colaborando con el Dr. Melchior, particularmente el Sr. Usandivaras, hemos recibido la propuesta de encarar el programa de medición de mareas gravimétricas. Para ello, el Observatorio Real de Bélgica nos propone, a partir de octubre-noviembre de 1977 realizar un curso de entrenamiento, posiblemente en Tucumán, Argentina, de tres semanas. Asímismo ofrece el préstamo durante el período de 1977 1979, de cuatro gravímetros geodinámicos LaCoste and Romberg y dos equipos de péndulos horizontales.

Las organizaciones de nuestro país han prestado ya el apoyo para poder realizar este proyecto, pero es imprescindible contar con el respaldo de los restantes países sudaméricanos así como del IPGH.

Dr. E. Kausel:

A continuación el Ing. Aldo Brussoni del Uruguay tiene la palabra.

Ing. A. Brussoni:

Voy a exponer un corto trabajo sobre la historia de la actividad geofísica en Uruguay. Respecto a la sismología y al geomagnetismo he encontrado que en Uruguay operó desde el año 1887 una estación sismológica que llegó a trabajar hasta el año 1925. En este momento estoy a la búsqueda de los registros, si es que todavía permanecen en algún lado. Hay otro dato respecto a la sismología.

En el año 1910 aproximadamente se creó el Instituto Nacional de Meteorología, que fué una estación modelo en su momento y que estuvo también equipada con equipos sismológicos. Esta estación operó hasta el año 1940, y estoy también a la búsqueda de los registros de la misma.

A partir del final de la segunda guerra mundial la compañía Estatal Petrolera llevó a cabo un programa muy serio que incluyó trabajos geológicos, geofísicos y perforaciones. Para la época fué una magnitud bastante importante dado que la inversión hecha desde el año de 1948 hasta el 58 se sitúa alrededor de diez millones de dólares pagados por el propio Gobierno del Uruguay. Estas exploraciones dieron por resultado, aparte del conocimiento del subsuelo a través de las perforaciones, el hecho de que en el país existan desde el año 54 aproximadamente unas 26,000 estaciones de gravimetría hechas con equipo Worden y además hechas con criterios muy serios dado que en el país ya existía una red de nivelación de primer orden.

En esta primera etapa, el Servicio Geográfico Militar publicó las primeras cartas geomagnéticas. Esta tarea fue interrumpida alrededor de los años 50. Posteriormente a esto se abre un segundo período vinculado en cierta manera a una coordinación horizontal con la Universidad Nacional de Buenos Aires, dió como resultado el establecimiento de una serie de programas con Uruguay. El primer resultado de esto fue la coordinación de un trabajo que se hizo como prolongación del perfil gravimétrico de Este a Oeste, en el paralelo 34, a raiz del cual se interesó al servicio Geográfico Militar del Uruguay a intervenir en problemas gravimétricos. Ese interés del Servicio Geográfico Militar Uruguayo dió por resultado la mediación de la red fundamental de gravimetría, cuyos resultados fueron publicados y ampliamente difundidos.

El trabajo fué realizado con equipo LaCoste and Romberg, utilizándose para la publicación fondos cedidos por el IPGH y se otorgará a quien lo solicite.

Posteriormente también con fondos del IPGH, se publicó una carta gravimetrica confeccionada en báse a los valores antes señalados.

Gracias a los potenciales recursos energéticos, hoy tenemos una cobertura en la plataforma continental de 9,000 kilómetros de línea sísmica. Está acompañada de observaciones gravimétricas y magnetometrícas (comenzaron en 1966).

Con relación a las actividades académicas, aún no se ha concluido la instalación de la estación sismologica programada, pero se espera ponerla en funcionamiento pronto.

En el aspecto de la enseñanza geofísica, recién desde hace dos años se dictan cursos regulares de geofísica y esperamos ampliar el campo de la investigación en los próximos años. Hay mucho interés puesto de parte de la Facultad de Humanidades y Ciencias para establecer un programa en el campo de las ciencias de la tierra.

Dr. E. Kausel:

Gracias Ing. Brussoni. A continuación, el Ing. Reynaldo Salgueiro de Bolivia.

Ing. R. Salgueiro:

El desarrollo significativo de las ciencias de la tierra es un hecho definido, para que las organizaciones, investigadores y técnicos de las Américas, consideren el problema creado por la explosión de la información derivada de la ingente masa de datos producida en las distintas actividades de la geofísica en los países americanos. Muy particularmente en aquellas naciones donde éstas actividades se han multiplicado extensamente debido a una activa política y estrategia científica-tecnológica, adoptada por los gobiernos en procura de crear un rápido desarrollo de las actividades relacionadas con la búsqueda y evaluación de recursos naturales.

La situación impresionante sobre el incremento de la información es de proyecciones imprevisibles y contrasta con el desenvolvimiento normal de las actividades geofísicas en el hemisferio, por cuya razón es conveniente plantear, definir y decidir por un esquema congruente e inteligente sobre politica de informacion a nivel científico, que contribuya eficazmente a una mejor inter-

acción, pretendiendo normalizar el sistema de informacion convencional que hoy defectuosamente rige en nuestras actividades y construir un sistema armónico que comprenda las multiactividades científicas y técnicas.

Este propósito de significado hemisférico, puede ser logrado si se proyecta un plan científicamente concebido, recordando que un sistema de informacion comprende una serie de hechos dentro del espectro total de las actividades humanas, es decir, está compuesta por componentes que cumplen funciones como la captura, clasificación, orígen, transmisión, almacenaje, recuperación, transformación, procesamiento, producción, presentación y diseminación de la información en función de los requerimientos, compatibilidad y finalidades para su mejor uso con el propósito de optimizar el rendimiento de las operaciones de campo, los trabajos de laboratorio, la validación de los datos, su estudio, investigación y obtención de resultados.

Diseñar un sistema global de información que no sólo tenga que ver con los países del hemisferio, sus organizaciones, sus científicos y sus actividades, ella debe proyectarse a todos los países de la tierra. Este hecho impone construir un sistema informativo (SIF) modular, armónico, flexible, compatible y adecuado a los requerimientos de los programas internacionales, regionales y nacionales.

Generalmente nos hallamos acostumbrados a nombrar que un sistema informativo se concreta al establecimiento de un Centro Internacional, regional o nacional, encargado del acopio de datos y bibliografía científica técnica de las ciencias de la tierra, cuya finalidad es la diseminación de la información; concepto definidamente erróneo, ya que un sistema de información como tal, no sólo involucra esta actividad sino todas aquellas que tienen relación con las actividades del geofísico en el modelo universal en el que vive, o sea prácticamente un sistema de información es un Universo que integra todo tipo de acción, manifestación, proceso, producción, desarrollo, resultados y decisiones que se adoptan en cualquier actividad en la que participa el hombre. Por lo tanto, al discutir sobre el diseño de un SIF tratamos prácticamente la solución de un problema al que debemos integrar sub-sistemas con el fin de construir un macro modelo total. Fig. 1. Por ello, al considerar el SIGEO estamos tratando un problema que dará origen a la base de datos Fig. 2 que tenga que ver multifacéticamente con todas las Ciencias de la Tierra, la que tiene relación, correlación y fundamento con el esquema general de la comunidad científica a la cual nos debemos porque de ella dependemos, para ella trabajamos y deseamos obtener un conjunto de mejores condiciones futuras de trabajo y producción científica.

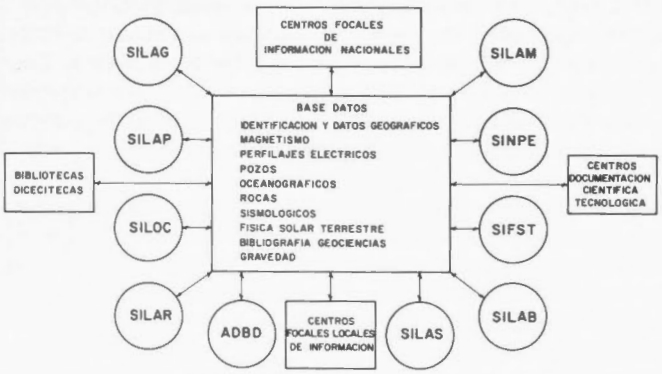

Figura 1. Base de datos de geociencias-BDGEO.

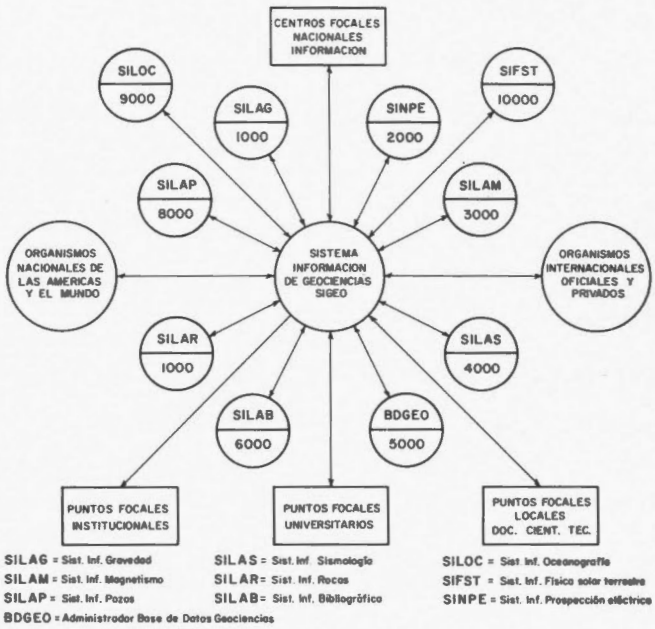

Figura 2. Sistema de información de geociencias.

Ahora bien, si pensamos en las enormes inversiones que hacen nuestros países cada año en los programas de prospección de minerales y petróleo, los estudios teóricos especializados y la investigación, probablemente estamos en una situación adecuada para juzgar con precisión los alcances del proyecto que pretenderíamos construir al decidir por un sistema de informacion integrado para las Ciencias de la Tierra, cuyos objetivos y lineamientos se deben fijar inicialmente, fisonomizando de esta manera el carácter integrativo del sistema. No podemos pensar en lograr éxito, si no creamos un instrumento de dominio público futuro como éste, para ser compartido entre las naciones americanas. En otras palabras, se debe pretender construir un SIGEO que no sólo sea integrado desde el punto de vista científico, sino debe ser dinámico con ideas orientadas a construir una sociedad que en el futuro se comprenda y viva mejor. Sobre este tema, deseo informar que se han implementado determinadas bases de datos orientadas a ciertas disciplinas de la geociencia, se ha diseñado e implementado el Sistema de Información de Gravedad SILAG cuyo "paquete" para el procesamiento de datos gravimétricos ha tomado años de trabajo en su elaboración y al presente se comparte entre aquellas instituciones que disponen de un "hardware" compatible. Asimismo, se ha formulado las metas y objetivos sobre ciertos Sub-Sistemas de Información como el de Datos de Pozos, Magnéticos y Bibliografía de Ciencias Geofísicas (SILAB) Fig. 3. Otros estudios parecen hallarse adelantados en vista de haberse encargado su elaboración a grupos de trabajo de especialistas de la Comisión de Geofísica del IPGH.

Especificamente, debemos aunar esfuerzos humanos y recursos económicos de los países americanos con relación al fomento, desarrollo e intercambio masivo de experiencias y divulgación de la información científica en todas las latitudes de las Américas. Sería práctico que a partir de esta reunión, se definiera el establecimiento del "sistema de informacion integrado de ciencias de la tierra" Fig. 1, para cuyo fin, se encargue a un grupo de trabajo especializado a elaborar un manual de instrucciones generalizado que dé los lineamientos básicos de la construcción de

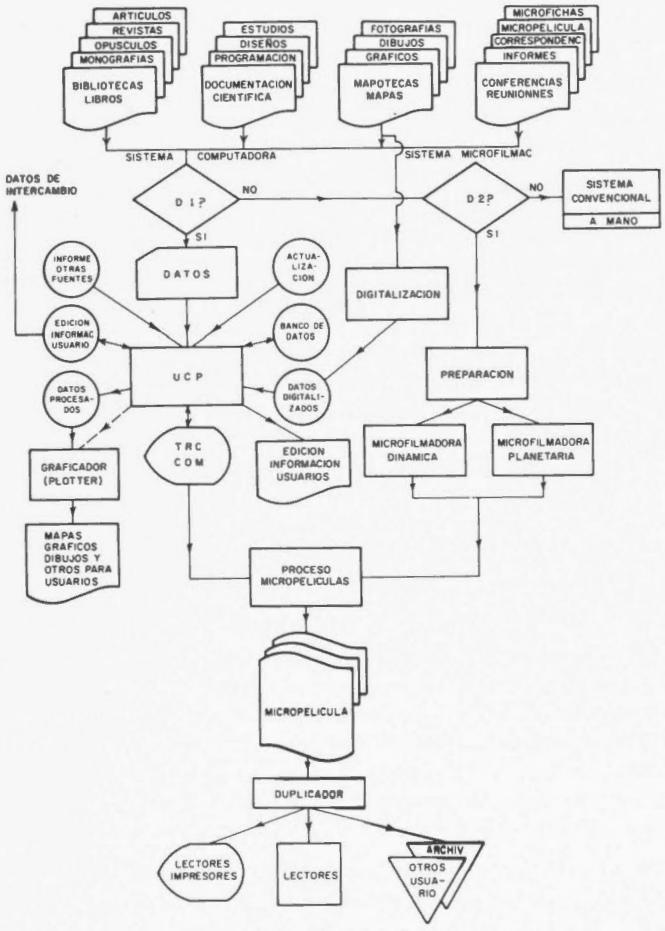

Figura 3. Sistemas de información operativo integrado de bibliografía.

los sistemas de información. Este manual debe incluir normas e instrucciones que sean el resultado del estudio sobre diagnóstico de la información, las experiencias logradas y que convengan ser adoptadas en las operaciones que ejecuten los especialistas dedicados a la información. Es fundamental evitar en lo posible, dispersión y duplicación de esfuerzos, debiendo pretender aprovechar y explotar al máximo los recursos humanos y medios disponibles; diseñar planes futuros que estén direccionados hacia el objetivo máximo de la política sobre información para las Américas.

Es importante que los organismos internacionales como Naciones Unidas, UNESCO, OEA, IPGH, IICA, Acuerdo de Cartagena, Convenio Andrés Bello, Corporación de Desarrollo Andino, ARPEL y otras, promuevan y proporcionen apoyo económico para cumplir estos propósitos y coordinen sus programas en el campo de la información para que cada una de ellas promueva la creación de sistemas y sub-sistemas congruentes al desarrollo socio-económico para mejorar las vinculaciones de las Américas.

En principio, podríamos formular las siguientes metas del SIF para este plan hemisférico.

1. Crear el sistema de información global SIGEO cuya finalidad es el desarrollo y control de calidad de los programas relevantes de la geofísica en áreas de prioridad que determinen los países miembros de la COMGEOFIS.
2. Construir sobre una arquitectura adecuada y ajustada a los requerimientos funcionales progresivos, un sistema de informacion multidisciplinario de geociencias cuyo diseño e implementación permita motivar y promover el desarrollo de instituciones cientificas, técnicas y profesionales de las Américas.
3. Aprovechar los medios y procedimientos existentes para promover el desarrollo a cargo de los organismos internacionales y nacionales especializados para compartir la producción del SIF mancomunadamente.
4. Establecer el sistema de información integrado de ciencias de la tierra sobre bases de organización y administración de sistemas que permita coordinar, relacionar, poner al día y elevar el rendimiento de las unidades operativas.

Para alcanzar las metas señaladas, deberá procurarse cumplir los siguientes objetivos:

1. Estudio de la situacion sobre los sistemas informativos de la geofísica existentes y en desarrollo; definir los sistemas prioritarios sujeto a los resultados de la investigación inicial y su diagnóstico.
2. Encargar la ejecución de este estudio a coordinadores especialistas de las entidades nacionales interesadas en esta problemática.
3. Fijar tareas que deben cumplirse para construir el SIF. Sin embargo, podríamos sugerir ciertas medidas iniciales conducentes a resolver este problema que requiere talento, perseverancia, tiempo y medios.
   3.1 Facilitar la implementación del SIF organizando Centros Focales Nacionales y Puntos Focales locales de Información, los que serían encargados de trabajar en base a un plan, el inventario de la bibliografía y documentación sobre geofísica producida en cada país.
   3.2 Conseguir fondos económicos para auspiciar reuniones de expertos geofísicos en información y medios que sirvan para implementar el programa SIGEO.
4. Auspiciar cursos, seminarios, reuniones y otros, para el entrenamiento del personal de alto nivel y otros, en los campos de la informática, la ingeniería de sistemas y documentación científica tecnológica relacionada con las ciencias de la tierra.
5. Coordinar la labor de los geofísicos de las Américas, definiendo una estrategia de intercambio y relación que se debe mantener latentemente con relación a la producción de la información en crudo, su elaboración y su impresión en revistas, folletos, instructivos y otras formas de presentación, siendo esta la única avenida a través de la cual podremos lograr los siguientes objetivos adicionales:
   5.1 Estrechar vínculos personales entre científicos, sus motivaciones y nuestros países;
   5.2 Fijar un flujo informativo intenso, mediante un esquema racionalizado que nos imponga una constante interrelación, que se ocupará de elevar en unos el nivel de sus conocimientos y en otros, estimulará su producción.
   5.3 Crear condiciones en lo que respecta a la relación que debe existir entre la sociedad científica con la comunidad americana y la internacional.
   5.4 Producir a nivel panamericano y del IPGH el primer sistema de informacion integrado, al que se agregarán otras disciplinas y actividades geofisicas, cuyo fin es el diseño y desarrollo del modelo "SIGEO".

De nada serviría que periódicamente tengamos la ocasión de reuniones como la de esta ocasión y no tratemos con suficiente amplitud y decisión este tema que se consagra en forma definida a

salvaguardar la historia científica que trasuntará nuestras inquietudes, preocupaciones y buenos deseos para una mejor producción cientifica y tecnica.

Dr. E. Kausel:

Gracias Ing. Salgueiro. A continuación el Ing. Roger Argenal del Instituto de Investigaciones Sísmicas de Nicaragua.

Ing. R. Argenal:

La red sismológica de Nicaragua cuenta actualmente con 14 estaciones telesísmicas. Esta red sísmica tuvo su origen precisamente a raíz del terremoto de Managua en diciembre de 1972 y fué inaugurada en mayo de 1975, mediante la ayuda de Estados Unidos.

Esta red recoge alrededor de 400 temblores por mes. Aproximadamente media hora después de haber sucedido el temblor, se tiene la información de donde ha sucedido. Esta siendo utilizada para hacer zonificaciones sísmicas y para el desarrollo de códigos de construcción.

Quisiera llamar la atención sobre los progresos efectuados por la sismología en Latinoamerica.

Ya existen redes sismológicas en México, Venezuela, Nicaragua, y pronto habrá una red integrada para todo Centroamérica. Ante la existencia de tales redes habrá que comenzar a pensar en un centro que esté capacitado para poder manejar los numerosos datos que van a producirse.

Dr. E. Kausel:

A continuación el Ing. Juan José Guevara del Instituto Geográfico Nacional de Honduras.

Ing. J. J. Guevara:

Los trabajos de levantamiento gravimétrico que se han venido realizando en la República de Honduras tuvieron su origen en la necesidad de efectuar el levantamiento de una red gravimétrica en los países Centroamericanos con el objeto de continuar la ya existente en México, considerando que los únicos datos gravimétricos que se tenían en Centro América y Panamá hasta 1956, eran las medidas pendulares realizadas por el Ingeniero E. Ruiz de la Secretaría de Agricultura de México, en 1936 y 1940; las de gravímetro realizadas por W. Harding en 1949 y W. Black, en 1952, ambos de la Universidad de Wisconsin y una línea transistmica sobre bancos de nivelación llevada a cabo por Joseph A. Koszlosky y el Inter American Geodetic Survey (IAGS) en la República de Panamá. En consecuencia fué en la República de Guatemala donde primero se puso en ejecución el levantamiento de la red gravimétrica de ese país, mediante arreglos efectuados por el Doctor Manuel Maldonado Koerdell, en ese tiempo Secretario del Comité Panamericano de Ciencias Geofísicas, aprovechando el viaje que realizó a la República de Guatemala en el año Geofísico Internacional, habiendo contado con la colaboración del Instituto de Geofísica de la Universidad Nacional Autónoma de México, del Instituto Panamericano de Geografía e Historia, de la Universidad de Wisconsin, y del Inter Américan Geodetic Survey. Posteriormente durante la segunda semana cartográfica Centroamericana efectuada en San Salvador entre el 2 y el 7 de Octubre de 1957, con la participación de los delegados de las Instituciones Cartográficas de Centroamérica y Panamá, se juzgó conveniente aprovechar el ofrecimiento de los señores Julio Monges Caldera, George P. Woollard, Joseph A. Kozlosky y Haroldo Duarte, para que con la colaboración del Instituto Panamericano de Geografía e Historia, el Instituto de Geofísica de la Universidad Nacional Autónoma de México, el Instituto Nacional de la Investigación Científica de México, la Woods Hole Oceanographic Institution y el Inter Américan Geodetic Survey se extendiera el programa gravimétrico iniciado en Guatemala a los demás países Centroamericanos. Fué así como en el año de 1959 el Ingeniero Julio Monges Caldera inició los trabajos en Honduras habiendo observado 101 estaciones gravimétricas, de las cuales 93 se establecieron sobre bancos de nivel y las 8 restantes en los aeropuertos de Tela, Ceiba, Trujillo, Olanchito, Yocón, Puerto Lempira, Ahuas y Catacamas, habiendo colaborado con estos trabajos el Ingeniero Marco Antonio Casco de la Dirección General de Cartografía de Honduras. A finales de este mismo año se realizó una segunda gira para continuar con la observación de estaciones gravimétricas, siendo el señor Francisco Laínez quién acompaño al Ingeniero Monges en ésta oportunidad; todas estas observaciones fueron realizadas con el gravímetro Worden No. 33, propiedad del Inter American Geodetic Survey (IAGS). A principios de 1960 Román F. Geller Jr., del Inter American Geodetic Survey (IAGS) con los gravímetros W-32b y W-326 ligó el Aeropuerto Internacional de Toncontín con los demás Aeropuertos de Centroamérica utilizando un avión de la U.S. Air Force, tomando como base la estación PAD-Pendulum Station de la Zona del Canal. Los valores obtenidos fueron los siguientes:

Managua, Nicaragua . . .	978.28571 gals.
San Salvador, El Salvador .	978.18803 gals.
Tegucigalpa, Honduras . .	978.08651 gals.
San José, Costa Rica . . .	977.97849 gals.
Guatemala, Guatemala . .	977.98071 gals.

En 1966 en que fué fundado dentro de la organización del Instituto Geográfico Nacional de Honduras el Departamento de Geologia e Hidrografía, los levantamientos gravimétricos pasaron a formar parte de las responsabilidades del Departamento en mención, y fué así como en 1969 y dentro de un programa cooperativo entre ésta Institución y el Servicio Geodésico Interamericano se planificó con el objeto de ponerlo en ejecución el Proyecto de levantamiento de la red gravimétrica básica de la República. Anteriormente al inicio del establecimiento y observación de ésta red gravimétrica básica se recibió entrenamiento y asistencia técnica de parte del Ingeniero Duane McDaniel del Servicio Geodésico Interamericano, habiendo observado el mencionado señor McDaniel conjuntamente con el Ingeniero Juan José Guevara Rodríguez y utilizando un gravímetro Worden, la línea de nivelación que de Tegucigalpa conduce al Valle del Zamorano y desvío a Danlí.

Como parte de la red gravimétrica básica de la República se principiaron a observar por vía terrestre y usando un carryall del IAGS las líneas que de Tegucigalpa conducen a la Aduana del Amatillo (Frontera con El Salvador) y San Marcos de Colón, las cuales fueron realizadas por los Ingenieros Perry Truxton y Juan José Guevara R., para lo cuál hicieron uso de dos gravímetros La Coste and Romberg, propiedad del Servicio Geodésico Interamericano.

En ésta oportunidad se establecieron y observaron seis estaciones gravimétricas las cuáles a continuación se describen:

1. Tegucigalpa
2. Sabanagrande
3. Nacaome
4. Goascorán
5. Choluteca
6. San Marcos de Colón

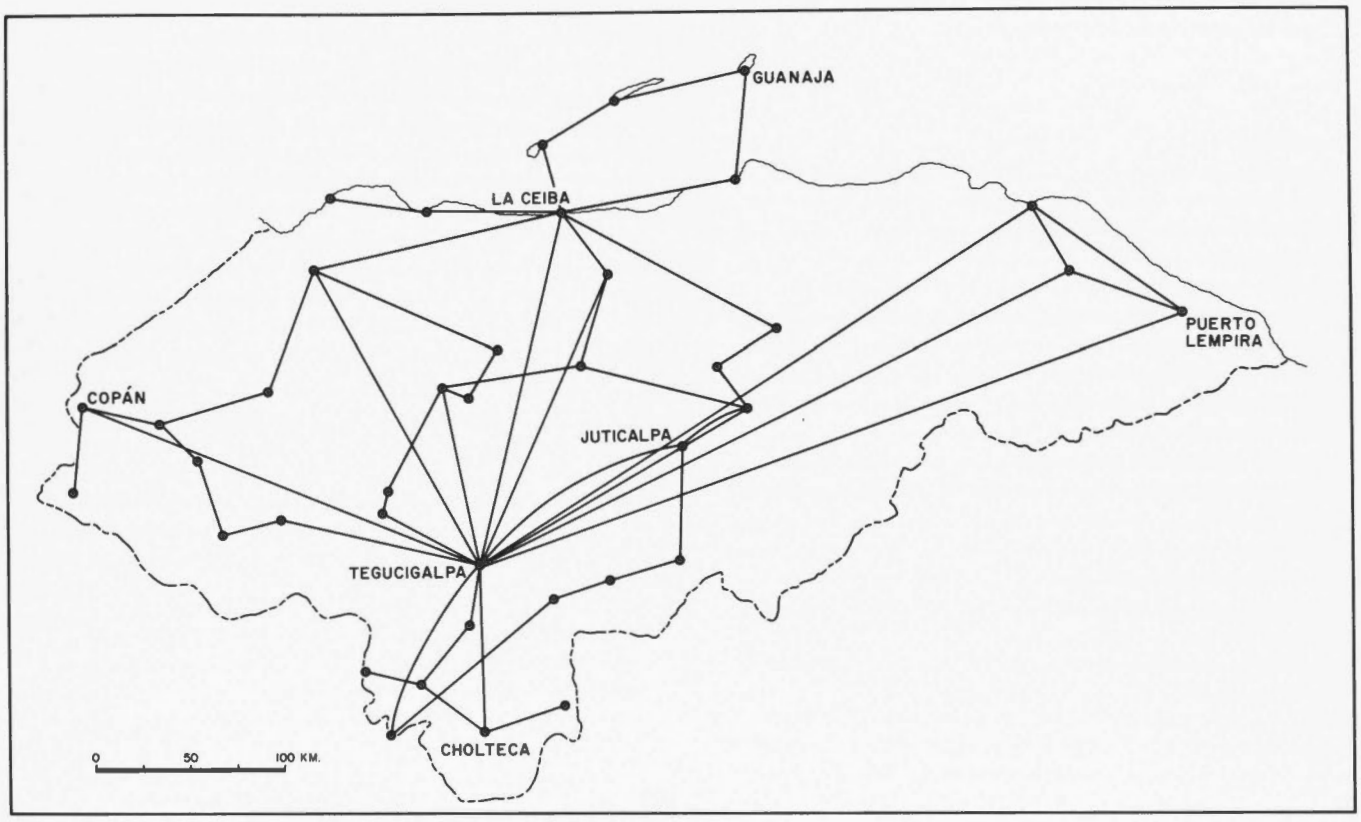

Figura 1. Estación de red gravimetrica de Honduras

Figura 2. Sumario de la gravedad. Traversas planeadas y completadas en Honduras.

Posteriormente y en el mismo año de 1969 se continuó con el establecimiento y observación de la red gravimétrica básica de la República, la cuál se realizó por vía aérea con la participación de los siguientes medios de transporte disponibles: Servicio Aéreo de Honduras (SAHSA), Fuerza Aérea Hondureña, Aéreo Servicios y una avioneta de Aeronaútica Civil.

Aproximadamente un 90% de éstas observaciones gravimétricas fueron realizadas por los Ingenieros Perry Truxton y Juan José Guevara R., en los diferentes aeropuertos y campos de aterrizaje existences en la República; un 10% de éstas observaciones fueron realizadas por el Ingeniero Duane McDaniel con la asistencia de los bachilleres Rogelio Lagos Cerrato y Rigoberto Granados. En todas éstas observaciones de la red gravimétrica básica de la Republica se utilizaron dos gravímetros LaCoste and Romberg, propiedad del Servicio Geodésico Interamericano. Las 39 estaciones que constituyen ésta red gravimétrica básica están localizadas en los siguientes lugares:

Tegucigalpa, Amapala, Yuscarán, Danlí, Santa María, Juticalpa, Sabanagrande, Nacaome, Goascorán, Choluteca, San Marcos de Colón, La Paz, Comayagua, Victoria, La Unión, La Esperanza, Erandique, Gracias, Santa Rosa de Copán, Copán Ruinas, Nueva Ocotepeque, Santa Bárbara, San Pedro Sula, La Ceiba, Tela, Puerto Cortés, Yoro, Sulaco, Utila, Roatán, Guanaja, Trujillo, Olanchito, Catacamas, Gualaco, — San Esteban, Puerto Lempira, Ahuás, y Brus Laguna. (Ver Fig. 1.)

La posición geográfica (latitud y longitud) y la elevación de las diferentes estaciones de ésta red básica fué determinada de mapas topográficos a escala 1:50,000, y fotografías aéreas a escala 1:60,000 donde no existían mapas; en los lugares donde se observó sobre bancos de nivel la elevación se obtuvo de los registros de éstos datos.

Una vez terminada la red gravimétrica básica se iniciaron en 1970 los trabajos de densificación de observaciones gravimétricas ligadas a ésta red básica y las cuales se han estado realizando a través de carreteras, senderos y ríos, habiéndose observado hasta la fecha un total de 2817 estaciones a una distancia entre éstas de aproximadamente tres kilómetros, las cuáles se han establecido aprovechando hasta donde ha sido posible, los bancos de nivel de las líneas de nivelación existentes. Donde no hay líneas de nivelación se han seleccionado puntos identificables como estaciones gravimétricas.

Estas observaciones están siendo realizadas por el Bachiller Rogelio Lagos Cerrato y en las cuáles ha utilizado los gravímetros Worden 682 y La Coste and Romberg No. G-23, auxiliado con mapas topográficos a escale 1:50,000, fotografías aéreas a escala 1:60,000 y descripciones de cotas fijas para la localización de los puntos observados. Parcialmente se ha contado también con la colaboración de los señores Julio Díaz Quintero y Pedro Gonzales, en lo que se refiere a la localización de los puntos observados.

En este mismo año 1970, el señor Mike T. Reblín, realizó el establecimiento y observación de estaciones gravimétricas en las rutas que ha continuación se detallan:

1. Tegucigalpa — Catacamas
2. San Pedro Sula — Taulabé
3. San Pedro Sula — Santa Bárbara — Taulabé
4. San Pedro Sula — Puerto Cortés — Cuyamel
5. San Pedro Sula — Progreso — La Ceiba — Olanchito.
6. Nueva Ocotepeque — Santa Rosa de Copán
7. Santa Rosa de Copán — Copán Ruinas.
8. Copán Ruinas — al Bm — U — 80 (Coíradia)

Este trabajo lo realizó el Señor Reblin sobre bancos de nivel, estableciendo estaciones gravimétricas en puntos identificables en los casos en que no se pudieron recuperar las cotas fijas, con el objeto de mantener una distancia aceptable entre estaciones; habiendo utilizado en este trabajo el gravímetro La Coste and Romberg No. G-193, auxiliado con mapas topográficos a escala 1:50,000, fotografías aéreas a escala 1:60,000 y monografías de cotas fijas para la determinación de la posición geográfica y elevación de las estaciones gravimétricas observadas. También el señor Reblin con la asistencia del señor Rogelio Lagos Cerrato, utilizando el mismo gravímetro LRG No. G-193 y un helicoptero del Servicio Geodésico Interamericano realizaron observaciones gravimétricas en los siguientes lugares: Tegucigalpa, Catacamas, Ahuasbila, Waspán, Twibila, Puerto Lempira, Trujillo, Iriona y Brus Laguna.

Durante 1970-71 el Instituto Geográfico Nacional prestó cooperación al Doctor Marco Antonio Zuñiga Izaguirre, proporcionándole vehículo, motorista, combustible, mapas topográficos a escala 1:50,000 y monografías de cota fija para que pudiera efectuar el levantamiento gravimétrico del Valle de Sula, trabajo que utilizó para elaborar una tesis que presentó como un requisito parcial para obtener el grado de "Doctor Of Philosophy" en la Universidad de Texas en Austin. El Doctor Zuñiga estableció y observó en ésta ocación un total de 397 estaciones gravimétricas en un área que cubre alrededor de 1500 kilómetros cuadrados y para lo cuál utilizó el gravímetro La Coste and Romberg No. 98, propiedad del Departamento de Ciencias Geológicas de la Universidad de Texas en Austin.

Con la coordinación de los Institutos Geográficos de Guatemala y Honduras y el Servicio Geodésico Interamericano, fué posible que el 10 de Abril de 1976, el Dr. Julio Monges Caldera del Instituto Geofísico de la Universidad Nacional Autónoma de México, con la asistencia del Bachiller Rogelio Lagos Cerrato y utilizando una avioneta comercial, efectuaran observaciones gravimétricas en los siguientes lugares: Tegucigalpa, Nueva Ocotepeque, Copán Ruinas, Santa Rosa de Copán, Santa Bárbara, San Pedro Sula y Puerto Barrios (Guatemala). El señor Monge observó con los gravímetros La Coste and Romberg Nos. G-143 y G-144, y el señor Lagos observó con el gravímetro La Coste and Romberg No. G-23. Los datos obtenidos ya están incluídos como parte integral del plan de estudios de terremotos que se llevarán a cabo en la División de Estudios Geofísicos del United States Geological Survey (USGS), en Menlo Park, California.

Del 3 al 15 de julio de 1976, el Bachiller Rogelio Lagos Cerrato efectuó la reobservación de las estaciones gravimétricas establecidas sobre la línea de nivelación que de Puerto Cortés conduce a Santo Tomás (Frontera con Guatemala) utilizando el gravímetro La Coste and Romberg No. G-23. La reobservación de estas estaciones gravimétricas fueron efectuadas con el fin de establecer diferencias con las anteriormente observadas como consecuencia del terremoto de Guatemala del 4 de febrero de 1976. Estos datos también fueron enviados a la División de Estudios Geofísicos del USGS, en Menlo Park, California, con el objeto de incluirlos en el plan de estudios de terremotos.

Observaciones magneticas

Las observaciones magnéticas de las estaciones establecidas en Honduras, forman parte del proyecto de: "Mediciones Magneticas en America Central", el cuál fué planteado en una reunión efectuada en el Instituto Geográfico Nacional de

Guatemala a fines del año de 1966. Los nombres y cargos de las personas que en aquel entonces participaron en la puesta en marcha del proyecto mencionado fueron: Ingeniero Alfredo Obiols Gómez, Presidente del Instituto Panamericano de Geografía e Historia y Director del IGN de Guatemala, Ingeniero Claudio Urrutia Evans, Presidente de la sección nacional del IPGH de Guatemala, Doctor Manuel Maldonado Koerdell, Secretario del Comité Panamericano de Ciencias Geofísicas, Ingeniero Julio Monges Caldera, Presidente del Comité de Geomagnetismo y Aeronomía del IFGH, el geólogo Jorge Godoy Jefe de la División Geológica y el Ingeniero Jorge Andrade Guillioli, Jefe de la División Geofísica del IGN de Guatemala. El proyecto consistió en un plan de colaboración científica en el que se recuperaron las estaciones magnéticas para el período 1970 a 1974 establecidas y observadas en años anteriores, y en el establecimiento y observación de nuevas estaciones; trabajo que estuvo relacionado con la primera publicación de la Carta Isogónica 1970 a 1974, así como con las observaciones del campo magnético terrestre de América Central. En éste proyecto tuvieron también una decisiva participación el Servicio Geodésico Interamericano (IAGS) y las demás Instituciones Cartográficas de América Central. Este trabajo estuvo a cargo del Ingeniero Jorge Andrade Guillioli y las últimas observaciones se terminaron en febrero de 1969. En lo que respecta a Honduras las estaciones magnéticas observadas fueron las siguientes:

Tegucigalpa	Reobservada
Tegucigalpa "B"	Establecida
Juticalpa	Reobservada
Santa Rosa de Copán	Reobservada
Trujillo "B"	Reobservada
Dulce Nombre de Culmí . . .	Establecida
Santa Bárbara	Establecida
Yoro	Reobservada
Puerto Cortés "B"	Establecida
La Esperanza	Reobservada
La Ceiba "C"	Establecida
Puerto Cortés	Reobservada
La Ceiba	Reobservada
Trujillo	Reobservada
Iriona	Establecida
Pito Solo	Establecida

Dentro del mismo levantamiento gravimétrico del Valle de Sula que durante 1970-71 efectuó el Doctor Marco Antonio Zuñiga Izaguirre, éste realizó también a la vez el levantamiento magnético de la zona mencionada; utilizando las mismas estaciones que se usaron para el levantamiento gravimétrico, es decir que se observaron un total de 397 observaciones magnéticas. El resultado de estos estudios magnéticos se encuentran incorporados en la tesis que el Doctor Zuñiga Izaguirre preparo como un requisito parcial para obtener su grado en la Universidad de Texas en Austin.

Como ya lo ha hecho en años anteriores, el Instituto Geográfico Nacional de Honduras en el mes de mayo de 1976, brindó cooperación al Ingeniero Carlos Cañón Amaro del Instituto de Geofísca de la Universidad Nacional Autónoma de México quién con el auspicio del Instituto Panamericano de Geografía e Historia (IPGH), realizó observaciones magnéticas en las estaciones de La Ceiba, Puerto Cortés, Santa Rosa de Copán, Tegucigalpa, Juticalpa y Dulce Nombre de Culmí, utilizando en éstas observaciones un total field magnetómetro y un magnetómetro convencional.

Objetivos

Los objetivos de las observaciones gravimétricas una vez terminada una densificación aceptable serán los de proceder con la asistencia de la ayuda técnica disponible, a efectuar el procesamiento de los datos gravimétricos obtenidos, tendientes a la elaboración y publicación de una carta gravimétrica provisional de la república. Esta carta gravimétrica provisional de la república vendrá a sumarse a otros trabajos de investigación, en especial a los estudios geológicos que se están realizando en nuestro país, con los cuales la Geofísica está intimamente relacionada y que conjuntamente con otros estudios de indole geofísico (magnéticos, eléctricos, sísmicos, radiactivos, etc), constituyen los medios que harán posible llegar a comprender ciertas incognitas relacionadas con la composición y estructura de la tierra; en otras palabras el papel de la geofísica es el de suministrar datos básicos para la solución de problemas geológicos, la cuál ha sido ya la clave de varios descubrimientos importantes que han ido paulatinamente en aumento. Esa íntima relación de la geofísica con la geología es la razón por la cuál en éste informe también se incluye una breve reseña de los estudios geológicos efectuados hasta la fecha.

Además la red gravimétrica básica de la república pasará a formar parte de la red gravimétrica mundial, luego de hacerse los ajustes necesarios de los valores gravimétricos obtenidos para referirlos al datum mundial de Potsdam (Alemania Oriental), esto demuestra claramente como todas las naciones del mundo han reconocido la importancia de realizar estos estudios.

Geologia

Siendo una de las funciones del Departamento de Geología e Hidrografía del Instituto Geográfico Nacional, la realización del programa de elaboración de mapas geológicos de la república a escala 1:50,000; recién fundado el departamento en mención se pensó en iniciar un programa cooperativo de levantamiento geológico a escala 1:50,000 con la Dirección General de Minas e Hidrocarburos de Honduras con el objeto de publicar las primeras hojas geológicas de la república; habiéndose logrado publicar bajo éste programa las hojas abajo especificadas, las que fueron analizadas fotogeológicamente por el Ingeniero Reniery Elvir Aceituno utilizando fotografías aéreas a escala 1:60,000 y de las cuáles se realizó poca comprobación de campo.

Nombre	Fecha de publicación
Nueva Armenia	Diciembre 1969
San Buenaventura	Diciembre 1969
Tegucigalpa	Diciembre 1969
San Juan de Flores	Marzo 1970

En la hoja San Juan de Flores las unidades estratrigráficas de San Juancito y alrededores fueron mapeadas por el Dr. Robert H. Carpenter. Sobre éstos estudios existe una publicación en español de traducción del inglés efectuada por el Ingeniero Reniery Elvir Aceituno con autorización del Dr. Carpenter y publicada por el Instituto Geográfico Nacional. Ahora bien con el objeto de ampliar el programa de levantamiento geológico que permitiera ir conociendo paulatinamente y con más detalles los diferentes datos que geológicamente fuera posible interpretar y representar en mapas, el Instituto Geográfico Nacional, acogió la idea del Instituto Centroamericano de Investigación y Tecnología Industrial (ICAITI), quién en un principio auspició el establecimiento de un programa cooperativo de levantamiento geológico con base en los mapas topográficos a escale 1:50,000,

contando también con la participación de la Dirección General de Minas e Hidrocarburos de Honduras y la asistencia Técnica de la Universidad de Texas en Austin, estudiantes de la cuál realizaron el levantamiento geológico de cuadrángulos a escala 1:50,000 de los cuales elaboraron tesises como un requisito parcial para obtener el grado de Doctores en geología o Master en ciencias. A continuación se dá una lista de los mapas cuyo trabajo de campo ha sido terminado.

Nombre	*Escala*	*Area*	*Levantado por*	*Publicado por*
Comayagua	1:50,000	500 kms²	John R. Everett	IGN
El Rosario	1:50,000	500 kms²	Robert H. Facundiny	IGN
Zambrano	1:50,000	500 kms²	William R. Dupré	IGN
San Pedro Zacapa	1:50,000	500 kms²	Richard C. Finch	En Procesco

Es oportuno mencionar y reconocer la valiosa colaboración científica que entre otros, han aportado a estos estudios los Doctores William Muehlberger y Gabriel Dengo de la Universidad de Texas y del Instituto Centroamericano de Investigación y Tecnología Industrial respectivamente.

El Instituto Geográfico Nacional conciente de la importancia de la realización de estos estudios y con el deseo de impulsar aún más la ejecución de los mismos ha estado trabajando estrechamente con la Universidad de Wesleyan de Middle Town Conecticut y el Cuerpo de Paz de los Estados Unidos en Honduras, habiendo logrado hasta la fecha finalizar el levantamiento geológico de los cuadrángulos que a continuación se especifican:

Nombre	*Levantado por*	*Publicado por*
Talanga	Allen P. King (Cuerpo de Paz)	IGN
Cedros	Allen P. King (Cuerpo de Paz)	IGN
Minas de oro	Genevieve Atwood, Charles H. Smith, James L. Cullen y Bruce M. Simonson. (Universidad de Wesleyan)	IGN
El Porvenir	Bruce M. Simonson (Wesleyan)	
Siguatepeque	Donald Curran (Cuerpo de Paz)	En proceso
Taulabe	Donald Curran (Cuerpo de Paz)	En proceso
Santa Cruz De Yojoa	Donald Curran (Cuerpo de Paz)	En proceso

Entre otros podemos mencionar la decidida colaboración científica que el Doctor Gregory S. Horn de la Universidad de Wesleyan ha aportado en la realización de estos estudios.

De una recopilación de datos geológicos existentes en la República, efectuada por el Ingeniero Reniery Elvir Aceituno de diferentes fuentes de información, el Instituto Geográfico Nacional publicó en Junio de 1974, un mapa geológico preliminar de la República de Honduras a escala 1:500,000.

Los trabajos sobre estudios geológicos que aquí se mencionan son en los que el Instituto Geográfico Nacional ha tenido una activa participación y que forman parte del programa de levantamiento, elaboración, y publicación de mapas geológicos de la República a escala 1:50,000. Más sin embargo existen otros datos muy valiosos sobre diversos aspectos de la geología del país, pero considero que muy pocos de ellos se han publicado en una forma efectiva.

Plan futuro

Dentro de los planes inmediatos del Instituto Geográfico Nacional a través del Departamento de geología e hidrografía se contempla continuar con el programa de levantamiento gravimétrico hasta obtener una densificación deseable con el fin de publicar la carta gravimétrica provisional de la República; y proseguir con el programa de levantamiento geológico de cuadrángulos de 10′ x 15′ a escala 1:50,000, seleccionando las áereas de mayor interés. También se espera seguir apoyando la recuperación de las estaciones magnéticas establecidas y al mismo tiempo promover y ampliar los estudios magnéticos, así como también otros estudios geofísicos que puedan aportar datos relevantes para el mejor conocimiento de la composición y estructura geológica del país, y por ende para el mejor conocimiento de sus recursos naturales.

Para terminar quiero dejar constancia del decidido apoyo que han prestado a la realización de estos estudios los Ingenieros Fernando Lanza Sandoval Director General del Instituto Geográfico Nacional (IGN) y Rodney W. Saubers representante Cartográfico del Servicio Geodésico Interamericano en Honduras (IAGS).

Dr. E. Kausel:

A continuación el Padre Jesús Emilio Ramírez del Instituto Geofísico de los Andes Colombianos.

Padre J. E. Ramírez:

Voy a presentar el Informe de la República de Colombia.

Proyecto Conjunto : Instituto Geofísico de la Universidad Javeriana y de la Universidad de Wisconsin

Del 15 de Agosto al 17 de Septiembre de 1976 se realizó en el Valle del Cáuca, Colombia, el trabajo de campo del "Estudio sobre la Estructura de los Andes Occidentales de Colombia; zonas de baja velocidad y obducción".

Este proyecto conjunto entre la Universidad de Wisconsin, EE.UU. y el Instituto Geofísico de la Universidad Javeriana, Colombia, fué auspiciado por la National Science Foundation de EE.UU. y COLCIENCIAS, la versión colombiana de aquella entidad.

El grupo de Wisconsin estuvo compuesto por el Sr. Joseph Lawrence y Walter Mooney bajo la dirección del Prof. de Geofísica Dr. Robert P. Meyer y el grupo de la Universidad Javeriana por el Dr. Hansjurgen Meyer, P. René van Hissenhoven, Sres. Juan Duarte y William Arias, bajo la Dirección del P. Jesús Emilio Ramírez, S.J.

En Yumbo cerca de Cali y al pie de la Cordillera Occidental, se aprovecharon las explosiones de las canteras de la Fábrica de Cementos del Valle para su registro en diferentes direcciones, especialmente N-S y se registraron además las descargas hechas en varios puntos a lo largo de la carretera Buga-Buenaventura.

Un trabajo sísmico similar se llevó a cabo luego en la región de Bucaramanga al NE de Colombia en colaboración con la Fábrica de Cementos Diamante de esa ciudad.

El objetivo fué múltiple: averiguar las causas de las aparentes disminuciones de energía sísmica, la profundidad hasta el material de alta velocidad y alta densidad que ha sido obducido y que da orígen a la anomalía gravimétrica excepcionalmente alta en la Cordillera Occidental de Colombia. Se examinó también la posibilidad de determinar la estructura del Macizo de Bucaramanga por medio de las velocidades en la corteza y en el manto superior de la tierra y concurrir así a un programa en desarrollo, consistente en el registro de sismos naturales procedentes de una región focal que posee quizá la más concentrada sismicidad de América del Sur.

Diseminación de información sobre Ciencias de la Tierra Sólida

Para dar cumplimiento a una moción sobre diseminación de información geológica-geofísica aprobada en la reunión del Grupo II de Geodinámica que tuvo lugar en Acapulco, México del 14 al 16 de junio de 1976, el Instituto Geofísico vivamente interesado en la diseminación de información y sistemas automáticos de bibliotecas, se comprometió a modo de ensayo, a enviar durante 10 meses información sobre artículos importantes y recientes de publicaciones científicas, a cada centro de los integrantes del Grupo II. Desde agosto de 1976 se están distribuyendo copias Xerox de la primera página de artículos geológico-geofísicos selectos.

Geofísica y Geología Marinas

El fondo del mar Caribe fué objeto de dos exploraciones geofísicas recientes. Con participación de oficiales de la Armada Nacional de Colombia, científicos franceses del buque "Florence" del Instituto Francés de Petróleos dirigidos por el Dr. Bicarrat, realizaron un perfil de reflexión sísmica del 25 al 30 de abril de 1976, tendiente a definir la estructura profunda del fondo del Mar Caribe a lo largo de la costa norte de Colombia.

"Se utilizó una fuente sísmica pulsante, un dispositivo de registro numérico flotante, con grupos de 48 hidrófonos y un dispositivo de aire comprimido que cause la explosión del flexichoc". Un magnetómetro de remolque midió las variaciones del campo magnético. Actualmente se analizan los registros.

Se han conocido algunos resultados petrográficos y paleontológicos de la exploración científica frente a Cartagena y Barranquilla en junio de 1975, realizada desde el buque oceanográfico "Le Noroit" (Francia) en colaboración con "Institut Géologique du Bassin d'Aquitan" y la Armada Nacional de Colombia.

Durante el crucero se tomaron 13 corazones y el resultado preliminar del análisis de los 10 corazones menos deformados y mejor consolidados, constata que todas las rocas submarinas están compuestas de limonitas de color gris verdoso o arcillolitas limoníticas.

El estudio micropaleontológico preliminar, hecho por la "Texas Petroleum Co.", muestra una clara diferencia de las faunas en tres biofacies distintas.

1. Bahías de aguas ligeramente salinas. Contiene una microfauna tipica de esta clase de aguas, que abundan en la región del Caribe.
2. Mar frente a la desembocadura del Magdalena. Es rica en materia orgánica, mas no contiene foraminíferos.
3. Aguas profundas, fuera de la influencia del Magdalena. Son extremadamente ricas en foraminíferos, particularmente de especies planctónicas. Foraminíferos arenosos y bentónicos calcáreos se encuentran asociados con los planctónicos y con diversas especies típicas de un ambiente marino sublitoral bajo (nerítico).

Complemento a un Proyecto Geofísico

Como una continuación o complemento del Proyecto Nariño, realizado en 1973, en la parte sur y central de Colombia y norte del Ecuador, geofísicos alemanes de la Universidad de Justus-Liebig en Giessen, adelantaron un estudio de las Cordilleras Central y Occidental de Colombia. Son ellos: Volker Gobel, Wolfgang Baum y Hans Werner Demmin, bajo la dirección del Prof. F. Stibane. Varias entidades colombianas han facilitado el trabajo de 5 meses (Febrero-Julio 1976), de los científicos alemanes, con el fin de investigar principalmente la petrografía de la Cordillera Occidental de origen oceánico y las grandes distancias de transporte que implica su naturaleza. Además se concentró el interés en la evolución y petrografía de las rocas metamórficas de la Cordillera Central. Para estos fines se hizo el trabajo de campo en varias traversas que cortan las 2 cordilleras, situadas en la mayoría entre Pasto e Ibagué.

Los resultados de los análisis geológicos, petrográficos, mineralógicos y geoquímicos de esta investigación, los publicará posteriormente la Universidad de Giessen.

Sedimentos volcánicos del Pacífico Oriental

En la región de la Cuenca de Panamá-Dorsal de Carnegie en el Pacífico, se han perforado en varias ocasiones unos 100 corazones, que fueron examinados por Dragoslav and Shackleton (1975). Estos corazones contienen material biogenético, carbonato detritico, arcilla mineral y capas de ceniza volcánica. De las muchas capas de ceniza, que hasta ahora se han identificado en el Este del Pacífico ecuatorial, la capa "L" parece ser la más extensa y se ha podido correlacionar a través de 16 corazones extraídos entre los paralelos 5°N y 10°S. Esta capa "L", que ocurre en espesores de 0.5 a 12 cms., muy probablemente fué originada por volcanes del Sur de Colombia y de Ecuador. Esto lo indican las isolíneas de espesor de "L" y el resultado del análisis de tamaño de partículas.

La distribución de las cenizas y el porcentaje de mica en estas, forman una W abierta hacia el Oeste, lo que sugiere que 2 ramas de la Corriente Cromwell, una que se mueve a lo largo del paralelo 0° y otra que va a lo largo de 3°S., han tenido significante influencia sobre la deposición de las cenizas. La distribución de las cenizas "L" también está de acuerdo con las corrientes marinas de aquella región. Todo esto demuestra que las corrientes atmosféricas y oceánicas han conservado su rumbo desde que fueron transportadas las cenizas volcánicas. La proximidad de estos sedimentos volcánicos a su fuente la establece la gradación del tamaño de particulas con respecto a la profundidad.

Un análisis del contenido relativo de K_2O en las cenizas confirmó que fuéron arrojadas por volcanes de la ya mencionada región. Con extraordinaria exactitud se pudo determinar la edad de las cenizas "L". Dos de los corazones penetraron un nivel bioestratigráfico muy bien establecido, el de la edad desaparición de la radiolaria *Stylatractus universus*. Además se hicieron otras determinaciones cronológicas independientes, entre estas, 2 a base

de análisis isotópico. Promediando los valores obtenidos, se llegó a una edad de 230.000 años (±5.000).

Tectónica

El Dr. Hermann Duque Caro (1975) ha publicado un estudio en el que "trata de correlacionar las incomformidades mayores y los períodos orogénicos terciarios colombianos con los eventos turbidíticos reconocidos en los márgenes costeros, como resultado de períodos de inestabilidad, consecuencia probable de la interacción continuada de la corteza Pacifico-Caribe de carácter océanico sobre la corteza septentrional de America del Sur de carácter continental".

Concluye el artículo anotando que el trazo del márgen continental que coincide con la prolongación de la Falla Romeral-Dolores, que corre de Norte a Sur desde el Sur de Cartagena, pasando por Cali, en Colombia, pone en contacto la corteza oceánica con la corteza continental, y sería el límite oriental o margen de una posible placa en el Pacífico y Caribe colombianos, caracterizada durante el Terciario por una pendiente casi vertical ("trench") similar a la actual de Perú-Chile.

Geoconductibilidad Eléctrica

De Febrero a Septiembre de 1976 funcionaron, con algunas interrupciones, 2 variógrafos geomagnéticos instalados uno en Palmira cerca de Cali y otro cerca a Buenaventura, Colombia. Su objeto era investigar la geoconductibilidad eléctrica de la estructura de esa región occidental de Colombia, utilizando al mismo tiempo para su comparación los magnetogramas de la estación magnética de Fúquene.

El proyecto fué propuesto por el Dr. L. T. Aldrich que había experimentado y obtenido buenos resultados en la parte central de Sur América. Colaboraron los Directores del Instituto Geográfico "Agustín Codazzi", Alvaro González Fletcher, del Instituto Geofísico de la Universidad Javeriana, P. Jesús Emilio Ramírez, y del Planetario de Bogotá, Dr. Clemente Garavito. Este asumió la responsabilidad técnica de la escogencia de los sitios supervisión y construcción no magnética de las casetas e instalación de los variómetros. Los resultados se analizarán en la Carnegie Institution de Washington, D.C.

Geotermia, Volcanismo

Se han seguido observando mediante la estación sísmica de Pasto las manifestaciones de actividad del Volcán Galeras consistentes en constantes erupciones suaves y fumarolas. Anualmente se informa de esta actividad a la Asociación Internacional de Volcanología, que las publica en sus boletines regulares.

Geotraversa

En la geotraversa que cruza el país entre 6°N y 7°N, se han intensificado los perfiles gravimétricos y magnéticos. Así en la zona de mayores fenómenos sísmicos del Macizo de Santander, se realizó el amojonamiento de 60 puntos en 1975, para determinar un perfil gravimétrico así como una triangulación exacta con el fin de determinar futuros cambios geotectónicos. Se han dado los primeros pasos para un trabajo gravimétrico conjunto entre la Universidad de Wisconsin y el Instituto Geofísico, en esta misma región.

El mapa isogónico de Colombia para 1975, preparado por el Instituto Geográfico "Agustín Codazzi" saldrá en el próximo mes de noviembre.

Investigaciones Geológicas

Los Profesores Restrepo, J. J. y Tousaint J. F., de la Facultad de Minas de Medellín, han contribuído a la interpretación de la evolución andina Central y Occidental de Colombia, con varios estudios.

Me es grato presentar aquí el Mapa Metalogenético de Colombia, preparado por el Ing. Darío Barrero y recién publicado por el Instituto Nacional de Investigaciones Geológico-Mineras de Colombia. Este mismo instituto prepara una nueva edición del Mapa Geológico de Colombia que aparecerá en 1976.

La intensidad total del campo magnético de la región del Caribe se ha mostrado en un mapa (Matthews, 1976) preparado por el Geological Survey en cooperación con el U.S. Naval Oceanographic Office. Incluye la Sierra Nevada de Santa Marta y parte de la costa norte de Colombia. Acompaña a los "mapas batimétrico y geológico-tectónico de la Región del Caribe". Los mapas de anomalías de Bougueur y de aire libre de la misma región están en preparación y pronto se darán al público.

Relacionados con el área del Caribe y del Norte de Sur América, aparecieron recientemente dos artículos de actualidad. El uno interpreta los movimientos actuales de la Placa del Caribe (Jordan, 1975) y el otro, las estructuras submarinas y de los margenes continentales del norte de Sur América, relacionadas con los movimientos relativos de la Placa de Nazca y Sur América, desde el Cretácico (Silver, Case y Macgillavry, 1975).

Cartilla Popular sobre Terremotos

Esta cartilla encargada por el IPGH al Instituto Geofísico de los Andes Colombianos, se terminó en cuanto a su redacción, diagramación, armada y levantada del texto y carátula, en diciembre de 1974. Contiene unas 60 páginas y 60 dibujos. Se entregó al Secretario General del IPGH en México, todo el trabajo listo para su impresión y divulgación en enero de 1975. Esta secretaría inició la divulgación reproduciendo una hoja con dibujo y texto de la cartilla, se espera su aparición en un futuro cercano. A principios de este año, gran parte de la cartilla apareció publicada por capítulos en los principales diarios de varias capitales suramericanas.

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Dr. E. Kausel:

Gracias, Padre Ramírez. A continuación el Ing. Romeo Llinas la República Dominicana.

Ing. R. Llinas:

Todos ustedes saben la posición geológica de la Isla de Santo Domingo. Nosotros estamos rodeados de sistemas de fallas transformes activas. En el norte de la Isla de Santo Domingo, la continuación hacia el este del sistema de Badlet y la Trinchera de Puerto Rico.

En 1946 hubo uno de los eventos sísmicos más grandes que se haya registrado en este siglo. Un sismo de magnitud 8.1, con profundidad del orden de 30 kilómetros, las intensidades sobre la Isla de Santo Domingo variaron desde 11 en la parte más al norte de la Isla hasta 6 en la parte más al sur, en la escala modificada de Mercali. Desafortunadamente, en el momento en que sucedió este evento sísmico, las informaciones sobre los daños causados fueron restringidas.

En los últimos años ha habido un enorme desarrollo a nivel de construcciones en la República Dominicana. A pesar de ésto, no estamos muy conscientes de la importancia de la regionalización y los estudios sísmicos en la República Dominicana y todavía no se adopta un criterio antisísmico en el diseño y construcción de las estructuras de las obras de ingenieria. Pero no solo es a nivel de edificaciones; en los últimos seis años se ha iniciado la construcción de grandes presas, donde tampoco se efectúan consideraciones antisísmicas por falta de datos.

En el sur de la Isla hay una actividad intraplaca muy importante, con una frecuencia ligeramente menor que la frecuencia sísmica del norte. Se ha denominado a esa estructura como la "Trinchera de los Muertos" y tiene una orientación este-oeste, está aproximadamente a 90 millas al sur de la ciudad de Santo Domingo y una produndidad del orden de los 5 kilómetros.

Este cuadro nos ha movido a nosotros, a partir de la Reunión sobre Riesgo Sísmico en Costa Rica, a plantear la necesidad vital de establecer una red sísmica en la República Dominicana.

Hemos hecho ya la proposición formal para que se establezca dicha red, que tendrá unas tres o cuatro estaciones, incluyendo la estación central que pertenece a la Universidad de Santo Domingo, pero que funciona en forma precaria.

Esta nueva red se pretende enlazarla telemétricamente a través de la Isla Mona, con la red de diez estaciones que tiene la Isla de Puerto Rico. Esto en cuanto a los problemas sísmicos.

Pasando al aspecto gravimétrico, existe una red gravimétrica, pero hay una gran deficiencia en cuanto a su interpretación, ya que en nuestro país no tenemos un mapa geológico regional confiable. Lo que existe en un mapa geológico preliminar, confeccionado fundamentalmente a través de la interpretación fotográfica, y no tiene verificación de campo. En nuestro país, que tiene 50,000 kilómetros cuadrados, hay aproximadamente un 15 a 20% del área mapeada con geología regional confiable.

Por esa razón, la interpretación y correlación con las estructuras en tierra, de los datos gravimetricos existentes, y que eventualmente podrían aumentarse, es todavía deficiente. Ese es otro de los problemas importantes que tenemos, ya que no sabemos que interacción ha habido en las estructuras oceánicas que nos rodean y cuál ha sido el comportamiento tectónico de las misma frente a las estructuras geológicas en tierra. Ese es un aspecto que podría, dentro de una segunda fase del programa, incluirse ya luego de establecer una red sismica.

Dr. E. Kausel:

Gracias, Ing. Llinas. Finalmente el Dr. L. Ocola nos hablará sobre **"resultados de programas geofísicos del Perú".**

Dr. L. Ocola:

Tratar de resumir la labor realizada por los colegas peruanos necesitaría bastante tiempo, pero sin embargo, ellos tuvieron la gentileza de colaborar con el suscrito y preparar el informe nacional. Algunos ejemplares del mismo han sido puestos a disposición de los colegas y, si alguien necesita una copia, debe solicitarla al Instituto Geofísico del Perú.

El informe comprende el área de sismología, gravimetría, mareas terrestres y magnetismo. Se ha optado por el sistema de resúmenes preparados por los investigadores que están trabajando en el área.

Voy a aprovechar la oportunidad para puntualizar ciertos problemas que hemos encontrado en nuestra investigación y que son de interés regional, en especial lo referente a riesgo sísmico. A la parte de gravimetría y geofísica marina con muchos de los colegas de acá lo comentamos en Panamá y también en la reunión de Costa Rica. Pero creí que es ilustrativo en especial teniendo en mente el objeto de las reuniones de hoy día que es tratar los lineamientos generales de la investigación para los próximos cuatro años en las Américas en especial en Latinoamérica. Actualmente trabajamos con colegas de Colombia, Ecuador, y Bolivia, en el Proyecto Multinacional de Sísmicidad Andina de la OEA, cuyo producto final es evaluar de una manera preliminar el riesgo sísmico para estas repúblicas.

La evaluación del riesgo sísmico se hará en báse a la teoría de Cornell, que permite integrar tanto la actividad sísmica como geológica, y también obtener parámetros que son útiles en la ingeniería.

Para evaluar el riesgo sísmico tenemos que considerar todo el proceso. Usualmente se consideran los eventos sísmicos como si fueran uno solo, pero en el sísmo de Lima en 1974, que tuvo una duración excepcionalmente larga, los colegas del Geological Survey hicieron un estudio de los sismogramas a larga distancia, distancia de 69 grados y 96 grados, y han logrado identificar para ese sismo en particular, 9 eventos. Esto trae un problema, porque hasta hace poco tiempo teníamos un parámetro que caracterizaba el tamaño de un sismo, la magnitud. Cuando tenemos múltiples eventos, la pregunta surge: "esa magnitud para cuál de todos los eventos es?" Pregunta número uno; y pregunta número dos: "tantos eventos evidentemente no representan un punto en el mapa cuando se evalúa el riesgo sísmico". Esto trae a la luz el problema de que cada vez que ocurre un sismo tenemos eventos que ocurren en una área bastante grande, el área de las réplicas.

El estudio de esta área para el sismo de Lima, se hizo también en colaboración con el Geological Survey. Cuando ocurre un sismo grande en realidad estamos hablando de una área, y consideramos de que los eventos tanto en espacio como en tiempo no son independientes, es una de las asumciones básicas que se hacen para la evaluación del riesgo sísmico que los eventos sean independientes. Esto es una parte, es un problema que tenemos que resolver para Sudamérica, hay muy pocos estudios, este es el primero que se ha hecho para Sudamérica, determinar el área de réplicas para un sismo destructor, esto necesitamos para las diferentes zonas sismogénicas.

Esto es en cuanto a espacio, en cuanto al tiempo, se hizo también un estudio y el número de sismos decae más o menos en una

curva parabólica con el tiempo. Que problemas crea esto? En principio, hay muchos sismos que siguen después del sismo principal, entonces debemos tener alguna manera de eliminar aquellos que no son independientes, esto es, eliminar aquellos sismos que son réplicas del principal. Cómo lo podemos hacer? Es precisamente estableciendo cuál es la ley de decaimiento para cada una de estas zonas sismogénicas. Estas leyes se pueden usar como filtro, lo que nos permitiría limpiar el catálogo final y hacer una evaluación más racional del riesgo sísmico.

Fué interesante comparar los estudios detallados que se han hecho para Grecia, con los parámetros preliminares que se pueden obtener de este estudio en Lima. Ambos son muy parecidos. Esto fué muy importante para el suscrito, dado que estamos haciendo estudios de sismicidad inducida en el norte del país, en una represa, y evaluamos la actividad de microtemblores en el área del reservorio. Sucede que en esa área hubo un sismo de gran magnitud hace tres años y esto nos permitió asignar cual fué la actividad asociable con el sismo, y diferenciar aquella actividad que podía asociarse con fallas locales de aquella de carácter regional.

EIGHTH SESSION
Thursday, September 30
Friday, October 1

HUITIÈME SÉANCE
Le jeudi 30 septembre
Le vendredi 1er octobre

OCTAVA SESIÓN
Jueves, septiembre 30
Viernes, octubre 1

ROUND TABLE DISCUSSION OF PROGRAMS AND PRIORITIES OF THE GEOPHYSICS COMMISSION

TABLE RONDE SUR LES PROGRAMMES ET LES PRIORITÉS DE LA COMMISSION GÉOPHYSIQUE

MESA REDONDA SOBRE DISCUSION DE PROGRAMAS Y PRIORIDADES DE LA COMISION DE GEOFISICA

Chairman/Président/Presidente

DR. E. KAUSEL

Speakers/Conférenciers/Expositores

PROF. S. RADICELLA
CAPT. P. CABEZAS
PADRE J. E. RAMIREZ
DR. E. KAUSEL
DR. M. A. SHEA
DR. J. G. TANNER
DR. A. GIESECKE

Dr. E. Kausel:

En la reunión de autoridades de la Comisión de Geofísica en Lima (marzo de 1976), se resolvió concentrar los esfuerzos de la Comisión en ciertos temas centrales en cada uno de los Comité.

Para el Comité de Tierra Sólida se pensó en "riesgos geofísicos"; para Océanos y Atmósfera, en "corrientes marinas anormales" y para Física Solar Terrestre en "la atmósfera como recurso natural".

Sin embargo, antes de tomar una decisión definitiva, se decidió aprovechar esta reunión para plantear lo propuesto y conocer la opinión de los Geofísicos presentes.

Las resoluciones que aprovemos al respecto, serán discutidas en la próxima Reunión de Consulta sobre Geofísica, a realizarse en Quito, en agosto de 1977.

Vamos a comenzar a tratar el primero de los seis puntos planteados en el programa: Líneas Centrales de Investigación. Para ello cedo la palabra al Presidente del Comité de Física Solar Terrestre.

Objetivos Basicos

Prof. S. Radicella:

Voy a exponer sobre la "orientación de la actividad del Comité FIST del IPGH, hacia una temática maestra vinculada al Desarrollo de Latinoamérica".

Una de las componentes principales del desarrollo económico y social de una región es, sin duda, el desarrollo tecnológico. Esta a su vez está en buena parte condicionada por la capacidad de investigación científica y técnica. Para que la mísma resulte efectivamente integrada al desarrollo, debe estar orientada hacia objetivos bien definidos y cuantificados que respondan a los necesidades de la región y tengan en cuenta los recursos humanos y materiales de que se dispone.

Cuando se han definido los objetivos y se canalizan los esfuerzos y medios economicos hacia los mismos, en proyectos cientificos y tecnológicos adecuados, se puede esperar: a) una tendencia natural hacia la concentración y coordinación de actividades, evitando la dispersión de esfuerzos hacia varias direcciones con la inevitable pérdida de rendimiento y efectividad; y, b) la real inserción de las investigaciones científicas y técnicas en el proceso de desarrollo tecnologico y, por ende, del desarrollo económico y social.

La acción a nivel de Comité FIST

Sobre estas premisas se basa la búsqueda de una temática maestra hacia donde se deberían orientar los limitados fondos con que puede contar la Comisión de Geofísica del IPGH y, en particular, el Comité FIST de la misma.

Una vez aprobada la temática maestra en las instancias superiores que corresponda, la misma debería difundirse adecuadamente, solicitando la presentación de proyectos que tiendan a dar cumplimiento a los objetivos fijados para la misma. A partir de allí, la elección de los proyectos a ser apoyados economicamente debería basarse en la calidad técnica y grado de factibilidad de los mismos, siempre que su presentación cumpla con los requisitos formales y administrativos que fija el IPGH. En general, debería tenerse en cuenta que el volumen de los presupuestos financieros en juego a nivel de Comisión o Comité, en el área de Geofísica, no permiten encarar investigaciones de gran envergadura. El apoyo económico del Instituto se puede centrar en aspectos que hacen a la promoción y coordinación de esfuerzos en una temática maestra. De esta manera se puede esperar un aumento notable del rendimiento de los grupos de investigación dispersos.

Es, además, indispensable instrumentar el control de gestión y la evaluación de las estapas y resultados finales de las investigaciones que se apoyan.

La tematica propuesta: La atmosfera como recurso natural

Los temas FIST

Los temas que abarca el Comité de Física Solar Terrestre van desde la propagación de la radiación cósmica en el espacio interplanetario hasta los posibles efectos de la actividad solar sobre el clima o las condiciones meteorológicas en la superficie de la tierra, pasando, entre otros, por la física del sol y de la magnetósfera e ionósfera de nuestro planeta.

Es evidente que el área cubierta es enorme y que, de no orientarse el interés del Comité hacia una dirección más restringida, los esfuerzos del mismo se verían inexorablemente atomizados con rendimiento real bajísimo.

Por otra parte, si bien el interés científico de todos los temas del área es muy grande, algunos son más facilmente asociables a problemas concretos del desarrollo tecnológico en Latinoamérica. De estos, debemos elegir aquellos para los cuales existe una "masa crítica" minima de recursos humanos y materiales en nuestros países.

La experiencia recogida en proyectos del Comité FIST ejecutados o en ejecución en los útimos dos años: Proyecto Multinacional de Coordinación de Investigaciones Ionosféricas, Curso de Verano y de Post Grado en Aeronomía y Radiopropagación, Catálogo de Actividades en Física Solar Terrestre en Latinoamérica y Relevamiento de las Posibilidades de Desarrollo de la Investigación en Física Solar Terrestre en la región del Caribe, permite ahora definir la temática maestra que se deberá adoptar: La Atmosfera Como Recurso Natural.

Los recursos naturales

El sentido del término Recursos Naturales ha ido evolucionando en las últimas décadas, pasando de uno restringido a las materias primas tales como los combustibles y los minerales y recursos vivientes como la pesca y las forestas, a uno más amplio que abarca a todo el ambiente humano que incluye, a la atmósfera, los océanos, los desiertos, las regiones polares, el medio natural en donde se propagan las ondas electromagnéticas que se utilizan para las radiocomunicaciones y otros, todos ellos entendidos como recursos valiosos de cuya utilización racional depende la sociedad humana.

Este nuevo concepto proviene esencialmente de considerar a la tierra como un vehículo en el espacio interplanetario, de capacidad y recursos muy grandes pero limitados por el aumento constante de la población, cuya actividad y mantenimiento afecta cada vez más el ambiente natural.

La atmósfera como recurso natural

La atmósfera es un recurso natural directo e indirecto de gran importancia, Tienen lugar en ella los procesos que controlan la influencia solar sobre la tierra y, en particular, sobre los sistemas ecológicos y también los procesos que originan los cam-

bios meteorológicos y climáticos, algunos de los cuales pueden ser provocados por la actividad humana.

Los cambios climáticos a su vez, tienen un impacto directo en la explotación de otros recursos comos los agrícolas y el estudio de su predictibilidad es fundamental para el desarrollo económico y social de todos los países de Latinoamérica.

Estudios actuales muestran claramente que el volumen de las cosechas de granos está vinculado, tanto a nivel regional como global, a la variabilidad año a año de parámetros climáticos como precipitación de lluvias y temperaturas extremas. Por ejemplo: variaciones de 20 milimetros en la lluvia caída en julio en la zona maicera de Estados Unidos influye en un 20% en la cosecha de maíz de ese año. Sin embargo, los estudios que abarcan a Latinoamérica son sumamente escasos y no permiten extender los resultados hacia la predictibilidad de los fenómenos que afectan a la producción de granos. Menos aún, se conoce la interrelación que puede existir entre las variaciones climáticas y meteorológicas y otros parámetros solares y terrestres en nuestra región goegráfica.

El equilibrio de los sistemas ecológicos es condicionado profundamante por las condiciones atmosféricas. Estas a su vez pueden ser alteradas por la actividad humana, particularmente cuando la misma es concentrada en espacios reducidos. Por ejemplo: la presencia de grandes urbes en Latinoamérica (Tabla 1), que encierran una gran parte de la población de nuestros países habla a las claras de la importancia de estudiar el impacto de estas sobre el clima de las zonas densamente pobladas, que tiende a cambiar de una manera todavía no determinada.

TABLA I

Población de Grandes Ciudades en Latinoamérica

Ciudad	Año 1975 (millones)	Proyección año 2.000 (millones)
México D.F.	10.9	31.6
Sao Paulo	9.9	26.0
Buenos Aires	9.3	13.9
Río de Janeiro	8.3	19.3
Bogotá	3.4	9.5

A este efecto integrado tenemos que sumar el impacto ecológico y económico de la contaminación asmosférica que a su vez esta vinculada a las condiciones meteorológicas y climáticas locales.

La atmósfera juega también un papel fundamental en las radiocomunicaciones. En efecto, estas pueden considerarse como el aprovechamiento de un recurso natural, el medio de propagación de ondas, realizado por el hombre mediante la tecnología electrónica. Esta situación puede compararse al caso del aprovechamiento de las energías: solar, eólica, hidráulica o mareomotriz, que están afectadas por factores terrestres y externos. La atmósfera como medio de radiopropagación está condicionada por fenómenos locales: rotación de la tierra, condiciones meteorológicas, ruido de origen industrial, etc., y por fenómenos de origen exterior como la radiación solar, el ruido cósmico, etc.

El estudio de la atmósfera como medio de radiopropagación en Latinoamérica no se ha realizado aún en forma adecuada y los requerimientos de comunicaciones hacen necesario y urgente una investigación exhaustiva, tanto para las comunicaciones vía satélite y por microondas, que son afectadas por las condiciones meteorológicas en la tropósfera, como para las comunicaciones via ionosfera, más económicas y sencillas de utilizar, que responden a las variaciones de la atmósfera superior inducidas principalmente por la acción solar.

En los párrafos anteriores hemos tratado de justificar la elección de la Atmosfera Como Recurso Natural como temática maestra para la actividad del Comité FIST. El enfoque principal ha sido la aplicabilidad concreta de los estudios sobre la atmósfera, reconociéndola como el elemento que controla la influencia solar sobre los sistemas ecológicos y el que interviene en muchos aspectos de la propagación de las ondas de radio. Sin embargo, la temática así definida es aún demasiado amplia para ser considerada como eje central de un programa cuatrianal. Es necesario acortar los aspectos más urgentes y de factibilidad concreta de estudio. Esta tarea debería ser la que emprenda el Comité FIST durante los próximos seis meses.

Dr. E. Kausel:

Bien, con el objeto de tener la idea global de cada uno de los Comités, yo creo que sería conveniente que quedaran planteadas las líneas generales de los otros dos comités de inmediato, con el objeto de discutir en conjunto todas estas líneas. A continuación el Presidente del Comité de Océanos y Amósferas.

Capt. P. Cabezas:

Nuestros comités no pueden llevar a cabo grandes proyectos porque los fondos del IPGH son restringidos, de tal forma que debemos servir como una semilla para que otras organizaciones a escala mundial ayuden o coadyuden a los países pequeños de Latinoamérica en sus investigaciones oceanográficas.

El proyecto regional, que gracias a la felíz iniciativa del Perú se está desarrollando ya en sudamérica: el estudio regional del fenómeno de "El Niño", que justamente concuerda con un plan establecido por el Comité de Océanos y Atmósferas. Este proyecto regional que comprende los países de Colombia, Ecuador, Perú y Chile, lleva ya dos años de planificación y ha tenido cuatro reuniones internacionales con apoyo de la Comisión Oceanográfica Intergubernamental.

Justamente, ahí está el detalle de que nuestros países traten, los que ya están dentro de la Comisión de llevar a cabo todos los proyectos que ha planteado esa Comisión y sobre todo aquellos países pequeños que aún no se integran a la Comisión Oceanográfica Intergubernamental, traten de integrarse pues esta organización, que es dependiente de la UNESCO, ofrece una ayuda ilimitada para el desarrollo de las ciencias marinas en los países en vías de desarrollo.

Este proyecto del estudio regional del fenómeno de "El Niño", es un proyecto de vital importancia para la región del Pacífico oriental de Sudamérica. Las implicaciones que tiene este fenómeno, esta corriente marina anómala, son inmensas, muchos de ustedes conocen los grandes recursos en pesquerías que existen en la costa oriental de Sudamérica. Estos recursos naturales se ven afectados seriamente por la presencia de esta corriente anómala, de ahí la importancia de que sea estudiada y poder llegar a predecir en un futuro, cuándo este fenómeno de la naturaleza va a producirse a fin de tomar las debidas precauciones. Las economías de nuestros países se ven seriamente afectadas cada vez que este fenómeno, dentro de un proceso acíclico, ocurre. Nuestros colegas peruanos saben cuanto afectó a la pesquería del

Perú. En el Ecuador también causó sus efectos, no solamente en esta influencia negativa sobre la pesquería, sino también por las grandes inundaciones que trae como consecuencia la presencia de este fenómeno. Son pérdidas inmensas para nuestros países todavía en vías desarrollos pérdidas que pueden llegar a valorarse en millones de dólares.

De ahí, la importancia de continuar con el apoyo de la Comisión Oceanográfica Intergubernamental y de instituciones como la National Science Foundation que está apoyando a un grupo de científicos norteamericanos que están trabajando en Perú y también lo van a hacer en Ecuador para el estudio de las urgencias costeras, un proyecto que está desarrollándose justamente en estos momentos en el Perú y también va a ser ampliado hacia las Islas Galápagos.

Entonces, habiendo aquí representantes de países de Centroamérica, que creo que todavía no son miembros de la Comisión Oceanográfica Intergubernamental, me atrevería a sugerir que ellos interpongan sus buenos oficios ante las autoridades respectivas para que esos países se integren a esta comisión a fin de que con fondos de grandes organizaciones como la UNESCO y el programa de las Naciones Unidas obtengan fondos para llevar a cabo el desarrollo de instituciones dedicadas a la investigación oceanográfica en sus países.

Puedo decir con satisfacción que el Ecuador ha sido un ejemplo del apoyo recibido de la Comisión Oceanográfica Intergubernamental para el establecimiento de un Instituto Oceanográfico en el país, y se está llevando a cabo varios proyectos para el desarrollo de las ciencias marinas en nuestro país.

Quisiera ampliar esta disertación sobre el beneficio que traería para Latinoamérica el integrarse decididamente a esta Comisión, ya que esta Comisión Oceanográfica Intergubernamental tiene varios grupos de trabajo, varios comités dentro de sí, de los cuales se puede obtener beneficios. El próximo mes de noviembre, por ejemplo, en Montevideo, Uruguay, va a llevarse a cabo una reunión del tema, el tema es un grupo de enseñanza y ayuda mutua, y justamente va a ser dedicado para los países de Latinoamérica. Me imagino que la UNESCO a través de sus agencias nacionales habrá enviado la información a su debido tiempo, pero valga esta oportunidad para aquellos representantes de los países pequeños, sobre todo, de que ingieran ante sus representantes nacionales la asistencia a ese congreso en Montevideo.

Se va a hacer un inventario de las necesidades y de los recursos en especialistas en ciencias del mar, especialmente en biología marina, pesca, química oceanográfica, geología marina, oceanografía física y otras ramas que cada país quisiera interesarse en investigar. Por ello, insisto en la importancia del estudio de las corrientes marinas anómales.

Por último, como representante del país que será anfitrión de la próxima Asamblea General del IPGH, quisiera que todos ustedes sean bienvenidos a mi país, a la capital Quito, cuando nos reunamos en agosto del próximo año.

Dr. E. Kausel:

Hará uso de la palabra el Presidente del Comité de Tierra Sólida.

Padre J. E. Ramírez:

Yo creo que ustedes están de acuerdo conmigo en que uno de los beneficios que ha traido casi siempre al mundo una gran catástofre telúrica, ha sido la cocientización de que es necesario saber defenderse de esa catástrofe, y algunos de los eventos últimos, como el terremoto de Guatemala y el de Nicaragua, han servido para esa concientización de la población y de los Gobiernos en darle un impulso nuevo a la sismología en nuestros países.

Todos sabemos que los terremotos no se pueden evitar, pero sí puede uno defenderse de los males que traen.

Para la defensa contra los temblores, yo creo que tenemos el Código de Construcciones que se ha adoptado en algunos países, en otros está en vía de adopción o de restitución. De manera que, para mí, creo que una de las principales ayudas que el Instituto Panamericano de Geografía e Historia puede dar al impulso de la sismología, es el impulso a los códigos de construcción.

Pero para que un código de construcción se pueda hacer correctamente, se necesitan estudios previos, por ejemplo, el estudio de riesgos sísmicos, y para que un estudio de riesgos sísmicos se pueda llevar a cabo, se necesita un mapa de epicentros, y para que un mapa de epicentros se pueda realizar, necesitamos estudiar la historia sísmica del territorio. Aún más, es necesario estudiar la tectónica, por ejemplo, los mapas tectónicos y de fallas. Saber donde están las fallas activas del territorio, porque ellas también deben entrar en el mapa del riesgo sísmico. De manera que todas estas cuestiones las considero yo de gran importancia para que nuestro Instituto Panamericano de Geografía e Historia, en su Sección de Geofísica las considere, las pondere y las ayude.

Discusión

Dr. E. Kausel:

Con estas tres introducciones yo creo que podríamos comenzar a discutir el tema.

Ing. J. Guevara:

En lo que respecta a mi país, en lo que nosotros estamos interesados es en sismología, entonces, Honduras apoya la parte sismología.

Dr. L. Ocola:

Yo estoy de acuerdo con el Padre Ramírez, de que el énfasis en la parte sismológica debe estar sobre lo que llamaría en general "evaluación del peligro sísmico", que no solamente se traduce en códigos de construcción, sino en toda una implementación mucho más grande cuya finalidad es la protección de los habitantes en las zonas sísmicas.

Una misión que debe cumplir el IPGH es mantener la vinculación entre los diferentes grupos de investigación, mucho más que dar énfasis a proyectos pequeños. Creo que ganaríamos muchísimo si toda nuestra discusión la centramos hacia ese fin, construir grupos de trabajo con los cuales se pueda alcanzar cosas concretas.

Ejemplos de ello lo dan los grupos trabajando en gravimetría y geomagnetismo. Ambos han logrado resultados palpables. Puede que sus objetivos no esten directamente ligados al riesgo sísmico, pero nos dan elementos básicos que nos permiten encarar la predicción sísmica y la evaluación del riesgo sísmico.

Hay líneas de investigación que aparentemente son básicas, que no dan resultados visibles a corto tiempo, y para la cual es difícil en nuestros países lograr financiamiento, justamente por tal condición. Por ello creo, que tales lineas de investigaciones, condicionadas por su propia especificidad, que dan frutos a períodos largos, son

los que justamente deben ser financiados por los organismos como el IPGH seguramente en el curso de la investigación llegaremos a casos más concretos, como ya sucede con los grupos que antes mencioné.

Ing. R. Salgueiro:

Los conceptos teóricos son lógicamente aceptados, pero ya en el terreno práctico la figura es diferente. Sabemos que nuestro IPGH lamentablemente tiene restricciones de orden económico y tiene que distribuir su presupuesto en cuatro comisiones, una cuarta parte le corresponde a la Comisión nuestra y lamentablemente con ella es imposible hacer desarrollo de planes de tipo global como el que se ha manifestado. Como lineamiento, lógicamente es aceptado, pero sin embargo en la práctica tiene que tener diferente impacto. Considero por otra parte que también dentro del terreno de la administración científica necesitamos planificar ya de antemano, para cada cuadrienio una serie de programas que deben estar encargados a los grupos de trabajo.

Necesariamente requerimos definir metas que nos establezcan cuáles van a ser estas fases para poderlas cumplir dentro de un período de tiempo determinado, pues tendríamos que considerar en esta planificación proyectos a largo plazo, a mediano plazo y a corto plazo, porque siempre han de existir requerimientos inmediatos de parte de los países para ser resueltos o de alguna especialidad dentro de los comités que tenga un requerimiento que sea ejecutado en el curso de un año.

Definiendo esta planificación, las metas y luego los objetivos prácticos para el desarrollo anual que debe ejecutar la Comisión así como también sus comités o grupos de trabajo que sean constituídos y definan un determinado proyecto deberán lógicamente pasar este tipo de trabajo posteriormente a un tipo de evaluación como bien se ha señalado, evaluación que lógicamente debe llegar a conocimiento de las autoridades de gobierno de nuestros países con el objeto de que estos gobiernos puedan dar un mayor apoyo al IPGH una de las metas que es permanente para las autoridades del IPGH es conseguir mayores recursos y apoyos económicos para poder realizar mayor número de programas.

Aquellos gobiernos que tienen problemas directos e inmediatos y que sufren el impacto de estos riesgos sísmicos u otros geofísicos, de tal manera que sería conveniente que en este sentido se promueva, en primer lugar, la constitución de un grupo de trabajo, probablemente de especialistas que laboren y enfoquen realmente en un documento, un plan que se ocupe de estudiar estos riesgos geofísicos, los tipifique y luego diseñe este plan como proyecto, una vez formulados a los gobiernos ver la reacción y si ellos están dispuestos a participar en este tipo de programa.

Yo creo que la documentación de una elaboración de proyectos, siendo en algunos casos anteproyectos y luego madurando estos estudios y pasando a la fase de proyectos tendrían un mayor impacto y serían mucho más eficaces ante las autoridades gubernamentales.

El caso del sistema de información integrada de geociencias, es una tarea posiblemente del próximo siglo, pero es necesario iniciarle hoy; identificar que tenemos y que deseamos obtener.

Ing. R. Argenal:

En Latinoamerica existen algunas regiones poco accesibles, resultado del cual han sido muy poco estudiadas. Para subsanar esto y tener una cobertura del 100%, creo se debería dirigir la investigación hacia el campo del aeromagnetiometría. Esto nos daría una cobertura rápida para América Latina.

Siendo precisamente el magnetismo tan importante como gravedad, etc., estoy notando que en estas líneas no se le ha dado la importancia que merece.

Prof. S. Radicella:

Quiero referirme a lo expuesto por el Ing. Salgueiro. La idea de definir una línea maestra, no es definir objetivos, sino grandes direcciones. A estas direcciones debemos "vestirlas" con proyectos que se integren y se conviertan en un programa. Y este programa debe estar listo para la Reunión de Consulta en Quito.

Por ello considero debemos ponernos primero de acuerdo en cuanto a las grandes líneas, luego sobre la mecánica de procedimientos para la estructuración del programa.

Deja abierta la posibilidad a pequeños trabajos que se tengan que hacer a nivel de un año, digamos, eso es necesario evidentemente, pero tenemos que ser muy conscientes de poner una cuota, un límite bien determinado, bien definido, a cuantos fondos estamos dispuestos a volcar a esos miniprogramas o miniproyectos. Personalmente creo que dedicar más de 20% del total de los fondos disponibles para la Comisión sería un error.

Además una cosa que creo que es muy importante referido sobre los grupos de trabajo es que hay que dejar la libertad a los países que presenten proyectos siempre que respeten una determinada línea maestra.

Pero si pretendemos que un grupo de trabajo formado por dos o tres o cuatro personas presente un programa, luego ese programa necesariamente va a tener que ser aprobado en cada país y es muy dificil que eso se pueda hacer en un término. Así que pienso que tenemos que aceptar la necesidad de que pidamos proyectos y luego analicemos simplemente si los proyectos responden realmente a la línea maestra y son factibles a nivel de montos, de costo efectidad y que uno pueda analizar en cada proyecto.

Ing. E. Malavassi:

Considero que el IPGH debe implementar programas que vinculen la investigación al desarrollo de los países. Por ello apoyo la idea de la redacción de los Códigos sísmicos. Es una realidad tangible, que evitará la cantidad de muertes que las catástrofes periódicas, producen en nuestros países.

También veo interesante lo expuesto por el Presidente del Comité de Oceános y Atmóferas, sobre el estudio de las corrientes marinas anómalas, pues ello puede traer un solido beneficio en la pesquería, recurso esencial para la alimentación de nuestros pueblos.

Finalmente, es fundamental terminar lo que ya esta en marcha, como el caso del proyecto de gravimetría.

Debemos evitar que este trabajo quede a medias.

Dr. E. Kausel:

El señalar tres direcciones principales de estudio, no significa que se eliminen absolutamente otros desarrollos,

como los sistemas de información o el adiestramiento. Sin embargo, justamente con la idea de ser realistas, conociendo la mecánica del IPGH, considero que debemos concentrarnos en algunas líneas sin que ello signifique que desconocemos la importancia de otros temas.

Dr. L. Ocola:

Pienso en que lo fundamental de esta reunión será la parte resolutiva, es decir, las recomendaciones que aprobemos. Volvamos a revisar las grandes líneas enunciadas,sin por ello dejar morir lo que esta en marcha.

Prof. S. Radicella:

Con respecto a las palabras del Ing. Malavassi, creo que no se ha comprendido el significado de la tematica del Comité de Física Solar Terrestre, "la atmósfera como recurso natural".

Entiendo que el problema climático y más específicamente al agroclimático, es de fundamental importancia.

Si el IPGH lograrase colocar y hacer germinar la semilla de un buen programa agroclimatológico, habremos dado un paso muy importante que va a beneficiar al desarrollo económico y social de la región.

Por otra parte, si bien para países de pequeña superficie no es importante el problema de la radiopropagación, se torna fundamental para naciones como Venezuela, Perú, Brasil, Argentina, etc.

Dr. E. Kausel:

Hasta este momento no he escuchado a nadie oponerse a adoptar las líneas globales señaladas para el próximo Cuadrienio, con la debida aclaración de que se debe mantener el apoyo a los sistemas informativos, mapas temáticos y adiestramiento.

De manera que no deberíamos entrar a discusiones generales y si concentramos a determinar si realmente hay alguna proposición nueva al respecto.

Ing. R. Salgueiro:

Sería interesante que aprovechando la presencia del señor Secretario General del IPGH, él nos haga una breve relación sobre la situación financiera para el próximo cuadrienio, de acuerdo a la programación que tienen fijada, de tal manera que esas referencias puedan servir a los comités a objeto de elaborar sus proyectos y ver en que medida sus ambiciones podrían realizarse desde un punto de vista práctico.

Ing. J. Sáenz:

Creo que es de todos conocido que el presupuesto con el cual trabaja el Instituto Panamericano de Geografía e Historía es limitado, pero estoy seguro que cualquier presupuesto de cualquier fundación siempre es más corto que las necesidades que se tienen. Se ha solicitado un aumento para el próximo cuadrienio. Un aumento casi diríamos natural pero de todas maneras la aplicación de los fondos depende en especial de la presentación de los proyectos, de la excelencia y de la forma en que son presentados.

No podemos decir en ningún momento de que a un comité o una comisión se le da más o menos que a las otras, sino que se aprueban o desaprueban las solicitudes de financiación de proyectos.

Actualmente la Comisión de Geofísica está en la mejor posición para la Asamblea General, gracias a esta reunión, en la cual están miembros de los tres comités. De aquí puede sugerir la acción que permita la presentación de proyectos mejor estudiados y mejor presentados.

Ing. J. Guevara:

Desde el punto de vista de las prioridades para nuestro país, considero que un objetivo inmediato es el de terminar el programa de levantamientos gravimétricos.

Asimismo, dado al interés que el gobierno ha demostrado en el estudio sísmologico, creo es importante lograr la cooperación de organismos como el IPGH, a fín de hacer factible la iniciación de proyectos con esa temática.

Procedimientos Administrativos

Dr. E. Kausel:

Creo que en forma paulatina vamos entrando en el tratamiento del punto dos:

"Mecanismos de selección y control", hay un pequeño manual, bastante resumido, que indica cual es la forma de presentar solicitudes de financiación de proyectos al IPGH.

Estos proyectos así presentados son los que la Comisión de Geofísica reuniría, evaluaría y pondría a consideración de la Reunión de Consulta y la Asamblea General.

Para la correcta formulación de dichas solicitudes, deben respetarse las normas del Manual de Proyectos, por ejemplo que deben considerarse fechas de entrega de los proyectos, tienen que ser vistos por una reunión de autoridades antes que llegue al Consejo Directivo, etc.

Respetando las líneas centrales y encuadrando el Proyecto dentro del Manual, tendremos la documentación preparada para su evaluación y discusión en Quito, en agosto de 1977.

Discusión

(Habla Godoy de Brasil y propone que se enfatice en la importancia de los antecedentes de los investigadores que presentan proyectos, como criterio de evaluación de estos)

Prof. S. Radicella:

Coincido con el colega de Brasil, en que los antecedentes de los investigadores principales, es decir, los responsables de los proyectos, deben tenerse como importante criterio de evaluación de los proyectos.

Nuevos comites de la comisión

Dr. E. Kausel:

Si ustedes creen que debiera dársele peso a la parte educativa dentro de los proyectos yo creo que quizás podríamos discutirlo en el punto seis como incluyéndolo dentro de las condiciones de los proyectos que se tienen que presentar.

Si estan de acuerdo, podríamos comenzar a tratar el punto tres.

Dentro de la Comisión de Geofísica nosotros tenemos tres Comités. Uno de ellos, el Comité de Geofísica de la Tierra Sólida contiene no solamente lo que clásicamente se define como geofísica sino que también Geología y muchos geólogos me han indicado de que consideran la geología suficientemente impor-

tante como para que estuviera formando parte separado de los tres que actualmente existen y es un punto que es posible presentarlo ante la asamblea general del año de 1977 para formar este comité nuevo, no lo podemos presentar en ninguna otra ocasión, cada cuatro años es posible presentar la formación de nuevos comités. Ofrezco la palabra en ese sentido.

Discusión

Dr. T. Feininger:

Siempre me he preguntado porque está el Comité de Gravimetría y Mareas Terrestres bajo de la Comisión de Cartografía, me parece que esa es una situación que se debe aclarar y debe pertenecer a Geofísica y no a Cartografía.

Dr. E. Kausel:

En cuanto a grupos de trabajo como el Grupo de Mareas Terrestres y Gravimetría, yo creo que el sistema de grupos de trabajo que clásicamente ha tenido el IPGH hasta este momento va a tener un cambio importante en el futuro en el sentido de que me parece no adecuado el formar grupos de trabajo sin que ese grupo de trabajo tenga una labor específica que realizar.

Yo creo que los grupos de trabajo deben ser más bien mucho más dinámicos, nacen y mueren de acuerdo al trabajo que se esté realizando dentro del IPGH. De manera que yo creo que no es importante que exista un grupo de mareas terrestres en la Comisión de Cartografía incluso hubo un tiempo en que se habló de que ese grupo pertenecía a las dos Comisiones y yo creo que da un poco lo mismo, porque de todas maneras hasta el momento ni la Comisión de Geofísica ni la Comisión de Cartografía han hecho algo de mareas terrestres.

Ing. J. Sáenz:

Existía un comité de Mareas Terrestres y Gravimetría dentro de la Comisión de Cartografía. La razón que ellos aducían era que eso solamente era del punto de vista de utilización de esa información para elevaciones, etc., y para Geodesia. Tanto es así que en este cuadrienio el Presidente de la Comisión de Cartografía, entiendo que hizo consultas a los países, a los comités y decidieron fundir este Comité de Gravimetría y Mareas Terrestres con el Comité de Geodesia y así es como está actualmente operando.

Dr. E. Kausel:

Justamente hoy el Ing. Mazzini presentó un proyecto en Gravimetría y Mareas Terrestres. Yo creo que en el momento que se concrete un proyecto y el IPGH apruebe una línea de trabajo en ese sentido inmediatamente se forma un grupo de trabajo y morirá cuando se termine el proyecto.

Ing. E. Malavassi:

Volviendo al tema, quiero apoyar la idea de la creación de un Comité de Geología, pues creo es un momento oportuno para hacerlo.

Ing. A. Fonseca:

Yo en realidad lo que he venido notando es que en las reuniones de las comisiones de geofísica participan esencialmente tres disciplinas, o sea: Gravimetría, Geomagnetismo y Sismología, o sea que en la parte de Tectonofísica y Vulcanofísica no hay representante y posiblemente no hay presentación de programas.

Dr. E. Kausel:

Sí, yo creo que la razón de eso es que en muchas ocaciones el llegar a trabajar en la parte tectónica, ya sea la geológica de la tectónica o geofísisca de la tectónica requiere de ciertos antecentes básicos con los cuales uno puede trabajar en esa línea, y como nosotros justamente en Latinoamérica estamos recién comenzando a trabajar en Geofísica, resulta que nos falta la base para poder utilizar esos antecedentes de trabajo de mayor regionalización, trabajos que cubren un campo mayor.

Bien, entonces yo creo que haríamos una resolución en el sentido de que en esta reunión se propone la creación de un Comité de Geología.

Dr. L. Ocola:

Todo lo contrario, no debemos continuar atomizando la Comisión. Debería ponerse énfasis en los grupos de trabajo a cargo de proyectos. La existencia de tres Comités como hasta el presente es suficiente.

Mr. R. Geller:

This may be a point too obvious to mention but we have spoken a great deal about the lack of resources and limited resources. There have been two questions concerning the function of PAIGH — is it a political organization or an operational organization? I think an organization with limited resources perhaps could function best in a political sense. This relates to the formation of the new committee. How can PAIGH function best with limited resources? Perhaps to promote communication among professionals — among specialists. In addition I think to identify resources and to manage resources better. Quite often it seems that there are sufficient resources to support a meaningful program but there is not common awareness of them. This can only come about by communication among the people at meetings of this sort. Once the resources are identified they can often be better managed.

Touching on the comment by the delegate from Costa Rica, there are more than enough gravimeters distributed in Central America in relation to the resources available for their support, so the solution is increased mutual awareness among the interested individuals in Central America and better coordination of their programs. In geomagnetism I know this is true. There are many identifiable resources in geomagnetism in Latin America. What we lack is better coherence, more mutual support and better management. I think this function to a great extent has been and can be more completely fulfilled by PAIGH.

Dr. L. Ocola:

Yo creo que la formación, la comunicación y la información sobre fuentes de financiamiento deberían estar a cargo de las comisiones nacionales.

De aumentar el número de Comités de la Comisión de Geofísica, se van a necesitar mas fondos para reunir a sus autoridades para la toma de decisiones a ese nivel.

Ing. A. Fonseca:

Lo que dice Ocola me parece razonable. Los miembros del Comité de Tierra Sólida podrían extender mapas de la

información a los geólogos para que se integraran más a este Comité, podría ser positivo, porque como les decia antes, solamente vemos estas reuniones de geofísica participación con informes relacionados con la gravimetría, el geomagnestismo y la sismología a pesar de que asisten bastantes geólogos pero no hay ejucución de proyectos específicos e información sobre la parte geológica.

Dr. E. Kausel:

Tradicionalmente los comités del Instituto Panamericano de Geografía e Historia se han formado con el objeto de atacar un cierto problema que tenga un nivel panamericano, problemas o temas en que sea necesario de que haya un representante de cada país sin excepciones. Un grupo de trabajo ha sido un grupo pequeño de personas que están trabajando a nivel más bien regional o subregional en que haya involucrados dos, tres o cuatro países solamente.

La Comisión de Geofísica nuevamente ha considerado que el comité es algo distinto que el resto de las comisiones. En la Comisión de Geofísica los comités son una simple subdivisión de todas las líneas que existen dentro de lo que nosotros podemos llamar Geofísica, es decir, no es que se haya formado un comité porque ha aparecido un problema específico.

Hasta el momento, en la Comisión de Geofísica ha habido poca intervención de geólogos a nivel de asesoría, de manera que cuando se presenta un proyecto de geología, en la Comisión de Geofísica no tenemos una persona o grupo de personas que nos pueda ayudar a decir si ese proyecto es conveniente realizarlo o no. Esa es la única razón en realidad por lo cual podría ser conveniente de que existiera ese comité, simplemente como una asesoría sobre aquellos proyectos que tengan esa línea.

Por eso es que yo creo que no sería mala idea formar un comité, sobre todo que los mismo geólogos han estado solicitándolo y de hecho hay algunos geólogos de algunos países que incluso han considerado que sería conveniente formar una Comisión de Geología.

Dr. L. Ocola:

Si la función es de que el Presidente de la Comisión tenga asesoramiento para juzgar proyectos, yo creo más bien en ese caso debe crearse un comité de "referees", que no solamente sea de geología sino de diferentes disciplinas de la tierra sólida a través de los cuales se haga esta consulta sobre proyectos o dictámenes, etc.

La razón que me preocupa es la multiplicación. Aquí tenemos tres Comités grandes que representar esencialmente todas las disciplinas que se conocen y yo creo que esos llevan la voz y asesoran el campo grande al Presidente.

Dr. E. Kausel:

No es solamente en la parte de juzgar proyectos, sino que es un asesoramiento de ayuda a promover ciertas líneas de trabajo.

Yo estoy en cierta manera de acuerdo en que las tres divisiones son suficientes, pero lo que sucede es que clásicamente todavía la geología y la geofísica no se han juntado suficientemente, la geología es mucho más antigua, empezó antes que la geofísica, o por lo menos antes de que se hablara específicamente en términos de lo que nosotros llamamos geofísica actualmente, y si nosotros tomamos por ejemplo subdivisiones que se hacen en otras instituciones incluso a nivel de uniones internacionales, hay una unión internacional de geofísica, una unión internacional de geología.

Dr. V. Graterol:

Quiero decir que estoy completamente de acuerdo con el Dr. Kausel en la creación de un Comité de Geología por varios motivos.

En primer lugar, una de las líneas generales que creo hemos aceptado en el aspecto de la tierra sólida, es la del riesgo geofísico. Indudablemente que yo espero y estoy casi seguro, que van a aparecer varios proyectos en nuestras próximas reuniones relacionados con la cuestión del riesgo sísmico y en este campo indudablemente que se va a necesitar del apoyo geológico.

Por otra parte, la mayoría de los países latinoamericanos tienen un gran porcentaje de recubrimiento gravimétrico. Casi todos los países cuentan con cartas a escala 1:1,000,000 de cartas gravimétricas de anomalías de Bouguer y es indudable que no tardarán mucho tiempo en aparecer proyectos en los cuales va a estar implicada la interpretación geológico geotectónica de estos mapas de Bouguer. Por consiguiente vamos a necesitar también del apoyo geológico. Por tales motivos, creo que sí debe aceptarse la creación de un comité de geología dentro de la Comisión de Geofísica.

Ing. J. Monges:

Si los geólogos quieren entrar a la Comisión de Geofísica que se vuelvan geofísicos, entonces están bien en la Tierra Sólida. Si son geólogos puros entonces no tienen nada que hacer en Geofísica, que hagan su comisión o que comiencen como nosotros comenzamos en Geofísica todo lo que era Geofísica estaba en Cartografía.

Ing. A. Fonseca:

Quiero añadir que seguramente los geólogos aspiran no a integrar un comité sino a formar una comisión de geología semejante a la Comisión de Geofísica.

Ing. V. Mazzini:

Además que los tres comités que existen son interdiciplinarios y que cada uno de los especialistas puede actuar individual o colectivamente en un proyecto cualquiera, pero además se produce al márgen del problema del Comité de Geología se produce también dentro del IPGH prácticamente una dualidad.

Dr. E. Kausel:

Yo insisto de que la parte de grupos de trabajo no tiene mucha importancia donde están sino qué es lo que están haciendo.

En relación al problema mismo de Geofísica y de Geología, yo creo que efectivamente existió un problema entre Geología y Geofísica. Los geólogos decían que las interpretaciones geofísicas eran muy simples y los geofísicos siempre consideraban que las interpretaciones geológicas eran muy complicadas, justamente porque el geólogo podía mirar muy cerca a la superficie y por lo tanto podría ver detalles, en cambio los geofísicos en general trataban de mirar más al interior. Con el advenimiento de la teoría de Placas yo creo que cada vez se están acercando más las

ideas de los geólogos y de los geofísicos, ya hay muchos lugares en que no hay departamentos de Geología y de Geofísica separados sino que son Departamentos de Geociencia, realmente la Geología y la Geofísica están cada vez más cerca y no se puede hacer nada en Geofísica si no se ve la parte Geológica o al revés. En la reunión de Panamá nosotros tratamos de que hubiera en cierta forma representación de Geólogos al nombrar como Vicepresidente de la Comisión a un Geólogo, en el sentido de que fuera de los tres Presidentes de comité especialistas en cada una de las tres líneas de la geofísica, el Vicepresidente como geólogo también fuera un cuarto asesor y cubriríamos esa área que quedaba un poco afuera.

Con el objeto de dejarlo más claramente establecido de que la geología es parte de los que a nosotros nos interesa que esté incluido dentro de geofísica, quedaría entonces en forma oficial como comité a pesar de que yo estoy seguro de que todos los proyectos van a ser combinados entre Geofísica y Geología. Creo yo que es una manera de reconocimiento de que la geología es parte de la Comisión de Geofísica. Otra manera sería llamar la Comisión de Geofísica "Comisión de Geociencias", pero eso es mucho más difícil, conseguir una cosa de ese tipo dentro del Instituto Panamericano de Geografía e Historia que simplemente considerar dentro de la Comisión de Geofísica que nosotros estamos de acuerdo de que haya un nuevo Comité.

Prof. G. P. Woollard:

What I would like to comment on comes primarily from many years and many boards of the National Academy of Science in the United States. We had geology boards, oceanography, geophysics and geochemistry boards. The big problem was each one was operating in a vacuum with respect to the others. This to me was very sad because you cannot divide the earth sciences into unrelated components. If we are going to have a commission of geology, the next one we would set up would be one on geochemistry because the next big break-through is going to come out of geochemistry. I think it would be better if we called ourselves earth scientists. I think our interests are to advance knowledge of the frontiers in understanding the earth and the phenomena that we see, whether they are related to ore deposits, soils, hydrology, economic problems or seismic risk. All of you when you get down to brass tacks are geologists and you only have to go back to the basic definition of the word, which is the study of the earth, to see this. All geology means is "earth science" — "geo" comes from earth, "ology" is science; so all of you have been doing geology whether you thought you were or not. In terms of what is commonly accepted — going around with a hammer in your hand, banging on rocks, etc. — you have not done it, but you have been banging on them with explosions or the equivalent. Therefore, I would like to see, instead of a dispersion of organizations, things kept tight. If you would like to bring in somebody who is not a geophysicist, bring him in and educate him to our work, but let us not set up another committee.

Ing. R. Salgueiro:

De las exposiciones la más adecuada es evitar la atomización de la Comisión de Geofísica porque en principio cuando se organizó la misma se pretendió minimizar su burocracia de tal manera que ella sea suficientemente flexible para ser más operativa en lo que respecta a su función y finalidades. De ahí que estoy plenamente de acuerdo a respaldar de que no se llegue a diversificar el número de comités, tal vez la Comisión de la Tierra Sólida podría inclusive, para incorporar más integralmente a todos los profesionales que están interesados en el estudio de la Tierra, a darle una nominación mucho más adecuada para el efecto en la cual queden incorporados los geólogos. Yo creo que ellos van a aceptar simplemente un término más generalizado que el de la Tierra Sólida que actualmente no lo aceptan, según tengo entendido, por las exposiciones de algunos de los colegas, pero dentro de ella está considerada la incorporación cabalmente de la geología.

Dr. E. Kausel:

Creo que ha llegado el momento de efectuar una votación. (Se vota por no formar un Comité de geología.)

Dr. E. Kausel:

Corresponde hoy comenzar con el punto cuatro "Centros de Información de Datos". Pido a la Dra. Shea nos haga una introducción al tema.

Information centres

Dr. M. A. Shea:

Mr. Chairman, Prof. Radicella asked me to present some introductory remarks on information centres. I have some thoughts that I would like to talk about for a few minutes — primarily for people to think about and perhaps discuss. These are really things that should come to mind when considering the subject of information centres. At the present time in the world data system there are no large information centres in Latin America that the rest of the world utilizes to a large extent — contacts appear to be made on an individual or institute basis. One of the advantages of having world data centres in Latin America would be that scientists in those countries could go to the centres and work with the records that are on file. If the centres are located on another continent it is very difficult, particularly for graduate students, to work with the data on research projects or theses. Eventually in working with the data, professors will find and suggest areas where improvements can be made. This is the basis for establishing a "feedback loop" involving the data centre in improving both the service and the data collection process.

One idea that Prof. Radicella asked me to discuss was that of subregional data information centres. For example, you may have one centre in the Mexican, Central American and Bolivian area, another in the northern part of South America and a third in the southern part of South America. Now what I am describing is actually a major epoch involving a five- to ten-year planning and implementation period. You have to start on a small scale of perhaps installing these centres in a location where you already have a large amount of records. These centres could be modest initially, but would eventually grow in concert with increased usage. Another suggestion would be to place data information centres in institutes where there is already local interest and definitive local support. An example would be an information centre on oceanography in one location, another on solar-terrestrial physics in a second location and perhaps one on solid earth in a third

location. What I am suggesting is that institutes can take the lead in their area of expertise and exchange their data and information so that all places have the same records.

What are the advantages? Well there are several. You can define what data are available, what data are used and what data are useful to the scientific community. It is a way of keeping an inventory of the data that are available. To a certain extent it also establishes a method of quality control because if there are problems with the data you could go to the scientist who obtained the data for clarification.

Now I would like to mention that every discipline has different problems with respect to data. It is well known there are certain information systems that are keyed to libraries and indexed by author, journal, subject, key words, all methods well known to those who utilize libraries. Data information is something else again. For example, you gather your data by graphs, digital or analog processes or just by tabulation. Some institutes have gone directly to computer cards, some to computer tape, some are using microfilm and others, particularly in seismology and mineral exploration, are using large maps. These different problems in different disciplines are not insurmountable, but do emphasize that one has to be careful when establishing a data centre. I suggest that, as a minimum, one has to consider the following in establishing data information systems:

(a) a physical location with a few rooms for storage of the data,
(b) a retrieval system such that if you want the data for a certain section of Venezuela or for a certain time you can obtain that data without waiting two or three weeks to have it turn up on your desk,
(c) personnel: initially one person full time, with the qualifications needed for the job and a clear agreement for assistance from scientists collecting the data,
(d) there must be archiving and copying facilities and provision for the publication of the holdings of the data centre in Spanish and Portuguese and perhaps occasionally in English so that scientists in the United States, Canada and elsewhere can utilize your data systems,
(e) there should be coordination with the world data centre system which provides for your data being sent to the world data centre and exchanged for a like amount of data in which you may have interest.

I feel this latter point is particularly important as it guarantees maximum use of the data and, in my opinion, the maximum benefits.

As geophysics is not an isolated subject but one that is global, many of the phenomena that we talk about, even though local in occurrence or effect, have a world-wide interest. An example is a large local earthquake that many people in other parts of the world will study to learn something about the behaviour of the earth.

Another subject about which I know Prof. Radicella is particularly keen, as I am, is the possibility of solar influence on the climatic changes of the world. This is an area of study that is brand new and one that is being received, and pursued, with considerable interest. It is in this area that we will be looking to Latin America for weather records that may have been maintained over the years as there will be a need to put the weather and the meteorology records together for as long as we have them. Some have records for a considerable length of time, others for perhaps only ten years and some may be just starting. With that I will throw the question to the floor and perhaps to Prof. Radicella who is also very much interested in this project.

Discussion

Prof. G. P. Woollard:

Having run three data centres, one of them related entirely to gravity when I was making the gravity map of the United States, I appreciate their benefits. One of the main problems is funding to maintain a centre of this type that can be truly effective. At the present time, for example, consider the combined budgets of various departments of the University of Hawaii. They are included with data in meteorology, geophysics, astronomy and astrophysics at a level of about $700,000 a year. This is one institution worrying about its own data and no one else's. This is just what it takes to get the data in shape, to microfilm the records and, as Data Centre A wishes, to get it on disk so it can be distributed. There is no hand labour to speak of except for a few people to keypunch, operate the equipment and so on. My own feeling is that in terms of general dissemination and exchange of data with other institutions it would be a lot better if we could work through central centres such as Data Centre A or, for more specialized fields such as gravity studies, through the Earth Physics Branch or the DMA gravity library.

I just do not see where you are going to get the funding. In terms of exchange of data I find it is much easier to write to Lamont-Doherty or the University of Washington where we know we have overlapping surveys and exchange data with them. This to me is more effective than trying to set up a regional centre. It is a problem of funding — it is not a lack of interest or lack of recognition of the values that could be obtained. I think everyone realizes this. There is no agency at least in the United States that will fund it, because every year I have to bootleg funds out of my university budget to keep this activity halfway viable.

When people write in for data and information we know it costs a lot of money to get them out — it is just like trying to get oil company data. They will be glad to give you the data but you must send someone to get them under their supervision. They have not got the time or money to devote to preparing them for you.

Dr. E. Kausel:

Tiene la palabra el Prof. Radicella

Prof. S. Radicella:

Estoy completamente de acuerdo con el Dr. Woollard de que hay un problema económico muy serio con respecto a como subvencionar un centro de datos. Creo conveniente la idea que ha esbozado la Dra Shea de explorar las posibilidades concretas que existen en distintos países de nuestro continente, en cuanto a ir estableciendo pequeñas concentraciones de datos que luego se conviertan en centros de datos en un sentido más amplio.

Creo que es absolutamente imposible pensar en que podamos hacer algo del tipo de los Datos de Centro A en Estados Unidos, sin embargo, es muy importante la subregionalización de la concentración de datos, porque puede permitir un mayor control sobre la existencia de ellos. Es una forma más fácil de saber donde están, de coleccionarlos y después diseminarlos.

La experiencia que yo tengo es que en la Argentina, se está viendo la absoluta necesidad de crear pequeños centros de datos a nivel nacional. Se piensa en establecer una infraestructura que eventualmente pudiera ampliarse para servir a otros países de la región. Estoy seguro que debe haber posibilidades similares en otros países del continente y creo que esto debiera ser una misión de la Comisión de Geofísica.

La misión debiera entonces ser la de averiguar en que países existe una posibilidad concreta de apoyo local para hacer que ese país sea un centro de concentración, llamémoslo así en el primer acercamiento de datos. De ahí entonces se pudiera partir más adelante hacia la realización efectiva de distintos centros de datos.

Otra cosa que creo fundamental es el hecho de que es absolutamente necesario saber con que datos se cuenta, nosotros creo que no tenemos un claro inventario de datos disponibles en los distintos países. Es también una tarea que se debería encarar en los próximos meses.

Dr. J. G. Tanner:

I would like to re-inforce George Woollard's remarks earlier with regard to the cost of data centres. These are very expensive items. There already exists a system of world data centres — for most disciplines there are World Data Centre A in the U.S. and World Data Centre B in Russia. The world data centre system also provides for specialty centres which can be located in various locales around the world, but World Data Centres A and B do take responsibility for all data which are covered by the guides for data exchange. Incidentally, these guides have been prepared after an extensive amount of work by a group consisting of about 10 people. In the course of operating these data centres, I would guess that World Data Centre A for example would spend a million dollars a year. I have no idea what is spent in Russia for World Data Centre B. The specialty centres would encounter fewer expenses but they would have to be tied to some agency that has some expertise in the field to survive. I think therefore before one attempts to build up major data centres in Latin America he should look carefully at the world data centres and see what is involved.

Padre J. E. Ramírez:

Yo he escuchado con mucho interés los comentarios que se han hecho sobre centros de datos, y quisiera exponer nuestra experiencia sobre una tarea más modesta,pero relacionada.

En nuestro Instituto, en Colombia, hemos publicado dos bibliografías con lista de autores, referencias de los artículos y libros existentes, indices de materias y regiones geográficas.

Esta tarea ha tenido una acogida muy positiva, no solo a nivel nacional, sino también en los centros internacionales, quienes han colaborado ampliamente con nuestra labor.

Ing. R. Salgueiro:

Creo que todos estamos conscientes que pretender organizar centros de la magnitud de los centros "A" y "B" internacionales no es bajo ningún punto de vista una pretención nuestra, al contrario, tratamos de establecer lineamientos iniciales que nos permitan en el futuro consumar el buen deseo que tiene todo científico de disponer de datos actualizados y datos históricos para sus investigaciones. Concretamente en el caso particular de las exposiciones que han sido vertidas en este simposio, hemos podido establecer que un número de personas que han intervenido, se han referido específicamente a la importancia de la información y muy principalmente a la conservación y disponibilidad por parte de los usuarios. En consecuencia, creo que el enfoque inicial a nivel internacional que le compete a la Comisión, es hacer un estudio general de la situación de los sistemas de información actualmente existentes en los países, con la pretención de que esta información sirva de base para estudios que no solamente involucren el campo de la geofísica sino inclusive la geografía, historía y la cartografía.

De ahí que considero conveniente que todo país dentro de su estructura de la información, trate de definir un centro focal, ya no hablo de centros grandes sino un punto focal nacional de información. Ahora, este punto focal nacional de información estaría vinculado en alguna forma con puntos focales locales. Normalmente esta función la pueden cumplir las universidades que están desplegadas geográficamente dentro de cada territorio.

En consecuencia, creo que es muy conveniente poder esbozar la filosofía de la forma como este estudio debe ser planteado. En principio, cuando empezamos la labor de hablar acerca de los centros de información o sistemas de información y su creación, habíamos considerado de que el Canadá era el país más adecuado para que en él se estableciera el sistema de información de datos de gravedad, de donde entonces el SILAG prácticamente está bajo la dirección y jurisdicción de esta representación.

En lo que corresponde a la bibliografía de Geofísica muy bien lo dice el Padre Ramírez, he podido comprobar que evidentemente tienen allá en Colombia establecida una biblioteca de primera dimensión latinoamericana, no internacional sino de primera dimensión latinoaméricana. De tal manera que sería probablemente el grupo más adecuado para dedicarse a estructurar lo que hemos venido a llamar el SILAB, o sea, el Sistema de Información Latinoaméricano de Bibliografía Geofísica. CERESIS sin lugar a duda es el centro que estaría a cargo de la estructuración del SILAS, los Estados Unidos han desarrollado bastante trabajo y tienen estructurado el sistema de información de datos magnéticos.

En la Argentina, Yacimientos Petroliferos Fiscales tiene un sistema de información de pozos muy efectivos. Si allí se concentrara la información de los países de la región, habríamos alcanzado un éxito rotundo desde el punto de vista hemisférico en lo que se refiere a sistemas de información.

Este estudio va a tomar muchos años para su consumación y lógicamente su destino final será fruto simplemente del interés que pongan los países para dar el apoyo económico necesario para el desarrollo de estos sistemas de información.

Prof. G. P. Woollard:

I would like to ask Mr. Svendsen if he could comment on the problems of WDCA. He told me yesterday for example that they have boxes and boxes of data that have

yet to be inventoried, let alone processed. They probably have the biggest budget of any group that I know of for trying to catalogue geophysical data and make it generally available.

Mr. K. Svendsen:

Well George, you report me accurately. However, I am not sure what the budget is. We operate both the national data centre and the world data centre and we cannot really say that so much is for the national data centre and so much for the world data centre, but I would guess that, based on the proportion of work of the two centres, the budget is probably something like a million dollars a year.

We are being inundated with data and we need more people and more money to do the best job in handling all of those data. So, as various people have said here, it is a big job running a data centre. At the regional centres we have had a little experience with this. Groups have come to us for assistance in establishing regional centres. This is a difficult job and they probably do not appreciate all the implications. Nevertheless, it really does not do any good to try to discourage them because they are probably going to go ahead anyway, so we try to be as helpful as we can. We usually end up starting the data centre by giving them some sort of a collection, but the big problem comes from updating the collection because the distribution system is such that the contributor does not always give the data to the regional centres. Instead they give it to the world data centre and then the world data centre has the responsibility for updating the collection. Or if it works the other way then we would have a problem at the world data centre of updating our collection. There are many problems of this kind.

Prof. G. P. Woollard:

The only comment I would like to make is regarding the budget. I think you are off by 100 per cent. From what I have seen of the budget of the data centres during the International Geophysical Year, when they were first set up, the figures were quite large — much larger than a million dollars.

I think that from a practical standpoint to have an effective centre you just cannot set up a lot of regional centres although there would certainly be a number of them that would grow on a natural basis. A good example of this that is very effective is Dr. Giesecke's seismology centre (CERESIS) for Latin America. This is a natural outgrowth of a healthy local program. Forced growth in my view is unnatural and will not work well.

Dr. L. Ocola:

Yo estoy de acuerdo con el Ing. Salgueiro de que debemos dar énfasis a la parte nacional de estos centros focales nacionales de información, porque pienso que es la célula en base a la cual se puede construir el centro regional y los centros mundiales. Si cada país no tiene un centro en el cual se reunen los datos, se califican y se distribuyen, entonces el problema crece y la utilidad a la información decrece enormemente. Mi sugerencia es que la Comisión de Geofísica promueve la creación e implementación de estos centros y más bien que estos centros mantengan estrecha relación con los centros mundiales ya establecidos, tanto para saber que es lo que tienen los centros mundiales y hacer una puesta al día de todos los registros y datos que ya existen.

Ing. R. Salgueiro:

Yo creo que es un asunto de dimensión, de ninguna manera pretendemos de que al hablar de algunos centros de esta primera fase estos lógicamente tengan que ser del volumen y magnitud de los centros mundiales actuales. Estamos muy lejos de poder conseguir ese tipo de objetivo o meta. Con el tiempo esos centros van a desaparecer, porque al final con la cantidad de datos que tienen que manejar, por ejemplo, los enormes problemas y la cantidad de dinero que se requiere para mantener un centro de esa magnitud al final va a resultar que estos centros van a tender a tener una actividad bien restringida dentro de determinadas áreas o disciplinas concretamente.

La Comisión de Geofísica debe pretender aparte de diseñar una política o estrategia de sistemas de información en campo de la ciencia y tecnología lo que debemos pretender es que estos sistemas de información sean normalizados, que todos los sistemas que lleguen

Dr. M. A. Shea:

I would like to add another comment. For the last nine years I have been acting as a consultant for World Data Centre A in my own area of expertise which is cosmic rays. One of the biggest problems we have had is simply to find out which individual is doing what type of science at what location and to set up a line of communication between the data centre and the individual involved. This latter can be a serious problem. For example, Prof. Radicella and I have had one full year of no correspondence between us although many letters have been sent. I am aware of problems of this type. In the paper that I prepared for distribution at this meeting I gave an overview of the international effort with emphasis on Latin American participation. In Table III of the manuscript I list the status of holdings with respect to the discipline of solar-terrestrial physics (I have not considered solid earth geophysics or geology). Thanks to Dr. Giesecke who looked the table over carefully, we can now update the records in the data centre. He came to me and indicated some changes that should be made. I have noted them and I will refer this back to the data centre. I also note from my table that there is approximately 50 per cent of the various disciplines which are not contributing their data to the data centre. We know the data exist but not how much. Perhaps it is a continuous record for 20 years, perhaps it is an intermediate record for three years; it may even have ceased for five years and started up again. Clearly one of the first things that should be tackled in Latin America is an inventory of what data exist. We can start the process by establishing an index of scientists active in the field, circulate this list and encourage exchange in an informal fashion to establish a rapport between the people involved. Perhaps if those present are interested enough in a brief inventory of what is available in the world data centre system for Latin America I can approach the people who can do this work, as can Mr. Svendsen, and we can prepare a listing of holdings in particular areas of expertise for distribution to scientists throughout the region.

Dr. A. Giesecke:

Con respecto al último comentario de la información que se desconoce en los distintos países y a qué científico está haciendo qué, sólo quiero comentar que en la Organización de Estados Americanos en su Programa Regional de Desarrollo Científico y Tecnológico ha habido un flujo de fondos no insignificantes hacia los diversos países para crear en estos países centros de documentación científica y tecnológica. Yo creo que la cantidad de fondos que se ha invertido en esta área no es despreciable, sin embargo, y hablando solamente por lo que veo en mi propio país, el estado en el que se ha desarrollado el Centro Nacional de Documentación Científica y Tecnológica dentro del Consejo Nacional de Investigación, porque son estos consejos CONASITS que se llaman generalmente en nuestros diversos países, son estos Consejos de Investigación Científica y Tecnológica que generalmente han sido los recipientes de estos fondos.

En teoría se supondría, después de varios años de este tipo de esfuerzo que existen ya centros nacionales de documentación científica y tecnológica que normalmente tendrían que ser, pues, quienes ya tendrían a disposición de la comunidad científica nacional e internacional el tipo de información que debe fluir a los centros como el World Epicenter, etc., hago este comentario porque debemos de tener presente esta otra inquietud paralela probablemente iniciada por muchos de nosotros mismos dentro del otro contexto y ver hasta donde uno puede apoyarse o aprender en esa experiencia o mejorar esa experiencia que está en plena etapa de desarrollo.

Dr. E. Kausel:

En latinoamerica tenemos poca experiencia respecto a centros de datos. Tal vez el único centro de ese tipo sea el CERESIS, y creo conveniente conocer la opinión de su Director, en el sentido de saber cuáles son las mayores dificultades que tiene para conseguir que los países respondan a su solicitud de datos.

Dr. A. Giesecke:

EL CERESIS es un centro de datos que tiene un presupuesto total anual de 30 a 40,000 dólares, no para el Centro de Datos exclusivamente, sino en general para la coordinación, promoción y toda clase de actividades del organismo.

El esfuerzo se ha hecho tras diversos objetivos: primero, el de recolectar sismogramas; segundo, el de recolectar todos los boletines que se puedan haber publicado o que se estén publicando; tercero, tratar de conseguir un flujo diario de información de la actividad sismíca y esto ha tenido diversas etapas de mayor o menor éxito. El flujo de los boletines es errático, a veces porque sencillamente no se continuan o están muy atrasados.

Muchos de estos datos, tipo boletín o tipo disponibilidad de sismogramas, se producen con atrasos de cinco y diez años, pero otras veces de pocos meses. Por ello mantener la homogeneidad en un flujo de este tipo de información es bien difícil.

La gente no está motivada para producir este tipo de información. En cuanto al flujo de datos, ya se hace un esfuerzo bastante grande por parte de algunas de las estaciones de la región sudamericana en enviar sus datos al Centro Mundial "A" y una vez que se hace eso ya hay la sensación de que se ha cumplido.

A través de los boletines se logró la recolección de datos sobre eventos que de no ser así, se perderían totalmente.

Lamentablemente, a pesar de todo esfuerzo, hay registros que se pierden. Por ello es importante que se recoleccionen datos a nivel regional y exista un depositario.

Prof. S. Radicella:

Hay mucha información que no llega a los centros mundiales, y puede ser encontrada a nivel subregional. Esto no significa pretender a través de centros subregionales cortar el flujo de información de los centros mundiales, sino todo lo contrario, es ayudar a que haya un mayor número de datos.

En la preparación del Catálogo de Actividades de Física Solar Terrestre, aparecieron muchos datos no registrados.

Yo propondría una resolución: "Considerando la importancia de la concentración y de diseminación ordenada de los datos geofísicos obtenidos en las Américas la Comisión de Geofísica resuelve realizar un inventario de datos geofísicos disponibles en las Américas y explorar el interés que pueden tener los distintos países de la Región en establecer centros de datos de carácter sub-regional basados principalmente en el apoyo local".

Ing. A. Brussoni:

El problema fundamental con relación a estos centros de datos es el problema económico. Evidentemente va a necesitarse que el país huésped del centro de datos sea el que lleve la mayor parte de la carga económica que significa el mismo.

Tratando de ser práctico o tal vez de complicar las cosas, yo me refiero a un organismo que existe y que funciona en América Latina y está financiado por las empresas estatales petroleras, este organismo tiene un aporte anual de una buena cantidad de miles de dólares de todas las empresas y funciona, en este momento tiene la sede en Montevideo. Pensando en las empresas petroleras por el poder económico que tienen, si nosotros lográramos buscar una solución de compromiso en la cual se interesara a este tipo de industria tal vez se lograse resolver un poquito el problema de que la carga del costo del centro no caiga sobre un sólo país.

En el mecanismo de CERESIS está previsto un poco el aporte de los distintos países. En cambio, de acuerdo a las ideas que estuvimos manejando aquí recaería fundamentalmente en un país, que mi exhortación sería estudiar alguna fórmula en la cual si bien el centro estaría radicado en un determinado país y este país pondría la mayoría de las facilidades disponibles, los demás países buscasen fórmulas de contribución, creo que debemos buscar una vinculación con la industria.

Dr. E. Kausel:

Deseo preguntar cuál es la opinión sobre la resolución propuesta por el Prof. Radicella.

Dr. M. A. Shea:

I have one other comment that perhaps our representative from the National Science Foundation could speak about better than I. I do know there is a regional Latin

American program with the NSF that operates on a joint basis in a fashion similar to PAIGH, that is the benefits must accrue to more than one country. Perhaps this is an avenue that could be explored at least initially for funds. It cannot support a large effort but perhaps something could be done to benefit scientists in the United States and Latin America by at least establishing where the data are throughout the latter region. If Mr. Feller is here perhaps he could indicate how something like this could be established so that the representatives from the U.S. could work with three or four key people in the Latin American region to establish the index of scientific activity that Prof. Radicella has recommended and I fully endorse. His handbook is certainly good, but not all inclusive. I am trying to prepare a counterpart document for the North American section which includes the U.S. and Canada. I have had approximately 120 responses from people who are quite interested in working with scientists in Latin America in general and who are willing to collaborate on all types of projects if they only knew who was doing what and where. So perhaps the NSF is one possibility for at least helping to fund the start of something of this type.

Cap. P. Cabezas:

Posiblemente la recomendación quede sólo en el papel, porque el mismo problema tenemos en Oceanografía desde hace tres años, tratando de establecer un centro regional de datos y aún no encontramos quién nos apoye económicamente. En la práctica una recomendación en el sentido de establecer un centro regional de datos se quedaría solamente en el papel.

Prof. S. Radicella:

La propuesta no es la de establecer centros de datos, sino de realizar un inventario y de explorar el interés de los países en apoyar un centro subregional.

Ing. R. Salgueiro:

Estaría de acuerdo con la resolución, pero creo que el inventario debe encargarse a las secciones nacionales, en tanto que la evaluación de la documentación debería darse a especialistas en sistemas de información geofísica. Ellos estarían en condiciones de recomendar sobre la constitución de los centros focales de la información nacional.

Dr. A. Giesecke:

En alguna manera debemos tener presente la existencia de centros nacionales de documentación científica y técnica.

Si bien el enfoque de tales centros nacionales ha sido la de hacer inventarios de actividades y personal dedicado a las ciencias, mucho de esta tarea puede y debe aprovecharse. Hay mucho de este trabajo que está hecho y que está enterrado en los Consejos, sencillamente se ha hecho y a veces los informes no se han publicado, también hay que ser realista y hay que recordar que en muchos de nuestros países las comisiones nacionales a veces no conversan con nuestros consejos nacionales de investigación porque las comisiones nacionales están generalmente no en manos de geofísicos sino de historiadores, geógrafos, cartógrafos y no tienen una vinculación muy estrecha con el consejo nacional de ciencia. Debemos evitar de ignorar la existencia de centros nacionales que tienen mucha de esta información.

Dr. J. G. Tanner:

I think that this idea of indices is one that we should support strongly. I think it is a case of having to walk before you run. We have a mechanism within the committee and working group structure of our commission to start the process of gathering an index. In the process I think that, while the chairman should consult scientific agencies throughout Latin America, they should probably involve the national sections as well. We had a discussion of this last night at our SILAG meeting and after some time we concluded that a start had to be made soon. Once the indices are established and we have a handle on what is available, we can assess the situation and determine what should be done about creating specialty data centres at various locales throughout Latin America. In so doing we should recognize that such centres will not flourish without some association with an institute with the requisite expertise.

Prof. G. P. Woollard:

One final comment before we get off the subject. I have talked to our NSF representative about workshops that can be supported through NSF funds. This can be done provided there is some sort of matching opposite number in the U.S. for the funding. I would like to suggest that personnel from World Data Centre A be involved in any such workshop consistent with the NSF guidelines for funding such activities. I think Dr. Tanner's ideas are good that we should, in the interim before the workshop is held, try to establish an index of what is available, who is doing what and where are the natural centres that might take the lead on a disciplinary basis. As Ing. Brussoni has suggested, Montevideo might be a good site to look at from the standpoint of a workshop. We would have to put material together before we start talking about a workshop, but I think the idea is quite feasible judging from the discussions I had yesterday with Mr. Feller.

Dr. E. Kausel:

Gracias Dr. Woollard, según lo que me ha dicho el Dr. Tanner, él más o menos tiene una idea bien clara de una Resolución respecto a Mapas Geofísicos, así que ofrezco la palabra al Dr. Tanner.

Special geophysical maps

Dr. J. G. Tanner:

During the course of preparing the agenda for this meeting I found out that there was a tectonic map of South America being prepared as well as a geological map. However, I had considerable difficulty in finding out exactly who was preparing them. After casting around for awhile I found out to my embarrassment that there is a special committee of the Cartographic Commission, chaired by Mr. Sebert, which has been responsible for these projects. Consequently, we invited him here to give a talk which you heard on Wednesday afternoon. These special maps are important to scientists engaged in activities in the various disciplines in geophysics and I think we should have some input into

their compilation to make sure that our needs are recognized. So I would very simply like to recommend that this group nominate a member of the Commission to sit on Mr. Sebert's committee and to have our President write him to this effect. I think the benefits would be great because we are talking about gravity maps of Latin America and other special maps for which we will require a good base map at the same projection and scale as thematic maps for other disciplines in the earth sciences.

Discusión

Ing. J. Sáenz:

Creo que es un proyecto especial que se aprobó y que está bajo la dirección precisamente de Lou Sebert de Canadá. El Sr. Sebert ha enviado una circular a las secciones nacionales, lo ha hecho desde el punto de vista cartográfico. Me parece que lo adecuado en este caso es que esa circular también se haga pasar a los miembros nacionales de Geofísica de cada país para que colaboren con el miembro de Cartografía y estén seguros de que se incorpore a este mapa toda la información geofísica necesaria. Eso no elimina la otra necesidad también de que haya una coordinación entre el Sr. Sebert y alguien que ustedes nombren de la Comisión de Geofísica para que trabajen en conjunto en este trabajo.

Dr. E. Kausel:

Gracias Ing. Sáenz. Entraríamos al Punto 6 relacionado con Adiestramiento y Capacitación. Voy a dar la palabra al Dr. Giesecke.

Dr. A. Giesecke:

Ciertamente que la inversión que se hace en la capacitación de personal, es una inversión sumamente importante por su efecto multiplicador y permanente en la investigación científica.

Yo quisiera empezar con el concepto de capacitación a niveles de los primeros años de enseñanza y de identificar la acción del IPGH dentro de este contexto.

Específicamente, en lo que se refiere a la Geofísica, nosotros observamos con preocupación que los textos en nuestros países normalmente dan poca relevancia a la realidad geofísica del país. He revisado con bastante detalle los textos en el Perú, tratando de encontrar alguna información que explique porque el cielo de Lima está permanentemente nublado, porque tenemos sequías en el altiplano, porque hay minerales en determinadas zonas de los Andes, porque el fenómeno de "El Niño", en fín, cosas típicas de las cuales el alumno en nuestras escuelas debería tener pleno conocimiento. He llegado a ver ciertos textos donde un dibujo muestra a la ciudad de Lima sobre una especie de repisa continental, debajo de la cual hay una enorme cavidad y la implicancia es de que en cualquier momento Lima puede caer en este abismo y desaparecer. Ese tipo de información escolar no es una cosa atípica.

La capacitación, podría empezar por mejorar el contenido de los textos. Primero, que enseñen sobre los fenómenos propios de nuestros países y, segundo, que la información venga con el mayor respaldo científico posible.

El Instituto Nacional de Investigación y Desarrollo de la Educación del Perú ha pedido al Instituto Geofísico, escribir un libro referencial, dando a conocer a los profesores y con fines de difusión cultural, explicaciones sobre los mecanismos que producen las características geofísicas propias de nuestro país.

Pasando a otro nivel, en el campo de la capacitación, voy a referirme a la necesidad de ampliar la información que aparece en castellano en nuestras revistas, la "Revista Geofísica" y "Geofísica Internacional". Son buenas revistas, pero contienen artículos más o menos parecidos a los que salen en las revistas más conocidas como "JGR" y "Journal of Geophysics" etc. Donde aparentemente tenemos un vacío absoluto, es en aquel tipo de boletín o de revista que recoja y difunda la información relacionada con la actividad geofísica práctica, por ejemplo, el estudio de sismisidad inducida. En el Perú hace cuatro años que se viene realizando un estudio en una presa grande, y es poco o nada conocida esta labor de la Comunidad Científica Geofísica del Perú. Trabajos de esa naturaleza caben en una publicación que sería sumamente útil porque primero, daría a conocer fuera de los confines del país cuanto está participandó la geofísica en problemas socioeconómicos del país; segundo, podría promover la participación de especialistas extranjeros en la ejecución de este tipo de trabajo. Tal participación es un sistema de capacitación específico, de interés específico y al mismo tiempo la experiencia de esta persona visitante es útil para el país, es de mutuo beneficio y yo creo que es una inversión sumamente eficiente. Puedo pensar no solamente en el caso de riesgo sísmico de la represa del Perú, sino también en el proyecto de microsonación que se lleva a cabo en México, es un proyecto de gran embergadura y no hay una participación significativa de personas de otros países que puedan beneficiarse, no para ir a una visita de dos días ni leer un informe, sino para trabajar allí. Hemos estado trabajando en microsonación en las ciudades importantes del Perú y el estado del conocimiento en este campo es tal, que cualquier nueva experiencia, cualquier nueva información es sumamente útil, porque en este tipo de trabajo no se puede ir a un libro de consulta y buscar la respuesta.

La participación de personal es un tipo de capacitación que se puede tratar de promover. El IPGH en este campo podría financiar viáticos o pasajes, es un tipo especial de beca.

A continuación me voy a referir al rol que pueden tener nuestras instituciones de investigación en función del sistema universitario de cada país. Evidentemente que los recursos económicos que tienen nuestros sistemas universitarios no permiten a cada universidad disponer de todos los laboratorios y facilidades que deberían de tener. Sin embargo, en casi todos nuestros países hay instituciones geofísicas. Es el caso del observatorio en Jicamarca, en Perú, que es el radar más grande del mundo y que posee una de las más importantes instalaciones para estudios de la alta atmósfera. Este observatorio está abierto a todo el sistema universitario del país, para que el alumnado que llegue a determinado nivel pueda hacer ahí su investigación, su tesis de grado y recibir enseñanza académica.

Pero creo que este tipo de institución puede también constituir un canal de capacitación a nivel regional, a nivel latinoaméricano.

Evidentemente no se va a multiplicar este tipo de facilidad en toda la región. La participación de personas de otros países en instalaciones de este tipo, también requiere un apoyo económico y creo que habría que estudiar la manera de como fomentar estas visitas durante períodos relativamente significativos, no son períodos de días sino a veces de semanas o meses.

Finalmente llegamos al tipo de capacitación con el cual estamos más familiarizados, la capacitación a través de cursos. El

curso de gravimetría que se ha propuesto en esta reunión; el curso sobre la ionósfera que se llevó a cabo en La Paz y hay otro programado en Buenos Aires; y el curso de sismología que se está llevando a cabo en San Juan con apoyo del IPGH y promovido por CERESIS. Este tipo de cursos son sumamente importantes. No consideraré la capacitación a través de becas, porque el IPGH no contempla tal posibilidad.

Discusión

Prof. S. Radicella:

Quizá el Dr. Giesecke podría formular una resolución, promoviendo la presentación de proyectos de capacitación, que sean parte del programa del cuadrienio 1977-81.

Dr. E. Kausel:

Creo que tal resolución debe ser bien concreta con indicaciones claras sobre el o los objetivos que se buscan.

Por ejemplo, que nosotros estamos interesados de que algunas organizaciones internacionales del fondo a requerimiento del IPGH o en fin, alguna cosa de este tipo con el objeto de que haya alguna forma en que la Secretaría General pueda empujar algún Acuerdo con organismos internacionales o con universidades. Por ejemplo, en la parte de la capacitación a nivel medio y nivel superior y con respecto a la posibilidad de una revista yo creo que indudablemente es conveniente que haya el máximo de revistas posibles de geofísica, porque de hecho son muy pocas, es bien difícil que esa revista tome importancia a corto plazo. Yo diría más bien que nosotros abriéramos la posibilidad dentro de la misma revista de geofísica que se incluyeran los temas que el Dr. Giesecke ha indicado o sea la posibilidad de publicar artículos que estén relacionados con problemas más bien prácticos, no solamente de temas necesariamente de investigación pura, yo creo que está abierto o sea nunca se ha cerrado esa posibilidad, y ya cuando se vea que el volumen es tan grande como para poder cubrir una revista se podría abrir una revista nueva. Sin embargo, la experiencia nos señala lo difícil que es conseguir un número suficiente de artículos a pesar de que la revista sale dos veces al año y nosotros no hemos puesto restricciones al tipo de temas que se pueden publicar en la revista.

Ing. J. Sáenz:

Me alegra mucho que el Dr. Giesecke haya mencionado esto de la comunicación sobre todo de las revistas y que el Dr. Kausel haya dicho lo mismo y yo quiero reforzarlo. En efecto existen por lo menos dos vehículos dentro del IPGH.

Está la Revista Geofísica está abierta a todos los colaboradores en materia de geofísica y que lamentablemente, no ha tenido un verdadero respaldo sobre todo de Latinoamérica. En algunos casos hemos tenido hasta que demorar la publicación de la revista porque no hemos tenido artículos, sobre todo de América Latina, hemos contado con una amplia colaboración de los Estados Unidos y de Canadá para obtener artículos, pero pensamos que es una revista panamericana y que se necesita mucho más conocer que es lo que se está haciendo, qué investigaciones se están llevando a cabo dentro del ámbito latinoamericano para que se conozcan entre sí y se conozcan también en le ambiente norteamericano.

Esto se ha luchado bastante, el Dr. Kausel ha estado haciendo comunicaciones solicitando y no podemos decir que el resultado ha sido satisfactorio.

Por otro lado está también a disposición y ya para noticias más cortas el Boletín Aéreo que debe incorporar noticias de todas las comisiones, pueden ser noticias locales, pero que se piense que pueden ser de interés a otros científicos de los otros países.

Esta es la razón por la cual solicitamos información para ponerla en el Boletín Aéreo que está saliendo con una regularidad casi de un 90% cada dos meses pero también nos encontramos nosotros en la Secretaría que no tenemos noticias y las que publicamos allí en buena parte se deben a informaciones que recibimos personalmente y que las pasamos entonces al Boletín Aéreo.

También estamos publicando un pequeño folleto de reuniones de interés no solamente panamericano sino reuniones mundiales dentro de las Comisiones Cartografía, Geografía, Historia y Geofísica, que pensamos también pueden ser de interés a algunos científicos, en esta forma pueden programar una posible asistencia a esta conferencia, etc., eso se lo solicitamos nosotros en la secretaría, quisiéramos tener más artículos de los colegas de la América Latina. Muy pocos se han obtenido.

Tengo que prestar mi agradecimiento a Canadá y Estados Unidos que sí nos han dado muy buena cantidad de artículos de alta calidad, no solamente en geofísica sino también en cartografía y en geografía.

Padre J. E. Ramírez:

Quiero informar, que dentro del Grupo II de Comités Nacionales de Geodinámica, se esta llevando a cabo una difusión experimental de material publicado sobre temas que interesan al grupo.

Esta difusión se efectúa a través del envío de fotocopias de las primeras páginas de los artículos que se editan referidos a la tectónica en Latinoamerica. Ese es un ensayo, y es un envío gratís que estamos haciendo a ver si eso produce algún impacto y deseos de que se prosiga y se busque alguna ayuda económica para seguir adelante.

Ing. R. Salgueiro:

Con referencia al tema de la capacitación al nivel de información para la educación elemental, quiero recordarles que una de las primeras tareas que realizó la Comisión Geofísica, fué la traducción del libro "Investiguemos la Tierra", que había sido publicado en los EEUU bajo los auspicios de la National Science Foundation.

Dicha pieza bibliográfica fué editada en Colombia y distribuida en un número limitado de ejemplares. Si bien las ilustraciones que consigna el libro son de ambientes geológicos en su generalidad de los Estados Unidos en un gran porcentaje se había sugerido la conveniencia de poder cambiar estas fotografías, por ejemplo, con la que correspondería a la del ambiente latinoamericano.

La pieza oceanográfica para nosotros, en Bolivia, es muy remota si bien va a estar incorporada, pero como nuestro país no cuenta con costa entonces no tenemos experiencia ni especialistas en esta rama de tal manera que sería interesante que algunos de los miembros del Comité de Oceanografía pudiese colaborar en esta tarea de revisión y adptación en base a la matriz que ya está elaborada y ha costado bastante tiempo. Tal vez esta

referencia sirva para la tarea que nos mencionó el Ing. Giesecke.

En cuanto a las facilidades que podrían proveer institutos como el Observatorio de Jicamarca, nos encontramos en condiciones de informar que las puertas del laboratorio de Física Cósmica de Chacaltaye se encuentra abierta a nuestro colegas latinoamericanos para hacer trabajos en las dependencias que existen allí a 5,200 metros sobre el nivel del mar en Chacaltaya. Pues tenemos facilidades amplias sobre el particular e inclusive se puede gestionar cierto tipo de ayudas a personal científico que quiera hacer trabajos allá. Creo que este tipo de labor es bastante viable ya que hemos podido concretar en los últimos meses un convenio con la Organización Nacional de Universidades Peruanas y la nuestra en Bolivia por el cual se ha concretado el intercambio de diez estudiantes de graduados que van a estar en nuestro país y también van a visitar el Perú para hacer cabalmente este tipo de estudios de acuerdo a los términos e ilustraciones que ha planteado el Dr. Giesecke.

El tipo de intercambio que se daría, debe ser ampliamente respaldado por el IPGH y fomentado en lo posible.

Puedo asímismo anticipar, en lo referente al Proyecto de Mareas Terrestres expuesto por el Ing. Mazzini, que las erogaciones que tuvieran que hacerse en Bolivia, no representarían problema alguno para nosotros y cuentan desde ya con nuestro total apoyo.

En lo que respecta al punto de publicaciones, estas lamentablemente no son tan amplias y hoy día confrontamos todavía con esta diseminación y transmisión de las mismas a todo nivel. Hace unos años el Servicio Geodésico Interamericano nos colaboraba en este tipo de relación, pero en los últimos años existen restricciones y ya no hay este tipo de intercambio de información.

Cabe señalar que casi todos los países del CONOSUR y algunos países del Norte de Suramérica tienen convenios culturales y transportes oficiales como el argentino, peruano, boliviano y brasileiro que quincenalmente se trasladan entre tres y cuatro países, entonces, la vía más segura es la de poder conseguir que este tipo de transporte sea empleado para el transporte de bibliografía ya que la finalidad concreta de estos convenios es cabalmente la de hacer este tipo de diseminación de la información cultural científica. Esa sería probablemente una de las vías que debe ser aprovechada al máximo por parte de las Secciones Nacionales y, en particular, la Comisión o cualquier organismo internacional para hacer llegar su bibliografía.

Ing. R. Llinas:

Desearía plantear la necesidad de contar con la posibilidad de becas, no sólo para cursos de especialización, sino también para cursos básicos.

Dr. E. Kausel:

Yo me preguntaba a veces cuál puede ser el camino más conveniente para aumentar, mejorar el nivel de geofísica en Latinoamérica. Se han hecho, se ha tratado de comenzar la capacitación por los niveles educacionales más bajos, es decir, en los colegios primarios para seguir posteriormente a niveles superiores e incluso se ha planteado por el Dr. Giesecke la necesidad que indubablemente existe de que haya textos apropiados. Yo me preguntaría si no es posible tratar de resolver el problema por la otra punta simultáneamente, es decir, ver la posibilidad de que en un tiempo corto, mirando la parte de geofísica no entrando a la educación en general propiamente, sino que mirando nada más que la parte geofísica, si yo no puediera en alguna forma ya sea a través del IPGH o a través de otras organizaciones de que se entregara un cierto número de becas masivas para estudiantes que quisieran seguir estudios de alto nivel con el objeto de que en pocos años, digo cinco o más años, todos los países tuvieran un grupo mínimo de científicos de un cierto nivel superior que sirviera como una alimentación hacia abajo, de manera que habiendo un cierto número de personas que estan trabajando en un país, en una cierta línea me de la impresión a mí que automáticamente eso tiene que rebasar hacia los niveles medios y hacia los niveles bajos.

Es difícil conseguir becas, pero si en alguna forma nosotros consiguiéramos ya sea de que se reconozca por parte de organismos internacionales de darle alguna facilidad al IPGH que, por ejemplo, por lo menos indique cuales son los países que necesitan tres o cuatro becas de inmediato para que puedan ir a estudiar a un país adelantado en esta materia y puedan volver en cuatro o cinco años, yo creo que eso podría ser una solución, puede que esté muy equivocado, pero quizás habría que probar.

Ing. R. Llinas:

Una pequeña aclaración Dr. Kausel. Quizás yo no entendí bien lo que decía Giesecke. Yo cuando hablo de cursos básicos no me refería a los niveles primarios ni secundarios, el problema es el siguiente: Yo he tenido experiencia de que profesionales de la ingeniería en general civil o mecánica pueden tener opción a hacer maestrías en campos específicos de geología o de geofísica, a mí me parece que eso es perjudicial. A lo que yo me refiero como cursos básicos es a los cursos de la formación general profesional. Por ejemplo, nosotros no tenemos ingenieros geofísicos, no tenemos geofísicos como tales, gente que tenga una universidad estudiando esa carrera durante cuatro años, a eso es a lo que yo me refería como cursos básicos. Yo creo que es muy conveniente que el IPGH haga un programa de becas porque indudablemente hay muchos países de latinoamérica que tienen geofísicos, pero hay otros que tienen una gran deficiencia en ese campo.

Ing. R. Salgueiro:

Podría complementar a nuestro colega de la República Dominicana que este programa ya ha existido y el señor Presidente debe recordar que la Universidad de Chile, como foco de excelencia, fue la primera en haber atraído una serie y un grupo amplio de jóvenes para hacer estudios superiores de geofísica de todos los países del CONOSUR, algunos de Centro América, y en lo que corresponde a Centro América propiamente dicha la Universidad de México ha sido encargada de la preparación de un grupo bastante grande de profesionales centroamericanos que han estado unos cinco años estudiante en la UNAM, uno de los productos es Angel Fonseca de la Universidad de

Chile, por ejemplo, y así hay muchos jóvenes bolivianos que han estado en estos cursos básicos que usted los señala de tal manera que el programa ha existido bajo los auspicios de la OEA. No creo que el IPGH esté en posibilidades de poder dar en una segunda fase un apoyo de esta magnitud, de tal manera que inclusive ese programa me parece que está montado, se conocen experiencias concretas sobre el particular y habría que simplemente hacer un acercamiento a esa organización para conseguir las becas que usted lo demanda, pero sí el otro tratamiento a nivel universitario de post-grado que ha señalado el Dr. Giesecke me parece más viable porque hay observatorios y laboratorios importantes distribuidos en América Latina que lo único que tienen que hacer es abrir sus puertas para que colegas puedan ir a hacer trabajos específicos de investigación y éstos si podrían ser auspiciados por el IPGH por tratarse de problemas concretos referidos lógicamente a procesos de desarrollo de nuestros países.

Dr. E. Kausel:

Yo quisiera referirme un poco a lo que acaba de dicir el Ing. Salgueiro con respecto a la capacitación de alto nivel o nivel más allá de la educación secundaria en geofísica en algunos centros que apoyó o está apoyando la OEA en este momento. El esfuerzo que ha hecho la OEA en realidad es grande en este sentido. Lamentablemente desde hace unos cuatro o cinco años a esta parte OEA ha cambiado el sistema de financiamiento de las becas. Inicialmente se les entregó a dos centros en latinoamérica, México y Chile, un cierto número pequeño de becas para que personas de otros países pudieran ir a estudiar geofísica a esos dos países, era de el orden de dos a tres becas anuales y eso funcionó más o menos durante los primeros tres años diría yo del programa, pero posteriormente OEA cambió el sistema de becas en el sentido de que las becas no eran entregadas al centro donde se podía estudiar geofísica sino que las becas tenían que ser solicitadas por el país que quería mandar al becario. Entonces ha resultado que, justamente aquellos países que tienen la necesidad de mandar algún becario a estudiar geofísica a estos dos centros o cualquier otro son los que tienen menos conocimiento de la importancia de la geofísica, y por lo tanto, las pocas becas que esos países tienen las utilizan más bien para otras cosas que probablemente pueden ser más importantes que geofísica, como en la capacitación de ingenieros civiles, la capacitación de personal para la agricultura y no se entrega simplemente ninguna beca, no se le da ninguna prioridad a la geofísica, de manera que en este momento no hay ningún país que esté solicitando becas a la OEA para mandar estudiantes a estudiar geofísica a México, a Chile o a otro lugar, sino que más bien son becas utilizadas en otras líneas y, por lo tanto, nosotros a pesar de que estaríamos capacitados para preparar a un cierto nivel de geofísica, indudablemente no el mejor nivel que nosotros pudiéramos esperar, pero por lo menos mejorar en cierta manera el nivel, en algunos países simplemente no hay alumnos que llegan, y es por eso que digo yo que podría ser conveniente que el IPGH promoviera, ya sea dentro de los países o convenciera a las instituciones internacionales que tienen los recursos necesarios como para dar becas y que la geofísica es importante.

Ing. J. Sáenz:

Actualmente creo que están en actividad unos cursos que se están dando creo que en San Juan para operadores de sismología, operadores de instrumentos en sismología u observadores. Pienso yo o quisiera yo preguntar, consideran ustedes que para empezar, este tipo de cursos con necesarios en América y quisiera preguntarles al Ing. Geller y al Ing. Monges que hacen trabajos creo que através de toda nuestra América, si dentro de los trabajos que ellos hacen consideran necesario también algo similar, que dificultades han tenido cuando han ido a alguno de los países a hacer las observaciones, han tenido el personal necesario para poder llevarlo a cabo? Estos son los tipos de entrenamiento, de adiestramiento que yo creo que debemos pensar, yo sé que el nivel nuestro, perdón, el nivel de ustedes aquí es un nivel muy alto, pero también debemos pensar en los otros niveles porque son en realidad los que sostienen prácticamente las instituciones, porque el éxito diría yo, de la Escuela Cartográfica en Panamá. Porque el nivel que se ha mantenido es para operadores, para aquellos que están comenzando en cartografía, en fotogrametría en dibujo, y es algo que es tal la necesidad de ellos que la escuela ya tiene más de 20 años de estar funcionando y siempre hay personal, siempre están los países detrás de esas becas por diversas razones, ya sea porque se capacita a la persona después, trabaja un tiempo en el Instituto Cartográfico de su país o Geográfico y después se va a otro lado porque tienen mejores beneficios, pero son beneficios que redundan para el país quizás no para la misma Institución esa pero para el país. Porqué no podemos pensar en la misma forma en esto de geofísica?

Ing. J. Monges:

Yo he andado con los observadores de casi toda América quitando el Sur de América, siempre he visto que les falta algo, he llegado en un país veía que hacían la medida y desconectaban el gravímetro porque las baterías eran más grandes y no cabían iban a otro lugar y lo volvían a calentar, medían inmediatamente. Que es uno de los errores más grandes que da unas fallas tremendas, y para ellos estaba bien. Muchas veces he tratado de corregirles a unos y los que se sienten muy orgullosos dicen: "No, si así me enseñó fulano y así lo hago". Pero la mayoría, cuando llego a cualquier país ya tienen una lista de preguntas que hacerme, además hay una cantidad de datos en esos países que no se han calculado, el observador va al campo, da una vuelta, quieren dinero y el Servicio Geodésico da a casi todos los países unos cientos o miles de dólares para que hagan trabajo.

Yo siempre he tenido la idea de darles un curso básico a los observadores, primero para que sepan lo que están haciendo, después para que lo hagan con un método, por eso hay que hacer un manual junto con un curso, por esto es que yo ya llevo como seis años luchando para que se dé un curso para observadores.

Ing. R. Llinas:

Yo no veo ninguna contradicción entre la proposición de apoyar becas y me ha agradado mucho el mecanismo que explicó el Dr. Kausel, el problema que tiene la OEA en los últimos tres años, yo creo que no hay contradicción en-

tre seguir haciendo los cursos básicos en San Juan específicamente, y en apoyar becas para entrenamiento profesional en ciertos países. Ahí tiene que haber una retroalimentación, si nosotros formamos un nivel y no formamos el otro, vamos a quedar siempre cojos.

Ing. J. Guevara:

Unicamente es para apoyar los dos niveles en que necesariamente se necesita capacitación, tanto en nivel básico como en nivel más alto, tomando en cuenta que la mayoría en ciertos países como el mío, tenemos limitaciones económicas en cuanto a realizar este tipo de trabajos, podemos poner como ejemplo el levantamiento gravimétrico, entonces el entrenamiento básico, porque considerando estas limitaciones económicas, los que realizan las observaciones gravimétricas deben estar conscientes de lo que están haciendo y saber exactamente todos los problemas. Apoyo los dos niveles, tanto el básico como el nivel más alto.

Dr. E. Kausel:

Muchas gracias Ing. Guevara. Me ha pedido la palabra el Ing. Argenal.

Ing. R. Argenal:

A lo largo de esa línea yo quería hacer la recomendación siguiente: Casi siempre, así como hay países también hay instituciones nacionales y hay personas que se vuelven expertos en conseguir becas, como también así precisamente hay la nueva generación que está levantandose que incluso no sabe donde ir a solicitar esas becas. Yo quería hacer una recomendación muy especial en la que esos canales de información fuesen lo más diseminado posible acerca de instituciones, asociaciones de ingeniería o a cualquiera de todas esas localidades que tuviesen posibles candidatos para solicitar este tipo de becas. En mi país, específicamente en Nicaragua, se pierden demasiadas becas por canales de información, muchas veces para estos tipos con poca experiencia en becas, el hecho de tener que ir a una oficina de la OEA ya es una malla bastante seria de sobrepasar.

Prof. S. Radicella:

Creo que pudiéramos pensar en una resolución sobre este punto que pudiera rezar así: La Mesa Redonda o la Comisión de Geofísica resuelve preparar un plan de coordinación y capacitación técnica y científica a distintos niveles para ser incluido en el programa de la Comisión para el cuadrienio 1977-81 que contemple las necesidades de concertación y coordinación de los esfuerzos de los grupos de observación o investigación en la región, el adiestramiento de observadores geofísicos y la preparación de personal científico estableciendo los contactos necesarios con otros organismos nacionales e internacionales para la financiación de estudios de grado y de post-grado.

Ing. R. Salgueiro:

Estoy de acuerdo con los términos de la propuesta, pero sin embargo en título de publicaciones que fué tocado también lamentablemente no se hace mención absolutamente de nada sobre este rubro, sería importante de que recordemos que hace ya algún tiempo se tiene la traducción del Manual de Observaciones de Observatorios Magnéticos y Trabajos de Campo, esto estaba a cargo de la Comisión y no ha sido publicado hasta el presente y puesto a disposición esta pieza bibliográfica a los especialistas, ya que UNESCO dió la autorización para esa traducción y este trabajo ha sido puesto a disposición de la Comisión para su publicación de tal manera que desearíamos saber acerca de su destino.

Ing. J. Sáenz:

Relativo a la resolución esa que se elimanara esto de operadores se deja amplio, no solamente son observadores sino otros niveles. Lo que dice el Ing. Salgueiro fué traducido ya en efecto, se obtuvo el permiso de UNESCO y está programado para aparecer en dos revistas consecutivas de "Geofísica".

Prof. S. Radicella:

Sí, con respecto a esto último que dijo el Ing. Sáenz sobre eliminar la palabra "observadores" lo que ocurre es que ponemos en este texto están las dos partes porque se habla del adiestramiento de observadores geofísicos y la preparación de personal científico que contemplaría las otras etapas en los otros niveles.

Además, yo creo que es muy pertinente la observación del Ing. Salgueiro y yo le propongo que cuando hablo que en el plan se contemplen: Las necesidades de información, concertación y coordinación de los esfuerzos. Con la palabra "información" se implicaría el problema que usted ha planteado. Creo que quedaría así incluido en la resolución.

Observaciones de clausura

Dr. E. Kausel:

Para concluir de parte de nosotros, los visitantes acá en Canadá, quisiéramos agradecer a la Sección Nacional del Canadá, al Comité organizativo de esta reunión, indudablemente al grupo que nos hizo todas las interpretaciones y también a las personas que nos ayudaron en la parte de secretaria, yo quisiera volver a recordar de que el apoyo que ha estado dando la Sección Nacional del Canadá al IPGH ha sido muy grande y yo creo que esa es una cosa que nosotros tenemos que agradecer nuevamente porque es un buen ejemplo para las demás secciones nacionales. Es una forma de demostrar que es posible si uno está interesado en que el IPGH avance y lleguemos entonces a ser una Institución más importante de la que somos en este momento.

Agradezco entonces nuevamente al Comité organizador de este simposio y a la Sección Nacional del Canadá por este brillante simposio que nos ha ofrecido. Muchas gracias.

APPENDIX I/ANNEXE I/APENDICE I

SUMMARIES OF THE EIGHT SESSIONS
RÉSUMÉS DES HUIT SÉANCES
RESUMENES DE LAS OCHO SESIONES

Summary of First Session
Opening Ceremonies

Dr. Blanchette, President of the National Section and Canadian Ambassador to the Organization of American States, officially opened the symposium by welcoming the delegates to Ottawa. In his address he pointed out that this was the 7th seminar that Canada has held in one of the disciplines of PAIGH. He went on to describe the structure of PAIGH and the activities of its four commissions through which PAIGH provides an umbrella of activities to spread knowledge throughout Latin America and assist nations with various aspects of their national programs.

Dr. Whitham, the Director-General of the Earth Physics Branch welcomed the delegates on behalf of the Department of Energy, Mines and Resources, Ottawa, Canada. He described the extensive involvement beginning some 15 years ago that his branch has had with PAIGH and which has led to Canada's participation in the establishment of the Latin American Gravity Standardization Net. Dr. Whitham then commented on the changing attitudes of society towards science with particular emphasis on geophysics and noted in particular the increased emphasis on mission-oriented research particularly in the field of environmental-related studies. Finally, he pointed out that the organizers have attempted to develop a well-rounded program to give a balanced perspective on the contributions to geophysics from scientists employed by government, universities and private exploration companies.

Ing. Sáenz, Secretary-General of PAIGH, outlined the history and structure of PAIGH, its relationship to OAS and the manner in which the Geophysics Commission operates within PAIGH. The institute coordinates and stimulates studies within the various disciplines with programs being developed and reviewed every four years. It was now necessary to start the development of programs for the period 1977-1981. He hoped that the symposium would produce a master plan for the Geophysics Commission with particular consideration to the problems of the countries which were less developed in geophysics. Ing. Sáenz conveyed the thanks of the commission to all responsible for the formation of the symposium.

Prof. Garland in a theme-setting talk discussed the extensive social and economic involvement that geophysics has had and will have in society. The first part of his discussion concentrated on the historical reasons for the development of many of the disciplines which are well known in geophysics today. In describing the current involvement of geophysics in human social and economic problems he considered such subjects as relatively slow movements of the crust, seismological phenomena (including zoning), tsunami warning, induced seismicity and prediction, volcanic phenomena, energy related problems and problems related to minerals, petroleum and the environment. He then described the contribution of geophysics to current issues within these problem areas. He concluded by emphasizing the importance of international cooperation in geophysics citing the important role the International Union of Geodesy and Geophysics has played in world affairs and emphasized the continuing need for active contributions from it and other organizations such as PAIGH.

Prof. Radicella commented that Prof. Garland did not discuss matters relating to research involving the ocean and atmosphere, a subject which he hoped would occupy the minds of the conference later in the week.

Summary of Second Session
Background Papers

Dr. Kausel, President of the Geophysics Commission, gave a brief outline of geophysical activity in Latin America and noted the level of activity that has been attained by disciplines such as meteorology, geology and prospecting geophysics. Gravimetry has prospered because of the interest of geographical institutes, but this field still requires further work insofar as the interpretation of the results is concerned. In seismology he singled out the work of CERESIS, but emphasized the need to train personnel in this field because of the importance of seismic risk studies, the need to improve communications regarding seismic events and the need to develop methods of forecasting seismic activity, a field which is still in its infancy. He discussed briefly some research that is being carried out in Latin America although he considered the number of researchers working in Latin America to be low. He pointed out a great need for training and emphasized that the infrastructure of middle-level operating personnel must be improved and the number of researchers increased. Based on the contributions to the geophysical literature the relative weight of research being carried out in Latin America is disproportionately low. He concluded by emphasizing the need to improve geophysical information systems.

In discussing Dr. Kausel's presentation Ings. Geisecke and Brussoni pointed out that as some Latin American researchers are slow to publish their results there is a great deal of information yet to be published.

Prof. Woollard presented a wide ranging review of the status of geophysical research in Latin America. In his presentation he related the research to progress with the development of natural resources, social and economic problems, land use and scientific problems. Latin America was described as a continent rich in resources. As such, one of the most fruitful directions for research is to attempt to understand the development of ore deposits. With a major subduction zone located off the east coast of Latin America this vast region is clearly one of the prime areas of the world in which to pursue such geophysical research. Naturally occurring hazards, such as volcanoes and earthquakes, are a major social concern throughout many parts of Latin America. Geological and geophysical (seismological) research has concentrated on developing an adequate data base for understanding the occurrence of these phenomena within the context of the tectonic patterns present in Latin America. As Latin America is a region of dense jungle and rugged mountains Dr. Woollard emphasized that forethought must be used in land usage and noted that geophysical programs designed to enhance a well based land inventory have been modest to date. Finally he pointed out that a myriad of problems of a fundamental nature remain to be tackled in Latin America. The prospects are many but unfortunately the geophysicists too few. Such research will undoubtedly be extremely important in the long term for energy development, mineral exploration and problems of an environmental-social nature.

Dr. Lomnitz presented a frank talk on education in geophysics in Latin America, emphasizing that the views were his own and not those of any other organization or individual. He traced the development of university education in Latin America from its early days when it was primarily restricted to the professions of medicine, law and engineering through its more strongly political outlook of the mid 1900's to the recent strong emphasis on education in the non-scientific professions in private universities. He then pointed out that in a society where leaders are

becoming progressively more aware of the importance of earth scientists, the lack of trained professionals leaves Latin America distressingly dependent on foreign scientists. Consequently he stated a new stimulus is needed, a stimulus which must come from within if a satisfactory solution to long term social and economic problems involving the earth sciences is to be realized. As an example of this kind of development Dr. Lomnitz cited the RESMAC project in Mexico which has led to the development of an extensive network of seismic stations, linked by a nation-wide telemetry system, for which the basic design and much of the technology was generated within Mexico. As important as this development is, he indicated that much more is needed in the way of assistance from large corporations and that there is a need for the development of active Latin American professional societies.

Mr. Tanguay described CIDA's program of development in Latin America as one which is oriented toward providing a better environment and improved use of renewable resources. He indicated about 12% of CIDA's budget is directed toward Latin America with a total expenditure of about 60 million dollars annually spread over about 100 projects. By far the greatest proportion of these is directed toward agriculture (50), but other fields include education (25), health (15), social infrastructure (3) and transport (3). He also pointed out that approximately 50 projects are in the planning stage. He indicated that projects within the spectrum of the earth sciences have taken place in the fields of remote sensing and mineral development in a number of countries, but in view of the obvious need for development in the fields of agriculture, etc., the earth sciences cannot be given the high priority that might be expected.

Ing. Salgueiro and Prof. Radicella pointed out the need to discover new forms of scientific cooperation that will take into account the level of expertise and realities in the countries involved. They both believed there was a need to give priority to education in any development program.

Mr. Feller presented a country-by-country list of projects taking place under the Latin American Cooperative Science Program. This program is designed to assist U.S. scientists who wish to extend their domestic research programs into a cooperative context with colleagues in Latin America and the Caribbean. The activities involved include cooperative research in basic or applied science, research-oriented workshops and scientific visits for program development or projects of short duration. The list of projects currently underway in the earth sciences is impressive and covers virtually all aspects in the field. The number of U.S. institutions involved is large and from most parts of the country. Mr. Feller also noted that marine geophysics is well represented in the program and cruises on a number of research vessels have been sponsored in waters adjacent to Latin America.

In response to a question by Ing. Malavassi, Mr. Feller outlined the means by which NSF could help a Latin American country set up a university course in geophysics by assisting U.S. researchers involved in joint projects with members of the university concerned.

Summary of Third Session
Objectives and Methodology of Selected North American Programs

Dr. Vaníček presented a discussion of the inter-relationship of geodesy and geophysics. His paper was presented on the assumption that the audience was familiar with geophysics but not geodesy. In the discussion he subdivided geodesy into three elements: positioning, the earth's gravity field and time variations in position and the gravity field. Positions (horizontal and vertical) of points on the earth's surface can be determined either by land surveying or by satellite techniques. Each technique has its advantages but in general land based methods produce better results over short distances (i.e., a few tens of kilometres) whereas satellite techniques are clearly superior at distances of the order of a thousand kilometres. A knowledge of the gravity field has many uses in geodesy with perhaps the principal application being the determination of the deflection of the vertical and the shape of the geoid. Time variations of position and gravity are important parameters in contemporary geodynamics. Dr. Vaníček stressed that nowhere is the symbiotic relationship between geodesy and geophysics brought out more dramatically than here and this will lead to more and more cooperative activities between geodesists and geophysicists.

Dr. Gibb described Canada's Gravity Service directed by the Gravity and Geodynamics Division of the Earth Physics Branch, Ottawa, for which the primary objective is to complete reconnaissance gravity mapping with gravity observations at intervals of 15 km or less. He gave a brief outline of the history of gravity measurements in Canada commencing with the early pendulum measurements and concluding with a description of the greatly accelerated modern program. He reported that approximately 80% of Canada's landmass, continental shelves and inland seas have been surveyed by four basic survey techniques; land, ice-surface, underwater, and sea-surface which require several different modes of transportation and a variety of instrumentation to meet the specifications of the national mapping program. He also described the reference standard for relative gravity observations in Canada which has recently been converted to the new International Gravity Standardization Net 1971 (IGSN71). Canada's National Gravity Net is tied to 20 stations of IGSN71 that are located in Canada. Finally he pointed out that, as of January 1976, the principal facts of 345,000 gravity stations were stored in the National Gravity Data Base at Ottawa from which information may be retrieved in a variety of formats. The Gravity Service publishes a Gravity Map Series (scale 1:500,000) and data are released on a timely basis through the open file system of the Earth Physics Branch.

Dr. Niblett stated that Canada's geography has provided an exceptional opportunity for Canadians in research in geomagnetism because the country contains the north magnetic pole and forms the best natural laboratory in the world for studying geomagnetic activity and the structure of the magnetosphere in auroral and polar regions. A brief account was given of the early observations and achievements of British seamen and army engineers during the nineteenth century, of the establishment of the Canadian magnetic observatory network and of the development of geomagnetic surveys in the national context. Dr. Niblett described the geomagnetic research within Canada under the headings of magnetic observatories, geomagnetic surveys and magnetic charts, paleomagnetism and rock magnetism, electromagnetic induction and theoretical studies. Although the bulk of his talk concerned activities at the Earth Physics Branch, reference was made to activities in other institutions in Canada. Some of the highlights he described included the unusually high conductivity anomalies in the Arctic and western Canada, the study of Precambrian pole positions and polar wandering paths,

the detailed low level airborne magnetic survey of Canada and the high level airborne surveys carried out for charting purposes.

Dr. Berry pointed out that most earthquakes occur at the edge of lithospheric plates and that a significant portion are large and damaging. Therefore, one of the main reasons for studying seismicity is seismic risk which he defined as the probability of occurrence of a degree of seismic ground motion during a specified period. He then went on to define the attendant seismic hazard as the consequences of the ground motion measured in terms of casualties and property damage per unit area per year. He broke seismic risk estimates into long, intermediate and short term for which, depending upon the degree of conservatism desired, one could set up a set of specifications in terms of building design. The higher the degree of conservatism, the more sophisticated are the methods of evaluation of buildings and cities in order to minimize loss of life. Long term risk prediction clearly involves the implementation of building codes and land use planning. At present short term prediction is at best a very uncertain process because of the lack of sufficient theories describing the earthquake process so that models for prediction can be built with a reasonable degree of certainty. Similarly, in Canada, Dr. Berry pointed out that we are unable to make intermediate predictions. The long term prediction process is reasonably well established in Canada and a seismic risk map has been produced which provides a good basis for a sensible building code.

Dr. Jessop divided geothermal studies in Canada into three parts: fundamental geothermics, geothermal energy potential and the thermal aspects of permafrost. Fundamental geothermics have been carried out in Canada for over 30 years. The objectives have been the measurement of heat flow and heat generation throughout Canada and their interpretation in the context of the tectonic structural regime in Canada. Geothermal energy studies are fairly recent to Canada. This late start compared to other countries is probably a manifestation of the hitherto abundant supply of other forms of energy. Permafrost is a phenomenon that is peculiar to Arctic countries. The thermal aspects of permafrost have become of significance in the last few years because of the behaviour of frozen materials near pipelines, oil wells, buildings, etc. Dr. Jessop pointed out that in places in northern Canada permafrost extends greater than 600 m.

Dr. Lambert described the way in which various geophysical measurements are being combined in Canada to study the deformation of the crust. Although there is no national program of crustal stability studies centred in one agency, nevertheless there has been a concerted effort in Canada to develop a program through the involvement of as many different government agencies as possible in certain specific problem areas. He noted that a noticeable deficiency is the lack of coordinated effort in the tectonically interesting west coast area but steps are now being taken to rectify this situation. He indicated that progress can be made without any major technical advances in instrumentation, stating that most of the instruments mentioned in his talk are commercially available. He also noted that a considerable volume of data collected for other purposes can be used for studies of crustal stability. Given these conditions he indicated it is often only necessary to identify areas of geophysical interest to ensure that a wide spectrum of data becomes available.

Dr. Simkin presented a paper on the volcanoes of Latin America. In his discussion he considered three aspects of the situation: (a) assessing the regional frequency or likelihood of eruptions, (b) a description of the hazards due to the volcanoes and (c) the various ways in which man can deal with these hazards. While eruptions cannot be prevented Dr. Simkin pointed out that much can be done to evaluate what to expect from a volcano and when to expect it. This depends on good communications and Dr. Simkin believed that PAIGH could assist here. Historians can compile histories of eruptions, seismologists can monitor volcanic regions and alert geologists to possible eruptions, geodesists can compile data on motions, geologists can compile "risk maps" and so on. By compiling the information provided by experts from these disciplines Dr. Simkin believed that we could build up a broad understanding of the distribution and timing of volcanic eruptions to the considerable benefit of Latin Americans.

Dr. Harlow described an operational "volcanic surveillance system". This system consists of an automatic seismic event logger and a tiltmeter linked by satellite to a central station capable of evaluating the recorded data with a view to forecasting the occurrence of volcanic eruptions. He stated that tests of the first version of the system in Guatemala have been encouraging to the point where a second version is being constructed. While the initial capital expenditures may be large, the efficiency of the system in terms of manpower usage will easily justify the basic costs. With the capability of this equipment, Dr. Harlow felt that scientists were placed in a much better situation with respect to forecasting the occurrence of eruptions.

Summary of Fourth Session Objectives and Methodology of North American Programs

Dr. Darnley put forth a case for the reasons why research into mineral exploration needs to be conducted within government. In his presentation he also discussed the type of research that needs to be done and presented a model for organizing this research. Dr. Darnley stated that in his view it was essential for government to be much more involved in exploration to ensure that exploration programs are designed to meet national needs at a time when the ratio of new resources to expenditures is probably decreasing. He pointed out that present practices allow private companies to retain valuable information confidential on the grounds that it would prejudice their competitive position. This he believed was not in the best interests of society and argued that they would be served better by making data available to government agencies and thus enhance their ability to carry out the studies necessary to develop national policies and new techniques for mineral exploration. Dr. Darnley then went on to describe his idea of an ideal organization to provide the government leadership needed to direct exploration programs. In the last part of his talk he described the geophysical research currently being performed within the Geological Survey of Canada.

Mr. Lindseth described the science of petroleum geophysics as a "microgeophysics" concerned with the finer detail within the thin sedimentary layer on the earth's surface. The preferred tool is the seismic method because of its ability to provide a clear picture of the detailed structure necessary for a successful oil exploration program. Other geophysical methods are used, but less frequently, and often only for reconnaissance purposes. He then went on to describe the two major advances which in his opinion have led to all other improvements in seismic exploration: reproducible recording and digital processing. Mr. Lindseth then took sharp exception to the suggestion by Dr. Darnley for an in-

creased concentration of exploration effort in one government agency. He submitted that history and experience have demonstrated that this approach is far less efficient than a multifaceted, more creative approach rising naturally from competitive situations involving a number of organizations or private companies. He indicated that while there are winners and losers in any given situation the relentless demands of competition force organizations to move on to the next problem without publicly agonizing over what went wrong. This healthy environment he claimed has largely been responsible for Canada's success in the petroleum field.

Mr. Pemberton opened his presentation on developments in private industry with respect to mineral exploration by stating that the industry accounted for nearly 9% of Canada's GNP and about one-third of its exports. Given this input he lamented the loss of the rapport which formerly existed between government and industry. He pointed out that it is absolutely essential that the government allow the industry to keep a fair share of the rewards to encourage mining firms to reinvest their profits to build an even stronger industry. Mr. Pemberton went on to point out the numerous developments in instrumentation and methodology which have been pioneered by the exploration industry in Canada. This technology has to a large extent been fostered by the complex nature of the business. The targets are varied and discoveries require methods which differ from one target to another and one area to another. The techniques of interpretation are far from simple and in the final analysis subject to individual judgement which in many ways renders exploration as much of an "art" as a "science".

Dr. Ballard presented a review of the study of the Mid-Cayman Rise in the central portion of the Cayman Trough. The first phase of the research program involved a multi-parameter geophysical and hydrographic cruise in the area which provided the detailed information for further studies. Subsequently, in 1976, a combined surface ship and submersible field study was carried out within the rift valley of the rise and its flanking slopes. Excellent photography of portions of the feature were taken both from the submersible and from cameras lowered to the ocean bottom from the ship. An excellent suite of samples was collected including some very fresh basalts which popped and cracked on the deck of the ship following their recovery. He reported that plans were being laid for three additional cruises during 1977 and 1978. The first will involve the submersible ALVIN used on the second cruise. Following that the bathyscape TRIESTE II will conduct a series of dives in the rift valley. Finally, the third cruise in early 1978 will involve a detailed seismic study of the trough using recently developed high resolution multi-channel seismic profiling equipment.

Summary of Fifth Session
Information Systems in Geophysics

Mr. McConnell described the National Gravity Data Base of the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa which provides storage and retrieval services for gravity data acquired directly by the department or contributed by other government agencies, universities and the petroleum and mineral exploration industry. The data base also includes the digital information and documentation describing the International Gravity Standardization Net 1971 and Latin American Gravity Standardization Net, which is maintained in conjunction with scientific and technical services provided to the International Gravity Commission and the Geophysics Commission of PAIGH. In his presentation, Mr. McConnell also described the organization and contents of the data base and its interactions with the software systems used to reduce, edit, store, update, retrieve and plot gravity data.

Ing. Salgueiro emphasized the importance of the work described by Mr. McConnell for the development of data bases in Latin America and for the exchange of ideas and information within the Geophysics Commission.

Dr. Wilcox described the U.S. Department of Defense Gravity Library and presented regional gravity and topographic maps for South America. The DoD gravity file now contains the results of some 11 million discrete gravity measurements. Of these about 6 million are stored on magnetic tape as an automated file known as Gravity Point Anomaly which serves as the basis for the automated storage and retrieval of data within the DoD gravity library. The remaining 5 million observations are maintained in a non-automated contingency file. Other files contained within the library include the author-index, the base station, mean anomaly, mean elevation and gravity map files. The library has the capability to generate information in a variety of formats including specialty plotted maps. Dr. Wilcox then went on to describe the four maps (regional structure, mean elevation, Bouguer and free air) which he had compiled in time for presentation at the meeting. The elevation and gravity maps were compiled from 1° x 1° mean values. The regional structure map was compiled to assist with the interpretation of the gravity maps.

In the discussion of Dr. Wilcox' paper Ing. Guevara described gravimetric and geological work in Honduras and the need for experts to handle the great amount of data. Ing. Salgueiro spoke of his wish to take advantage of the data systems and software described by Messrs. Wilcox and McConnell and the desirability of having a single gravity data computing centre in Latin America.

Mr. Svendsen described the World Data Centre System with particular reference to World Data Centre A located in Boulder, Colorado. This centre serves a large number of disciplines in the fields of solar-terrestrial physics and solid earth geophysics. He described the degree of success with the various disciplines as variable with data collection only just beginning in some cases. Overall he felt the best performance had been in the field of geomagnetism. The data centre receives and stores data in a wide variety of formats and an attempt is made to edit most of the data, although with the large volume the process is by no means perfect. Data are distributed to customers in all parts of the world in a wide range of formats. By far the biggest requirement is for microfilm copies of analog records (e.g., magnetograms). Mr. Svendsen also referred to the excellent cooperation World Data Centre A received from Latin American countries.

Mr. Callahan described the World Meteorological Organization with special reference to that portion of the network involving Latin America. The WMO operates sophisticated communications capable of transmitting vast amounts of weather observations to regional and world centres for synthesis and analysis to provide weather forecasts several times daily. The network in Latin America and the Caribbean is extensive and being improved all the time. There are currently over a 1,000 stations in the network taking ground observations and in excess of 100 taking upper air observations. Many of the stations are

currently being equipped for radio FAX transmission which enables photographs and other visual data formats to be sent.

Dr. Lachapelle presented a combined least squares collocation-integral formulae (Stokes' and Vening Meinesz's) method used to predict deviations of the vertical and geoid undulations on the basis of a set of geopotential coefficients, namely GEM8, and surface gravity data. He compared the predicted deviations with the corresponding astrogeodetic values for points in Canada and found excellent agreement with the rms differences being 1".26(ξ) and 1".48 (η) respectively. He compared the predicted undulations computed using the GEM8 model with the satellite doppler derived values and found the rms difference to be 2.62 m. A similar comparison with values computed using a combined GEM8 — surface gravity data model and doppler derived geoid heights gave an rms difference of 3.77 m. Dr. Lachapelle suggested this surprising result probably arises because of systematic differences in the cordilleran regions of western North America. When the points in this region were removed the rms difference was reduced to 2.74 m and 2.67 m respectively for GEM8 — gravimetric and GEM8 geoids respectively. He concluded that these differences are a manifestation of the comparatively poor gravity coverage in western Canada.

Summary of Sixth Session
Information Systems in Geophysics

Ing. Mazzini described a program to study secular gravity changes in the Andes, a cooperative project of the Naval Hydrographic Service and the University of Buenos Aires in 1973.

Three profiles were made: the north, the centre, and the south. Data from these profiles and their general characteristics were given, together with an interpretation of the results obtained. Mazzini suggested that variations in gravity between the 1973 results with LaCoste and Romberg meters and earlier measurements are probably due to calibration errors in the Worden 51 instrument used on the previous surveys.

In the discussion following Mazzini's paper Dr. Ocola referred to similar work being done in Peru. Both he and Mazzini emphasized the need for knowledge of instrument characteristics and for correct identification of reoccupied stations. Prof. Woollard pointed out he was not convinced that calibration errors were the cause of the gravity variations. He suggested the variations correlated spatially with changes in basement structure and hence different tectonic patterns.

Ing. Monges reported on studies of secular variations of gravity in Mexico and along profiles in Central and South America. In Mexico City a variation in gravity of 0.065 mgal per year had been observed. In Guatemala it was possible to reoccupy stations after the recent earthquake and to record significant changes in gravity. This result has stimulated re-measurement programs in earthquake prone areas of Mexico. In South America changes in gravity between 1961 and 1973 calculated at several localities lay between 0.15 and 0.33 mgal total change.

In the discussion which followed Monges' presentation, Ing. Argenal enquired whether there was any correlation between the secular variation in gravity and the drainage of the Central Valley of Mexico. No correlation has been found. Prof. Woollard then reiterated his belief that these changes of gravity are real secular changes. In support of his thesis he cited evidence from gravity ties in Mexico and the U.S.A. He concluded by stating that gravity is an inexpensive way to check areas of suspected vertical movements prior to relevelling.

Ing. Guevara asked if there was any variation in gravity in Honduras after the Guatemala earthquake. None was found.

Dr. Shea described the system of data exchange used in the discipline of solar-terrestrial physics. The medium chosen for this is the World Data Centre system. Since the International Geophysical Year an extensive world-wide data information and exchange system has been built up within the discipline. Scientists can avail themselves of this information in two ways. Contributors are entitled to draw data of equivalent value from a data centre free of charge. Non-contributors must pay the reproduction costs associated with the retrieval process. The existence of this system has facilitated the prediction of solar storms which disrupt telecommunications. Scientists are actively studying the possible effects of solar activities and cycles on our weather systems.

Dr. Smart presented a brief overview of solar-terrestrial physics and solar proton events. He pointed out that many Latin Americans are not familiar with these events as the earth's magnetic field restricts the influx of solar particles to polar regions. In his discussion Dr. Smart pointed out that no technique exists to predict solar flares even an hour or two in advance. However, once a flare has occurred some very large and complex computer programs exist to predict the character of the emissions over various energy ranges for periods of several days following the flare. This kind of information has a variety of uses, among which are applications to communications and possible effects on the weather or climatic patterns of both a long and short term nature. Dr. Smart also pointed out that a special handbook is being prepared for Latin America which contains basic geophysical parameters needed for research application in many areas of solar-terrestrial physics. The publication of this handbook is expected in 1977.

Dr. Giesecke, as Director of CERESIS, emphasized the special character of seismic data and the need for rapid public access to seismic information after earthquakes and for the evaluation of seismic risk. For this, many local centres of information are better than a central facility. Information centres must be up-to-date and be distributed without the great delays now common. To date few papers have been published. Preliminary studies indicate that world data centres are not receiving 20-25% of the events recorded. He stressed the international aspects of seismic data and the benefits of free exchange of information for relationships between countries. Dr. Giesecke then went on to discuss the problems of communication as networks do not all operate on a 24-hour basis. Some are in remote locations and only attended by temporary personnel. Information bulletins have proved extremely useful as permanent records, but many observatories have yet to release any. He also indicated there is also the need to standardize the digitization of data accelerograms.

In the discussion following Dr. Giesecke's paper Ing. Salgueiro stated his belief in the need for a Latin American seismology information system (SILAS) to integrate all seismic studies. The design of such a system should be the responsibility of CERESIS, which he considers has received an adequate level of international support from member countries.

Ing. Fonseca gave the reports for Venezuela on gravimetry, magnetism and seismology prepared by himself, and engineers V. Graterol, M. A. Lopez Mussa and E. Gajardo. He outlined the

history of gravity research in Venezuela and the development of the national gravity network, which recently was adjusted through the SILAG program. For the Bouguer map he reported that in addition to land-based measurements some petroleum company data for the Caribbean Sea area have been incorporated into the data set even though they were not tied to the continent. Further measurements are planned to complete the gravity coverage. Gravity measurements for geodetic purposes at intervals of 4 km only have been used to prepare the corresponding free air anomaly map. The Bouguer anomaly map is to be published at a scale of 1:500,000 in 1976.

Magnetic maps for Venezuela have been prepared every 5 years since 1955. After considerable difficulty in finding a suitable location, tests are now underway at Pozo Hondo where it is hoped to establish a national magnetic observatory within the next year. Aeromagnetic and radiometric maps have also been prepared for some areas. He reported that the national network of seismic stations transmit records daily to the Seismology Institute in Caracas, where monthly seismic bulletins and a seismic map of the country are published. The Venezuelan Foundation for Seismological Investigations, founded in 1972, is preparing seismic risk studies through OEA in collaboration with U.S. and South American organizations. Other networks of seismic instruments are under construction and studies are being carried out by personnel of FUNVISIS and geophysical engineering students.

Dr. Feininger described the Bouguer anomaly map of Ecuador which has been compiled from some 14,000 observations taken over the past 25 years. He described the variations of the Bouguer field in the context of the four principal physiographic provinces of Ecuador. In the process he noted that the total relief in the gravity field was over 450 mgal varying from a low of nearly — 300 mgal in the Sierra province to a high of more than +160 mgal in the Costa province. He correlated the positive Bouguer anomalies in the Costa region with occurrence of the Piñón formation which consists principally of basalt and diabase with infrequent intrusions of gabbro and peridotite. The negative anomalies in the Sierra region are a manifestation principally of the deep root under the Andes.

Mr. Sebert described cartography as one of the important services that support geophysics and indicated that there is a number of cartographic projects taking place within PAIGH that are pertinent to geophysical studies in Latin America. In the latter context he referred to the Geological Map of South America at a scale of 1:2,500,000 and the tectonic map of South America at a scale of 1:5,000,000. He described progress with the latter as disappointing because of the lack of funds despite efforts by several individuals to arrange even partial financial support through PAIGH. Other projects taken on by the Special Maps Committee which Mr. Sebert chairs include the formation and growth of map libraries in Latin America and the publication of national and regional atlases. He indicated a symposium on atlases will be held in about two years. He concluded his talk by presenting resolutions requesting support for the preparation of the tectonic map for South America and for the development of map libraries.

Mr. Jordan described the various schemes and programs which have been used to facilitate data exchange in the field of seismology, the experience with which he used as a basis for suggesting future improvements to the process. In describing the National Earthquake Information Service operated by the U. S. Geological Survey he noted the world-wide volunteer effort which has led to an efficient method for determining earthquake epicentres on a world-wide basis. He pointed out, however, that the information flow from Latin America is not adequate for modern studies of seismicity. He suggested a concentrated effort to improve communication systems as well as to increase the number of stations. He discussed a number of possible improvements to NEIS with emphasis on improved automated recording techniques, better data processing systems and the possible use of satellites.

Summary of Seventh Session
Review and Revisions of Programs and Priorities of the Geophysics Commission

Ing. Mazzini gave a brief outline of the project entitled "A South American Profile of Earth Tide Measurements" to begin with a training program at Tucuman in October 1977. He requested support for this project which is co-sponsored by the Royal Belgian Observatory and the University of Tucuman in Argentina.

Ing. Brussoni reviewed the history of geophysics in Uruguay. The Uruguayan Government carried out a major gravity and drilling program between 1948 and 1958 to determine basement structure. By 1954, 26,000 gravity stations were produced. The Military Geographic Service has published the first geomagnetic maps and, with the National University of Buenos Aires, developed the national gravity network. PAIGH supported the publication of gravity data and maps. Since 1966 seismic and magnetic observations have been made on the continental shelf. A seismology network is approaching completion and regular university courses in geophysics began 2 years ago. He also reported that a major search is underway for seismic records recorded between 1887 and 1940.

Based on his study of other systems implemented throughout the world, Ing. Salgueiro outlined the factors that should be considered in setting up the Integrated Earth Science Information System (SIGEO) to store and retrieve the results of studies carried out on the oceans and continents. The system should be structured to take account of, in a flexible way, the problems associated with the taxonomy, processing, storage, retrieval, transformation, presentation, and publication of geophysical information in the Americas.

Ing. Argenal reported that a seismic network has been operating in Nicaragua since May 1975 and that the results have been used to develop seismic zones and a construction code. Together with other countries a seismic network for the whole of Central America should be operating within one or two years. He indicated there is a major need to consider the problems of handling the mass of data which will be produced.

Ing. Guevara reported that only a few gravity measurements had been made prior in Honduras to 1956 but since 1969 the basic gravity net has been developed. Magnetic work done up to 1969 was used to produce isogonic and terrestrial magnetism maps for 1970 to 1974. In 1974 a preliminary geological map of Honduras was published. Finally he indicated that a provisional gravimetric map will be produced as a basis for further geophysical studies towards determining geologic structure.

Father Ramírez reported on a number of geophysical projects in Colombia. The first is a joint project between the Geophysical Institute of the University of Javerina and the University of Wisconsin to study the structure of the Western

Colombian Andes, the most seismically active zone in South America. The second involved the dissemination of information on geology and geophysics by automatic library systems as discussed by Working Group II on the International Geodynamics Project at Acapulco, Mexico, June 14-16, 1976. The third project reported was the marine seismic reflection profiles and magnetic measurements observed off the north coast of Colombia in a joint study with the French Petroleum Institute in April 1976. Other projects reported included a continuation of the 1973 Narino Project of petrographic studies which were made in the central and western Cordillera of Colombia by the University of Glessen, Germany during 1976. Studies of volcanic sediments in the eastern Pacific Ocean off Colombia and of Tertiary orogenic periods in Colombia were published in 1975. An investigation was made of electrical conductivity and geomagnetic variations in western Colombia during the period February to September 1976 in collaboration with the Carnegie Institute of Washington. The seismic monitoring of the Galeras volcano is reported in regular bulletins and the geotraverse between 6°N and 7°N was augmented by additional magnetic and gravity stations in 1975. An isogonic map for 1975 for Colombia is in preparation. On a more general vein he stated that a new metallogenic map of Colombia has been presented, a new geologic map will appear in 1976, geophysical maps and publications for the Caribbean region have been published in the U.S. in 1975 and 1976 and that a popular booklet on earthquakes prepared by the Geophysics Institute of the Colombian Andes for PAIGH was ready for distribution in 1975.

Ing. Llinas reported that as a result of the major earthquake of 1946 and the recent heavy construction in the Dominican Republic there is an urgent need for seismic risk studies, a construction code and a seismic network. He indicated that a formal proposal has been made for a network of 3 to 4 stations, with additional stations to be established later. Finally he stated that the interpretation of gravity data is being held up by the lack of a reliable geologic map.

Dr. Ocola distributed copies of the report on seismology, gravimetry and magnetism in Peru, prepared by and available from the Geophysics Institute of Peru. He considered seismic risk evaluation to be the main problem confronting central and South America. The theory of seismic risk evaluation followed is based on the Cornell method which requires a good knowledge of the seismic activity and the tectonics of a region. A seismic risk map for South America has now been prepared. He reported that a particular problem is the description of large multiple earthquakes of long duration for which the normal definition of magnitude is inadequate. He also described a catalogue for eliminating independent events from aftershocks of major earthquakes.

Summary of Eighth Session
Round Table Discussion of Programs and Priorities of the Geophysics Commission

Dr. Kausel opened the discussion by making reference to the meeting of the authorities of the Geophysics Commission in Lima which established the objectives which served as a basis for the discussion that followed. This discussion took the form of six themes and for each theme a keynote speaker was selected. A discussion period was allotted at the conclusion of the theme-setting presentations. The first of these was the "Central Themes of Research" to which each of the chairmen of the three committees spoke in turn.

Prof. Radicella, chairman of the Committee on Solar Terrestrial Physics, discussed natural resources in terms of the earth as a space vehicle with limited resources but a growing population. The atmosphere was important for its influence on ecology and human activities. There are insufficient studies of climate in Latin America for the prediction of harvest yields. There is a need for studies of the climate effects of densely populated regions, including the effects of population, and of the state of communications in Latin America, including the use of satellites and microwave techniques.

Capt. Cabezas, chairman of the Committee on Oceans and Atmospheres, discussed the study of the anomalous marine currents off the eastern Pacific coast of South America and its serious effects on the economies of adjacent countries. A project is currently underway in Peru and will be expanded to include the Galapagos Islands. A meeting to be held in Montevideo was described.

Finally the chairman of the Solid Earth Committee, Father Ramírez, discussed the choice of the subject "Seismic Risks" as his Committee's central theme of research and of the need for epicentre and tectonic maps for the development of construction codes.

In the discussion Ing. Guevara supported the emphasis on seismicity. Dr. Ocola emphasized the contribution of gravimetry and geomagnetic studies to the basic research for the evaluation of seismic risk. Ing. Salgueiro indicated the need for an early start to the task of developing an integrated information system for the geosciences. Ing. Argenal argued for the importance of airborne geomagnetic studies for giving rapid coverage of almost all South America. Ing. Malavassi stressed the need for completing projects on hand and the importance of work on practical problems such as the seismic code and oceanic currents. In response to Ing. Salgueiro, Ing. Sáenz reviewed the manner in which Commission funds are distributed equitably.

The outcome was that central themes of research for the next four years were adopted, with the specification that support for data systems, thematic maps and training must be kept up.

The second topic on the program, "Selection and Control Mechanisms" was presented by Dr. Kausel who outlined procedures for submitting projects to PAIGH through the Geophysics Commission using the current revised formula.

In the discussion Ing. de Godoy emphasized the importance of the early history of projects as a criterion for their evaluation. Prof. Radicella agreed and urged that the record of the investigators also be included in the evaluation.

Dr. Kausel introduced the third topic, consideration of whether geology should be a separate committee of the Geophysics Commission. In response to Dr. Feininger, Dr. Kausel indicated that the Committee on Gravimetry and Earth Tides was within the Cartography Commission for classical reasons, but that there were no active projects in this area. Ing. Sáenz indicated that the committee was combined with that on geodesy. Ing. Malavassi supported the idea of a geology committee and Ing. Fonseca spoke about the lack of representation of tectonophysics and volcanology. Dr. Ocola spoke against subdividing the commission further. Mr. Geller pointed out the need for better management of available resources through PAIGH. Dr. Ocola indicated that increasing the number of committees would increase costs to the commission. Ing. Fonseca agreed that

geologic information could be integrated into existing committees. In response to Dr. Ocola, Dr. Kausel outlined the historic separation of geophysics from geology and indicated that there was support for a separate geology commission. Dr. Graterol agreed with the formation of a geological committee to help with studies of seismic risk and the interpretation of Bouguer anomaly maps. Ings. Monges and Fonseca argued against the formation of a geological committee if the geologists mean to form a separate commission. Ing. Mazzini pointed out the problems of duality within PAIGH which a geology committee may introduce. Dr. Kausel suggested that a geologist could be Vice-President of the commission to act with the committee presidents. Alternatively, but with more difficulty than forming a committee for geology, a geoscience commission could be formed. Prof. Woollard and Ing. Salgueiro spoke in support of not dispersing the organization by forming more committees.

A vote was held which saw a majority reject the establishment of the proposed new Geology Committee.

Dr. Shea introduced the fourth topic "Data Information Centres". In her talk she emphasized that the lack of any large or regional data centres in Latin America is a hinderance to the development of geophysical research in Latin America because various discipline data bases have left Latin America without any proper conveniently located central facility to work with global or regional data. Furthermore, she believed that the data collection process itself tended to stagnate because of the lack of any mechanism for input from users. She suggested that Latin America could correct this shortcoming by perhaps starting in a small way with centres or institutes where a significant collection of records exists. This could be done on a discipline basis according to the expertise of the particular centre. She concluded by listing several criteria with respect to space, personnel, etc., for establishing a modest data centre.

In the ensuing discussion Prof. Woollard outlined the costs of running an effective data centre and of retrieving data from it. He emphasized the difficulty in obtaining funding and emphasized there are no U.S. funding agencies for this work. Prof. Radicella agreed and spoke of the need to develop regional concentrations of data and bring them up to national levels. Dr. Tanner reinforced Prof. Woollard's remarks by referring to the costs of establishing World Data Centre "A" and suggested a modest start by assembling indices of data coverage. Father Ramirez gave examples of the good response his institute has had to their publications of reference lists and indices. Ing. Salgueiro indicated that the first work of the Commission should be a general study of the present status of information systems in Latin America and the need for centres of concentration of data. In reply to Prof. Woollard, Mr. Svendsen indicated that a big problem with regional centres was in updating the data. Prof. Woollard agreed that it was difficult to make regional centres effective. Dr. Ocola spoke in favour of the centres of national concentration suggested by Ing. Salgueiro, who urged that a normalized system of information be available for all countries, and that it be undertaken immediately. Dr. Shea spoke of difficulties with communication and in determining what data already exist. Dr. Giesecke spoke of the funds already provided by OAS for the establishment of centres of scientific and technological information. He also discussed, in response to Dr. Kausel, the main problems encountered by CERESIS, such as the erratic flow of seismic reports. Prof. Radicella proposed a resolution in favour of a geophysical data inventory. Ing. Brussoni spoke of involving industry in the formation of data centres. Dr. Shea mentioned NSF as a possible additional source of help. Capt. Cabezas indicated that the experience of the Oceanographic Committee was that lack of funds held up the formation of data centres.

Ing. Salgueiro stated that the formation of inventories should be the responsibility of national sections in the hands of specialities, while Dr. Giesecke pointed out that use should be made of the experience in data collection of the various national councils. Dr. Tanner supported the idea of making up indices as a first step. Prof. Radicella raised the possibility of organizing a symposium or workshop with the help of NSF. The resolution of Prof. Radicella was referred to the Resolution Committee. Dr. Woollard indicated that NSF support for a workshop was possible.

The fifth topic, "Thematic Maps" was introduced by Dr. Tanner who recommended that a member of the Geophysics Commission be appointed to sit on the special committee on thematic maps of the Cartographic Commission. Ing. Sáenz discussed the means by which the coordination between commissions could be carried out. Although no representative to the committee was nominated, it was agreed that the Geophysics Commission should maintain close liaison with it.

Finally, Dr. Giesecke introduced the sixth topic, "Training". He analyzed the concept of training with respect to different levels of education. He mentioned a need to expand the information available through Spanish language publications particularly with respect to journals which deal with the practice of geophysics, such as investigations of seismicity induced by reservoirs, both to inform Latin Americans and promote the participation of foreign specialists. There is also a need to provide through PAIGH greather opportunities for the exchange of geophysics professionals among Latin American research institutions. He felt that a maximum regional utilization of the facilities existing in Latin America should be sought. Finally he considered the courses organized by PAIGH, such as the course of gravity, the ionogram reading course, the seismograph operator course, etc., to have been highly beneficial.

In the discussion which followed Prof. Radicella suggested that a resolution be made on the promotion of training as part of the program for the next four years. Dr. Kausel pointed out that training was already a responsibility of PAIGH and that new journals should not be published as Revista Geofisica is available but receives few articles. Ing. Sáenz reinforced remarks concerning the need for more articles from Latín Americans for established PAIGH publications. Father Ramírez described an experiment in data transmission using photocopies of articles on tectonics. Ing. Salgueiro discussed use of the book "Investigating the Earth" and the attempt to use Latin American material in it, as well as the mutual use of observatory facilities, and existing methods of exchanging information.

Ing. Llinas spoke of the need for scholarships, which Dr. Kausel also addressed as well as the question of beginning at the primary and secondary levels of education with appropriate texts. PAIGH should identify those needing scholarships. Ing. Llinas returned to the need for scholarships at the university level in training engineers in geology and geophysics. Ing. Salgueiro pointed out that specialized undergraduate courses already existed at the University of Chile, although PAIGH could sponsor graduate courses as suggested by Dr. Giesecke. Dr. Kausel indicated that the OAS scheme has rarely been used for training geophysicists, so PAIGH should take the lead in promoting

geophysics at the higher levels. Ing. Sáenz enquired whether the training of operators in gravity and seismology was adequate compared with training from the School of Cartography in Panama. Ing. Monges outlined some of the deficiencies of gravity observers and urged the formation of a training course and manual. Ing. Llinas expressed pleasure with the training scheme outlined by Dr. Kausel and urged that training go ahead at all levels. Ing. Guevara also spoke in support of training at basic and higher levels. Ing. Argenal appealed for wide dissemination of information on scholarships. Prof. Radicella submitted a resolution that the Commission prepare a coordinated technical and scientific training plan for inclusion in the program of the Commission for 1977-81. Ing. Salgueiro pointed out that publications should also be mentioned, particularly those in the charge of the Commission but not yet published. Ing. Sáenz indicated that the manual mentioned by Ing. Salgueiro is being published in "Geofisica". In reply to a question by Ing. Sáenz, Prof. Radicella indicated that training for observers should be specifically mentioned in the resolution and that "information" should cover the subject raised by Ing. Salgueiro. The resolution was accepted.

The meeting was brought to a close by Dr. Kausel, who thanked those responsible for organizing and running the symposium.

Résumé des cérémonies d'ouverture de la première séance

M. Blanchette, président de la Section nationale et ambassadeur du Canada auprès de l'Organisation des États Américains, a officiellement ouvert le symposium en souhaitant la bienvenue aux délégués réunis à Ottawa. Il a souligné, dans son allocution, qu'il s'agissait du 7e séminaire que le Canada organisait à l'égard d'une des disciplines de l'Institut panaméricain de géographie et d'histoire. Il a ensuite décrit la structure de l'Institut et les activités de ses quatre commissions qui lui permettent d'organiser un vaste éventail d'activités de diffusion des connaissances dans toute l'Amérique latine et d'aide aux différents pays dans divers aspects de leurs programmes nationaux.

M. Whitham, directeur général de la Direction de la physique du globe, a souhaité la bienvenue à tous les délégués au nom du ministère canadien de l'Énergie, des Mines et des Ressources. Il a décrit de quelle façon sa Direction participe intensivement, depuis environ 15 ans déjà, aux activités de l'IPGH, ce qui a amené le Canada à collaborer à la création d'un réseau de mesures gravimétriques normalisées en Amérique latine. M. Whitham a ensuite fait des observations sur le changement d'attitude de la société à l'égard de la science, en particulier dans le domaine de la géophysique, et il a souligné l'intérêt accru porté à la recherche utilitaire, notamment dans les études liées à l'environnement. Enfin, il a fait observer que les organisateurs avaient essayé d'élaborer un programme bien équilibré pour éclairer dans une juste perspective la contribution à la géophysique fournie par les scientifiques des différents secteurs publics, des universités et des sociétés privées d'exploration.

M. J. Sáenz, secrétaire général de l'IPGH, a présenté un exposé sur l'histoire et la structure de l'IPGH, sur ses rapports avec l'OEA et sur le fonctionnement de la Commission géophysique au sein de l'IPGH. L'Institut coordonne et encourage l'exécution d'études dans les diverses disciplines, et ses programmes sont élaborés et révisés tous les quatre ans. M. Sáenz a déclaré qu'il fallait maintenant commencer d'élaborer les programmes pour la période 1977-1981. Il a souhaité que le symposium permette la mise au point, pour la Commission géophysique, d'un plan directeur qui tienne particulièrement compte des problèmes des pays où la géophysique est moins avancée. Il a remercié, au nom de la Commission, tous les responsables de l'organisation du symposium.

Au cours d'une allocution d'orientation, M. G. D. Garland a parlé de l'important rôle social et économique que la géophysique a joué et jouera dans la société. La première partie de son exposé a surtout porté sur les raisons historiques du développement de nombreuses disciplines qui sont aujourd'hui bien connues en géophysique. Tout en décrivant la participation actuelle de la géophysique à la solution de problèmes sociaux et économiques, il a traité de sujets comme les mouvements relativement lents de la croûte terrestre, les phénomènes séismologiques, y compris la délimitation des zones de séismicité, la signalisation des tsunamis, la séismicité provoquée et les prévisions, les phénomènes volcaniques, les problèmes liés à l'énergie, aux minéraux, au pétrole et à l'environnement. Il a ensuite décrit la contribution de la géophysique aux questions d'actualité dans ces divers domaines. Pour conclure, il a souligné l'importance de la coopération internationale dans le domaine de la géophysique et mentionné le rôle que l'Union géodésique et géophysique internationale a joué dans les affaires mondiales, puis il a insisté sur la constante nécessité de l'apport actif de l'UGGI et d'autres organismes comme l'IPGH.

M. Radicella a signalé que M. Garland n'avait pas traité des questions liées à la recherche sur les océans et l'atmosphère, et il a exprimé l'espoir que ce sujet serait étudié au cours de la semaine par les participants au symposium.

Résumé de la documentation présentée au cours de la deuxième séance

M. E. Kausel, président de la Commission de géophysique, a donné un bref aperçu des travaux de géophysique effectués en Amérique latine et il a indiqué le niveau d'activité qu'avait atteint certaines disciplines comme la météorologie, la géologie et la géophysique d'exploration. Les progrès réalisés en gravimétrie découlent de l'intérêt manifesté par les instituts de géographie, mais il faudra travailler davantage dans ce domaine, surtout en ce qui concerne l'interprétation des résultats. Pour ce qui est de la séismologie, il a fait remarquer le travail de CERESIS tout en insistant sur la nécessité de former du personnel dans ce domaine à cause de l'importance des études sur les risques séismiques, et il a signalé qu'il fallait améliorer les communications concernant les phénomènes séismiques et élaborer des méthodes de prévision de l'activité séismique étant donné que cette discipline en est encore à ses balbutiements. Il a ensuite traité brièvement de certains travaux de recherche effectués en Amérique latine en mentionnant qu'il n'y avait pas assez de chercheurs à l'œuvre en Amérique latine. Il a signalé la nécessité impérieuse d'accroître la formation et a insisté sur le fait qu'il fallait améliorer l'infrastructure des cadres moyens et augmenter le nombre de chercheurs. À son avis, si l'on se fie aux contributions à la documentation en géophysique, l'importance relative de la recherche effectuée en Amérique latine est faible et disproportionnée. Il a terminé en soulignant qu'il fallait améliorer les systèmes d'information dans le domaine de la géophysique.

En discutant de l'exposé de M. Kausel, MM. Giesecke et Brussoni ont souligné que de nombreuses données n'ont pas été

publiées parce que certains chercheurs de l'Amérique latine sont lents à publier les résultats de leurs travaux.

M. G. P. Woollard a présenté une revue très vaste de l'état de la recherche effectuée dans le domaine de la géophysique en Amérique latine. Dans son exposé, il a associé la recherche aux progrès réalisés dans la mise en valeur des ressources naturelles, aux problèmes sociaux, économiques et scientifiques, ainsi qu'aux problèmes liés à l'utilisation des sols. Il a décrit l'Amérique latine comme un continent riche en ressources. Par conséquent, l'une des orientations les plus prometteuses de la recherche est d'essayer de comprendre l'origine des gisements de minerais. Étant donné la grande zone d'enfoncement située au large de la côte est de l'Amérique latine, cette vaste région est évidemment une des principales zone de prédilection du monde pour les recherches en géophysique. Les risques d'origines naturelles, tels les volcans et séismes, font l'objet de graves préoccupations sociales dans de nombreux pays de l'Amérique latine. La recherche géologique et géophysique (séismologique) a surtout porté jusqu'ici sur la constitution d'une base de données qui permettraient de comprendre ces phénomènes à la lumière des caractéristiques tectoniques de l'Amérique latine. Étant donné qu'il s'agit d'une région où la jungle est dense et les montagnes sont accidentées, M. Woollard a fait ressortir qu'il fallait faire preuve de prudence dans l'utilisation des terres et il a indiqué que jusqu'à maintenant, les programmes géophysiques entrepris pour améliorer l'inventaire des terres avaient été modestes. Enfin, il a souligné qu'il restait à résoudre une myriade de problèmes de nature fondamentale en Amérique latine. Les perspectives sont nombreuses, mais malheureusement, il y a trop peu de géophysiciens. À long terme, cette recherche sera certainement très importante pour la mise en valeur des ressources énergétiques, pour l'exploration minérale et, enfin, pour la solution de problèmes de nature sociale et environnementale.

M. C. Lomnitz a présenté une franche discussion de l'enseignement de la géophysique en Amérique latine, et il a souligné le fait qu'il exprimait ses opinions personnelles et non celles de toute autre organisation ou personne. Il a décrit l'évolution de l'enseignement universitaire en Amérique latine depuis ses débuts, quand les universités étaient essentiellement réservées aux professions comme la médecine, le droit et le génie en passant par l'étape où elles ont adopté une orientation politique engagée, au milieu des années 1900, et pour enfin souligner le vif intérêt porté récemment à l'enseignement de disciplines non scientifiques dans les universités privées. Il a ensuite mentionné que dans une société dont les dirigeants prennent progressivement conscience de l'importance des géoscientifiques, l'Amérique latine dépend fortement des scientifiques étrangers à cause de la pénurie des professionnels formés sur place. Il a ajouté qu'il fallait en conséquence trouver une nouvelle source de motivation, et la trouver à l'intérieur de l'Amérique latine si l'on veut apporter une solution satisfaisante aux problèmes sociaux et économiques à long terme qui mettent en cause les sciences de la terre. À titre d'exemple de ce genre de progrès, M. Lomnitz a fait allusion au projet RESMAK qui a été exécuté au Mexique et a donné lieu à la création d'un vaste réseau de stations séismiques reliées par un système national de télémétrie dont la conception technique de base et une bonne partie de la technologie ont été mis au point au Mexique. Il a en outre indiqué qu'en dépit de ces progrès, il fallait que les grandes sociétés accordent une aide beaucoup plus considérable et qu'il était nécessaire de créer des sociétés professionnelles en Amérique latine.

M. P. Tanguay a décrit le programme que l'Agence canadienne de développement international exécute en Amérique latine et il a souligné que ce programme visait à assurer un meilleur environnement et à améliorer l'emploi des ressources renouvelables. Il a indiqué qu'environ 12% du budget de l'ACDI était destiné à l'Amérique latine et que les dépenses totales effectuées dans cette partie du monde (environ 60 millions de dollars par année) étaient réparties entre quelque 100 projets. La plus grande partie de ces dépenses est affectée à l'agriculture (50), mais d'autres projets visent l'éducation (25), la santé (15), l'infrastructure sociale (3) et le transport (3). Il a aussi signalé qu'environ 50 projets étaient au stade de la planification, puis il a indiqué que des projets qui mettaient en cause les sciences de la terre avaient été réalisés dans les domaines de la télédétection et de la mise en valeur des minéraux dans un certain nombre de pays. Cependant, à cause des besoins évidents de développement dans les domaines de l'agriculture, etc., les sciences de la terre ne peuvent recevoir la priorité à laquelle on pourrait s'attendre.

M. Salgueiro et M. Radicella ont signalé qu'il fallait découvrir de nouvelles formes de coopération scientifique qui tiendraient compte du niveau des compétences et des réalités dans les pays en cause. Ils ont tous deux affirmé qu'il fallait accorder la priorité à l'instruction dans tout programme de développement.

M. E. Feller a énuméré les projets réalisés dans chaque pays dans le cadre du Latin American Cooperative Science Program. Ce programme vise à aider les scientifiques des États-Unis qui désirent étendre leurs programmes intérieurs de recherche pour œuvrer en collaboration avec leurs collègues de l'Amérique latine et des Caraïbes. Les activités en cause comprennent: la recherche commune dans les sciences fondamentales et appliquées, des ateliers de travail axés sur la recherche; des rencontres à caractère scientifique destinées à l'élaboration de programmes ou à l'exécution de projets de courte durée. La liste des projets qui sont actuellement en voie d'exécution et concernant les sciences de la terre est impressionnante et couvre pratiquement tous les aspects du domaine. Un grand nombre d'institutions réparties dans presque toutes les régions des États-Unis participent à la réalisation de projets. M. Feller a aussi signalé que la géophysique marine était bien représentée dans le programme et qu'un certain nombre de navires de recherche avaient servi à des expéditions dans les eaux attenantes à l'Amérique latine.

En réponse à une question de M. Malavassi, M. Feller a indiqué les diverses façons dont la NSF pourrait aider un pays de l'Amérique latine à mettre au point un cours universitaire en géophysique en donnant son appui aux chercheurs des États-Unis qui participent à l'exécution de projets conjoints avec les membres de l'université en cause.

Résumé de la troisième séance
Les objectifs et la méthodologie de certaines études nord-américaines

M. Vaníček a présenté une étude des relations réciproques entre la géodésie et la géophysique. Il a fondé son exposé sur l'hypothèse que l'auditoire connaissait bien la géophysique, mais non la géodésie. Pour les fins de sa communication, il a divisé la géodésie en trois éléments: la géométrie, le champ gravimétrique de la terre et les variations dans le temps de la géométrie et du champ de gravité de la terre. Les positions (horizontales et verticales) des points de la surface de la terre peuvent être déterminées par levés topographiques ou par des techniques spatiales

(satellites). Chaque technique offre ses avantages, mais les levés sur le terrain donnent généralement de meilleurs résultats pour de courtes distances (c'est-à-dire, quelques dizaines de kilomètres) tandis que l'utilisation de satellites est nettement supérieure pour des distances de l'ordre de 1 000 kilomètres. La connaissance du champ de gravité sert à plusieurs fins en géodésie et sa principale application est, peut-être, la détermination de la déviation de la verticale et la forme du géoïde. Les variations dans le temps de la géométrie et de la gravité sont des paramètres importants de la géodynamique contemporaine. M. Vaníček a souligné que jamais la relation symbiotique entre la géodésie et la géophysique n'avait été mise en lumière de façon aussi spectaculaire qu'au symposium et que cette initiative amènerait les géophysiciens et les géodésiens à collaborer davantage à des activités plus nombreuses.

M. Gibb a décrit le Service canadien de gravimétrie qui relève de la Division de la gravité et de la géodynamique de la Direction de la physique du globe (Ottawa) et dont le premier objectif est de terminer une carte de reconnaissance gravimétrique fondée sur des observations de la gravité effectuées à des intervalles de 15 km ou moins. Il a ensuite exposé brièvement l'historique des mesures gravimétriques au Canada: il a d'abord décrit les premières mesures pendulaires et pour enfin décrire le programme moderne qui est considérablement accéléré. Il a déclaré qu'environ 80% de la masse continentale, des plateaux continentaux et des eaux intérieures du Canada avaient fait l'objet de levés au moyen de quatre techniques fondamentales: sur terre, sur la glace, sous l'eau et sur la mer; le recours à ces techniques nécessite plusieurs modes différents de transport et une variété d'instruments pour répondre aux exigences du programme national de cartographie. Il a aussi décrit la norme de référence utilisée pour les observations de la gravimétrie relative effectuées au Canada; cette norme a récemment été modifiée en fonction du nouveau réseau international des mesures gravimétriques normalisées (RIMGN-1971). Le Réseau national de mesures gravimétriques du Canada est relié à 20 stations du Réseau international qui se trouvent au pays. Il a enfin souligné que depuis janvier 1976, les principales données relevées par les 345 000 stations gravimétriques étaient mises en mémoire au Centre national de données gravimétriques (Ottawa) et qu'il est possible d'obtenir ces renseignements sous différentes présentations. Le Service de gravimétrie publie un jeu de cartes gravimétriques (échelle de 1/500 000) et la Direction de la physique du globe diffuse les données en temps opportun au moyen de son système de dossiers publics.

M. Niblett a déclaré que la géographie du Canada offre des possibilités exceptionnelles aux Canadiens qui effectuent des recherches en géomagnétisme, étant donné que le pôle Nord magnétique est situé au Canada et que ce pays constitue le meilleur laboratoire naturel au monde pour l'étude de l'activité magnétique et de la structure de la magnétosphère dans les régions aurorales et polaires. Il a brièvement décrit les premières observations et les réalisations des navigateurs anglais et des ingénieurs de l'armée britannique au cours du XIXe siècle, la création du réseau d'observatoires magnétiques du Canada, ainsi que le développement des levés géomagnétiques à l'échelon national. M. Niblett a ensuite décrit les recherches géomagnétiques effectuées au Canada dans les domaines des observatoires magnétiques, des levés géomagnétiques et des cartes magnétiques, du paléomagnétisme et du magnétisme rocheux, de l'induction électromagnétique et des études théoriques. Même s'il a surtout parlé de l'activité de la Direction de la physique du globe, M. Niblett a aussi fait allusion aux travaux d'autres organismes du Canada. Il a mentionné, notamment, les anomalies très marquées de la conductivité qui ont été observées dans l'Arctique et l'Ouest canadien, l'étude des propositions du pôle précambrien et du tracé de la dérive des pôles, les levés magnétiques aéroportés effectués à basse altitude pour obtenir des mesures détaillées et les levés aéroportés réalisés à haute altitude pour les fins de la cartographie.

M. Berry a signalé que la plupart des tremblements de terre se produisaient en bordure des plaques lithosphériques et que bon nombre d'entre eux étaient importants et causaient des dommages. Par conséquent, l'une des principales raisons des études de la séismicité est le risque séismique, qu'il a défini comme étant la probabilité qu'un certain déplacement séismique du terrain se produise pendant une période déterminée. Puis, il a défini les dangers séismiques qui en résultent comme étant les conséquences d'un déplacement de terrain qui sont évaluées en fonction du nombre d'accidents et de l'importance des dommages immobiliers par unité de surface au cours d'une année. Il a divisé les estimations du risque séismique en trois catégories, soit à long, à moyen et à court terme et déclaré que, selon le degré de prudence voulu, on pourrait établir dans chaque cas un ensemble de spécifications pour la conception technique des bâtiments. Plus le niveau de prudence est élevé, plus les méthodes d'évaluation des bâtiments et des villes doivent être perfectionnées afin de minimiser les pertes de vie. La prévision des risques à long terme entraîne évidemment la mise en œuvre de codes du bâtiment et la planification de l'utilisation des terres. Actuellement, la prévision des risques à court terme est, au mieux, une opération très incertaine à cause du manque de théories qui décrivent de façon satisfaisante le processus des tremblements de terre. Par ailleurs, M. Berry a souligné que nous ne pouvions, au Canada, effectuer des prévisions à moyen terme. La méthode de prévision des risques à long terme est passablement bien implantée au Canada et on a établi une carte des risques séismiques qui assure un bon fondement pour la mise au point d'un code rationnel du bâtiment.

M. Jessop a divisé en trois parties les études géothermiques effectuées au Canada: la géothermie fondamentale, le potentiel d'énergie géothermique et les aspects thermiques du pergélisol. On effectue depuis plus de 30 ans des études géothermiques au Canada. Les objectifs ont été de mesurer et d'interpréter le flux et la production de chaleur au pays dans le contexte du régime structural de la tectonique du territoire. Les études sur l'énergie géothermique sont assez récentes au Canada. Ce démarrage plutôt tardif, par rapport aux autres pays, dépend sans doute de l'existence d'approvisionnements jusqu'ici abondants en d'autres formes d'énergie. Le pergélisol est un phénomène particulier aux pays de l'Arctique. Les aspects thermiques du pergélisol ont pris de l'importance au cours des dernières années à cause du comportement des matériaux gelés près des pipe-lines, des puits de pétrole, des bâtiments, etc. M. Jessop a mentionné qu'à certains endroits, le pergélisol atteint plus de 600 mètres dans le nord du Canada.

M. Lambert a décrit la façon dont diverses mesures géophysiques sont combinées au Canada pour l'étude de la déformation de la croûte terrestre. Même si aucun organisme n'est chargé de l'exécution d'un programme national d'étude de la stabilité de la croûte terrestre, il y a toutefois au Canada un effort concerté d'élaboration d'un programme qui ferait appel à la participation du plus grand nombre possible d'organismes gouvernementaux dans certains domaines problématiques précis. Il a signalé qu'il y avait un manque évident de coordination des

travaux réalisés dans la région de la côte Ouest qui est intéressante du point de vue de la tectonique, mais que l'on prenait des mesures pour rectifier la situation. M. Lambert a ajouté qu'il serait possible de réaliser des progrès sans faire appel à de grandes innovations techniques dans le domaine des instruments scientifiques et a mentionné que la plupart des appareils dont il a fait état dans son exposé sont vendus sur le marché. Il a aussi indiqué qu'il était possible d'utiliser, pour les études sur la stabilité de la croûte terrestre, de nombreuses données compilées pour d'autres fins. Compte tenu de ces conditions, il a indiqué qu'il suffisait souvent de déterminer les régions intéressantes du point de vue de la géophysique pour disposer d'un vaste éventail de données.

M. Simkin a présenté un exposé sur les volcans de l'Amérique latine. Dans sa communication, il a tenu compte de trois aspects de la situation: a) l'évaluation à l'échelon régional de la fréquence ou de la probabilité des éruptions, b) la description des dangers présentés par les volcans et c) les divers moyens qui permettent à l'homme d'affronter ces dangers. Même s'il est impossible d'empêcher une éruption, M. Simkin a souligné que l'on peut faire beaucoup pour évaluer le moment et la violence des éruptions. Ce travail repose sur la mise en place d'un bon système de communication et M. Simkin a déclaré qu'à son avis, l'IPGH pourrait fournir son appui à cette fin. Les historiens peuvent établir l'historique des éruptions, les séismologues peuvent surveiller les régions volcaniques et signaler aux géologues les éruptions éventuelles, les géodésiens peuvent compiler des données sur les déplacements et les géologues peuvent compiler des « cartes de risques », etc. Selon M. Simkin, la compilation des données fournies par les experts de ces diverses disciplines permettrait d'en arriver à une compréhension approfondie de la répartition et du moment des éruptions volcaniques pour le plus grand avantage des pays de l'Amérique latine.

M. Harlow a décrit un système de surveillance des volcans qui est actuellement utilisé. Il s'agit d'un appareil d'enregistrement automatique des activités séismiques et d'un inclinomètre relié par satellite à une station centrale capable d'évaluer les données enregistrées afin de prévoir les éruptions volcaniques. Il a indiqué que les essais effectués au Guatemala sur la première version du système avaient été tellement encourageants que l'on en mettait actuellement une deuxième au point. Même si les coûts d'équipement initiaux peuvent être considérables, l'efficacité du système évaluée en fonction des économies de main-d'œuvre les justifiera amplement. Grâce aux ressources de cet équipement, M. Harlow croit que les scientifiques seront plus en mesure de prévoir les éruptions.

Résumé de la quatrième séance
Les objectifs et la méthodologie de certains programmes nord-américains

M. Darnley énonce les raisons pour lesquelles la recherche en matière d'exploration minérale doit être menée au sein du gouvernement. Après avoir parlé du genre de recherches qui doivent être faites, il a présenté un modèle d'organisation de cette recherche. À son avis, il est essentiel que le gouvernement participe davantage aux activités de prospection afin de s'assurer que les programmes mis en œuvre à cette fin sont de nature à satisfaire les besoins du pays, d'autant plus que, de nos jours, le rapport des nouvelles ressources découvertes aux dépenses engagées à cette fin va probablement décroissant. Il fait valoir que les pratiques actuelles permettent aux compagnies privées de garder confidentielles certaines informations précieuses sous prétexte que leur divulgation porterait préjudice à leur position concurrentielle. Il s'est dit d'avis que ces habitudes allaient à l'encontre des intérêts de la société, ajoutant que ce serait servir l'intérêt public que de divulguer ces renseignements aux organismes du gouvernement, de manière à leur donner les outils nécessaires pour mener à bien les études qui les conduiront à l'élaboration de la politique nationale et à la mise au point de nouvelles techniques de recherche minérale. Poursuivant dans la même veine, M. Darnley a exposé sa conception d'une organisation idéale, celle qui confierait au gouvernement la direction des programmes de recherches. En dernière partie de son allocution, il a décrit les projets de recherche actuellement exécutés au sein de la Commission géologique du Canada dans le domaine de la géophysique.

M. Lindseth a qualifié la science de la géophysique pétrolière de « microgéophysique », du fait qu'elle étudie dans les moindres détails la mince couche sédimentaire de la surface du globe. La méthode séismique constitue à cet égard l'outil privilégié car elle permet aux chercheurs d'obtenir de la structure du sous-sol la représentation détaillée dont ils ont besoin pour mener à bien un programme de recherche pétrolière. D'autres méthodes géophysiques sont utilisées, quoique moins fréquemment; encore servent-elles le plus souvent à des fins de recherches préliminaires. Puis, il a identifié les deux innovations qui, à son avis, ont fait le plus progresser la prospection séismique: l'enregistrement reproductible et le traitement numérique. M. Lindseth s'est ensuite inscrit en faux contre la suggestion de M. Darnley selon laquelle il faudrait concentrer davantage l'activité d'exploration au sein d'un organisme gouvernemental. Selon lui, l'histoire et l'expérience nous enseignent que cette approche est nettement moins efficace que l'approche pluridisciplinaire et plus créative que l'on obtient naturellement lorsqu'un certain nombre d'organismes ou de sociétés privées se trouvent en situation de concurrence. Il a ajouté que, même si, dans toute situation donnée, il y avait des gagnants et des perdants, les exigences implacables de la concurrence obligeaient les organismes à passer au problème suivant, sans avoir le temps de se lamenter publiquement de leurs échecs. C'est à cet environnement sain, poursuit-il, que peut être attribuée une bonne part du succès remporté par le Canada dans le domaine pétrolier.

Au début de son exposé, M. Pemberton a énuméré les faits nouveaux qui sont survenus dans l'industrie privée au chapitre de la recherche minérale, déclarant que cette industrie intervenait pour près de 9% dans le PNB du Canada et pour environ un tiers dans ses exportations. Compte tenu de cet apport économique, il a déploré la dégradation des relations qui existaient autrefois entre le gouvernement et l'industrie. Il est absolument indispensable, à son avis, que le gouvernement permette à l'industrie de conserver une part équitable des revenus, de manière à encourager les entreprises minières à réinvestir leurs bénéfices et à consolider davantage l'industrie. M. Pemberton rappelle ensuite les nombreuses innovations tant dans l'instrumentation que dans la méthodologie dont l'industrie canadienne de la recherche s'est fait le promoteur. La mise au point des nouvelles techniques dans ce domaine a été motivée dans une large mesure par la complexité de l'entreprise. En effet, les cibles sont variées et les découvertes exigent que l'on change de méthode d'une cible à l'autre et d'une région à l'autre. Loin d'être simples, les techniques d'interprétation font place, en dernière analyse, à un jugement personnel qui fait de la prospection autant un art qu'une science.

M. Ballard présente un compte rendu de l'étude de l'élévation Cayman qui se trouve dans la partie centrale de la dépression du même nom. La première phase du programme de recherche a consisté à mener, dans la région, une expédition géophysique et hydrographique à plusieurs paramètres; on y a recueilli une information détaillée en vue d'études ultérieures. Puis, en 1976, une étude par navire de surface et une autre par submersible ont été menées concurremment dans le fossé d'effondrement de l'élévation ainsi que sur ses pentes. D'excellentes photographies ont été prises de certaines parties du détail à l'aide d'appareils montés sur le submersible et d'autres descendus du navire jusque sur le fond océanique. Les chercheurs ont ramené une très belle collection d'échantillons, notamment quelques basaltes très frais qui s'écaillaient et se fendillaient sur le pont du navire après qu'on les eut extrait. M. Ballard a signalé que trois autres expéditions allaient être mises en œuvre en 1977 et 1978. La première mettra en jeu le submersible ALVIN qui a été utilisé au cours de la deuxième expédition. Ensuite, le bathyscaphe TRIESTE II effectuera une série de plongées dans le fossé d'effondrement. Enfin, au début de 1978, les chercheurs procéderont à une étude séismique approfondie de la dépression en employant les appareils de sondage séismique multi-canaux et à grand pouvoir séparateur, mis au point récemment.

Résumé de la cinquième séance
Systèmes informatisés en géophysique

M. McConnell a décrit la base de données nationales sur la gravimétrie qu'a constituée la Direction de la physique du globe du ministère de l'Énergie, des Mines et des Ressources, à Ottawa. Cette banque d'information sert à emmagasiner et à recouvrer des données gravimétriques que le Ministère a lui-même recueillies ou qui ont été fournies par d'autres organismes gouvernementaux, des universités ainsi que l'industrie de la recherche pétrolière et minérale. La base de données renferme également, sous forme numérique, l'information et la documentation qui décrivent le réseau international de normalisation gravimétrique (1971) et le réseau gravimétrique d'Amérique latine; cette base de données est mise à la disposition de la Commission gravimétrique internationale et de la Commission géophysique de l'IPGH en même temps que des services scientifiques et techniques. Dans le cadre de son exposé, M. McConnell a également décrit l'organisation et le contenu de la base de données, en la mettant en relation avec les programmes informatiques utilisés pour réduire, éditer, stocker, mettre à jour, recouvrer et tracer les données gravimétriques.

M. Salgueiro a souligné l'importance du travail dont a parlé M. McConnell en ce qui concerne la création de bases de données en Amérique latine et l'échange d'idées et de renseignements au sein de la Commission géophysique.

M. Wilcox a décrit la bibliothèque de données gravimétriques du *Department of Defense* des États-Unis et présenté des cartes gravimétriques et topographiques régionales de l'Amérique du Sud. Le fichier du ministère américain de la Défense renferme maintenant les résultats des quelque 11 millions de mesures gravimétriques distinctes. De ce nombre, environ 6 millions de mesures sont stockées sur bandes magnétiques et forment ce qu'il est convenu d'appeler le fichier *Gravity Point Anomaly* qui sert de base à l'emmagasinage et au retrait automatique des données à l'intérieur de la bibliothèque du ministère. Les 5 millions d'observations qui restent sont rangées dans un fichier de réserve qui, celui-là, n'est pas automatisé. À cette base de données, s'ajoutent des fichiers d'index-auteurs, de stations, d'anomalies moyennes, d'altitudes moyennes et de cartes gravimétriques. En outre, le fichier gravimétrique peut reproduire l'information dans une variété de formats, notamment sur des cartes spéciales. M. Wilcox a ensuite donné une description des quatre cartes (structures régionales, altitudes moyennes, anomalies de Bouguer et anomalies à l'air libre) qu'il avait compilées à l'intention des participants à la réunion. Les cartes de l'altitude et de la pesanteur ont été compilées à l'aide de valeurs moyennes de 1° x 1°, celle des structures régionales ayant pour but de faciliter l'interprétation des cartes gravimétriques.

Commentant le document de M. Wilcox, M. Guevara a rendu compte du travail gravimétrique et géologique accompli au Honduras et mis en évidence le besoin de spécialistes pour le traitement du fort volume de données produites. M. Salgueiro a exprimé son désir de tirer avantage des systèmes de données et des programmes qu'ont décrits MM. Wilcox et McConnell et formulé le souhait de voir en Amérique latine un seul et unique centre d'informatique pour données gravimétriques.

M. Svendsen a décrit le *World Data Centre System* et plus particulièrement le *World Data Centre A* situé à Boulder, au Colorado. Ce dernier dessert un grand nombre de disciplines dans les domaines de la physique solaire-terrestre et de la géophysique de la lithosphère. Il a fait observer que les performances réalisées dans les diverses disciplines dépendaient du nombre de données recueillies et que, dans certains cas, la cueillette des données ne faisait que commencer. Il s'est dit d'avis que le plus grand exploit avait été accompli dans le domaine du géomagnétisme. En effet, le centre de données reçoit et emmagasine des données dans un large éventail de formats; les chercheurs s'efforcent actuellement de mettre sous forme la majeure partie des données bien que, à cause du volume considérable de renseignements recueillis jusqu'à maintenant, la méthode n'est nullement parfaite. Diffusées à des clients de toutes les parties du globe, les données peuvent revêtir de nombreuses formes; les microcopies d'enregistrements analogiques (par exemple des magnétogrammes) sont de loin les formats les plus en demande. M. Svendsen a également souligné l'excellente collaboration que le *World Data Centre A* a reçue des pays latino-américains.

M. Callahan a parlé de l'Organisation météorologique mondiale et plus particulièrement de la partie du réseau qui concerne l'Amérique latine. L'OMM exploite des systèmes de communication très complexes, capables de transmettre de vastes quantités d'observations météorologiques à des centres régionaux et internationaux qui en font la synthèse et l'analyse, et publient des prévisions météorologiques plusieurs fois par jour. Le réseau de l'Amérique latine et des Caraïbes est vaste et en perpétuelle évolution. Actuellement, au-delà de 1 000 stations fournissent des relevés au sol, tandis que les observations aériennes s'effectuent à plus de 100 stations. Nombre de ces postes sont équipés du système de transmission radio FAX qui permet l'acheminement de photographies et d'autres données visuelles.

M. Lachapelle a présenté pour sa part une méthode réunissant des formules de rangement par les moindres carrés et des formules intégrales (Stokes et Vening Meinesz), qui sert à prévoir les déviations de la verticale et les ondulations du géoïde en se basant sur un ensemble de coefficients géopotentiels, notamment GEM8 et sur les données gravimétriques recueillies en surface. Il a comparé les déviations prévues aux valeurs astrogéodésiques correspondantes pour certains points au Canada et a obtenu une très

bonne concordance: les différences, exprimées en moyenne quadratique, étant de 1,26″ et 1,48″ respectivement. Il a comparé les ondulations calculées à l'aide du modèle GEM8 aux valeurs obtenues par satellites à effet doppler, et il a obtenu une différence de moyenne quadratique de 2,62 m. Puis, comparant des valeurs calculées à l'aide d'un modèle obtenu suivant GEM8 combiné avec les données gravimétriques de surface à celui provenant des élévations géoïdiques déduites par l'effet doppler, il a obtenu un écart quadratique moyen de 3,77 m. M. Lachapelle a fait remarquer que ce résultat étonnant inclut probablement des écarts systématiques qui se rencontrent dans les régions de la Cordillère de l'Ouest de l'Amérique du Nord. Si l'on fait abstraction des points de cette région, la différence de moyennes quadratiques est réduite à 2,74 m et 2,67 m pour les modèles gravimétrique GEM8 et géoïdique GEM8 respectivement. Ces différences, dit-il en guise de conclusion, témoignent de la couverture gravimétrique relativement pauvre de l'Ouest Canadien.

Résumé de la sixième séance
Systèmes informatisés en géophysique

M. Mazzini a parlé d'un programme que le Service hydrographique naval a mené en collaboration avec l'université de Buenos Aires, en 1973, et qui a pour but d'étudier les variations séculaires de la pesanteur dans les Andes.

Trois coupes ont été faites: le nord, le centre et le sud. Les chercheurs ont recueilli des données dans ces coupes, identifié leurs caractéristiques générales et procédé à l'interprétation des résultats obtenus. M. Mazzini a émis l'opinion selon laquelle les écarts entre les résultats obtenus en 1973 au moyen des indicateurs de LaCoste et Romberg et les mesures prises antérieurement sont probablement attribuables à des erreurs d'étalonnage dans l'appareil Worden 51 dont on s'était servi au cours des études précédentes.

Commentant le document de M. Mazzini, M. Ocola a fait état d'un projet de même nature actuellement réalisé au Pérou. M. Mazzini et lui ont mis en relief la nécessité de bien connaître les caractéristiques des instruments et d'identifier comme il se doit les stations que l'on réoccupe. M. Woollard a dit douter que des erreurs d'étalonnage aient été à l'origine des variations de la pesanteur. Selon lui, les variations observées peuvent être mises en corrélation avec des modifications de la structure du socle et, partant, des modèles tectoniques différents.

M. Monges a signalé aux membres de l'assemblée que des études sur les variations séculaires de la pesanteur étaient actuellement en cours au Mexique et le long de profils en Amérique centrale et en Amérique du Sud. À Mexico, on a observé une variation de la pesanteur de 0,065 mgal par année. Au Guatemala, on a pu réoccuper des stations à la suite du récent tremblement de terre et relever des changements gravimétriques appréciables. Ces résultats ont incité des chercheurs à procéder à de nouvelles mesures dans les régions du Mexique sujettes aux tremblements de terre. En Amérique du Sud, les mesures de la pesanteur prises en divers endroits ont indiqué une variation totale de 0,15 à 0,33 mgal entre 1961 et 1973.

Au cours de la discussion qui a suivi l'exposé de M. Monges, M. Argenal a demandé si l'on pouvait de quelque façon que ce soit mettre en relation la variation séculaire de la pesanteur et le drainage de la vallée centrale du Mexique. Aucune corrélation n'a été mise en évidence. M. Woollard a alors réaffirmé sa position selon laquelle ces variations de la pesanteur seraient véritablement séculaires. À l'appui de sa thèse, il a mentionné les rattachements gravimétriques au Mexique et aux États-Unis. Il a conclu son exposé en affirmant que la gravité constitue un moyen peu coûteux de vérifier, avant même le renivellement, si des mouvements verticaux se sont bel et bien produits dans une région donnée.

M. Guevara a demandé si l'on avait relevé une différence de gravité au Honduras après le séisme du Guatemala. La réponse a été négative.

M. Shea a donné les grandes lignes du système d'échange de données dont on se sert en physique solaire-terrestre; il s'agit du système du centre mondial des données. Depuis l'Année géophysique internationale, a été mis sur pied, à l'échelle internationale, un vaste système d'information et d'échange de données. Les scientifiques peuvent utiliser les renseignements de deux façons, selon qu'ils contribuent ou non à l'enregistrement de la base de données. Ceux qui y contribuent peuvent retirer gratuitement des données dont la valeur équivaut à celle des renseignements qu'ils ont déposés. Les autres doivent assumer les frais de reproduction que représente le retrait. C'est grâce à ce centre qu'ont pu être prévues des tempêtes solaires qui perturbent les télécommunications. Les chercheurs sont à étudier les effets possibles des activités et des cycles solaires sur nos systèmes météorologiques.

M. Smart a présenté un court exposé sur la physique solaire-terrestre et les phénomènes associés aux protons émis par le soleil. Il a fait observer que nombre de pays latino-américains ne sont pas très au fait de ces manifestations, car le champ magnétique terrestre limite l'émission des particules solaires aux régions polaires. M. Smart a mis en relief l'absence de techniques permettant de prévoir les irruptions chromosphériques même une heure ou deux à l'avance. En revanche, une fois qu'une éruption s'est produite, les observateurs disposent de certains programmes informatiques très vastes et complexes, à l'aide desquels ils peuvent prévoir les propriétés des radiations émises dans les diverses gammes de rayonnement pendant plusieurs jours après l'éruption. L'information obtenue a une variété d'applications, notamment dans le domaine des communications radio; elle permet aussi de prédire les effets possibles du rayonnement solaire à court et à long terme sur les systèmes météorologiques ou climatiques. M. Smart a également annoncé la rédaction, à l'intention de l'Amérique latine, d'un manuel spécial qui renferme les paramètres géophysiques de base nécessaires à la recherche dans de nombreuses disciplines de la physique solaire-terrestre. Ce manuel devrait être publié en 1977.

M. Giesecke, Directeur de CERESIS, a mis en évidence le caractère particulier des données séismiques, ajoutant qu'il était nécessaire que le public puisse avoir accès rapidement à l'information séismique après des tremblements de terre, et que l'on puisse évaluer les risques séismiques. À cet égard, de nombreux centres d'information régionaux valent mieux qu'un service centralisé. Ces centres d'information doivent tenir le dossier séismique à jour et diffuser les informations en éliminant les longs délais que l'on connaît actuellement. Jusqu'à maintenant, peu de documents ont été publiés à ce sujet. Des études préliminaires révèlent que les centres mondiaux des données manquent de 20 à 25% des manifestations séismiques enregistrées. Appuyant sur l'aspect international des données séismiques, M. Giesecke a fait observer que le libre échange de l'information favorisait les relations entre les pays. Puis, il a précisé que le fait que tous les réseaux ne fonc-

tionnent pas 24 heures par jour pose des problèmes de communication. En effet, certains d'entre eux sont situés dans des régions éloignées et les employés n'y travaillent qu'à titre temporaire. Les bulletins d'information se sont avérés très utiles en tant que dossiers permanents, mais nombre d'observatoires n'en ont diffusé aucun. Il a également parlé de la nécessité de normaliser la conversion numérique des accélérogrammes de données.

Au cours de la discussion qui a fait suite à l'exposé de M. Giesecke, M. Salgueiro s'est dit d'avis que toutes les études séismiques devraient être intégrées dans un système d'information séismologique d'Amérique latine (SILAS). La mise sur pied d'un tel système devrait revenir à la CERESIS qui, de l'avis de M. Salgueiro, a reçu un appui suffisant des pays membres.

Résumé de la septième séance
Étude et revue des programmes et des priorités de la Commission géophysique

M. Mazzini, ingénieur, a brièvement discuté du projet intitulé « Profil sud-américain des mesures des marées terrestres » qui débuterait par un programme de formation dont l'exécution est prévue à Tucuman en octobre 1977. Il a demandé d'appuyer ce projet qui est conjointement parrainé par l'Observatoire royal de Belgique et l'Université de Tucuman (Argentine).

M. Brussoni, ingénieur, a passé en revue l'évolution de la géophysique en Uruguay. Entre 1948 et 1958, le gouvernement de ce pays a exécuté un important programme de forage et d'études gravimétriques destinés à déterminer la structure du socle. Vers 1954, 26 000 stations gravimétriques étaient installées; le Service géographique de l'armée a publié les premières cartes géomagnétiques et, en collaboration avec l'Université nationale de Buenos Aires, il a mis au point un réseau national de mesures gravimétriques. L'IPGH a appuyé la publication de cartes et de données gravimétriques. Depuis 1966, on effectue des observations séismiques et magnétiques sur le plateau continental. L'installation d'un réseau de mesures séismologiques est sur le point d'être terminée et des cours universitaires réguliers en géophysique se donnent depuis deux ans. M. Brussoni a aussi signalé que l'on essaie de retrouver les enregistrements séismiques effectués entre 1887 et 1940.

À la lumière de l'étude qu'il a faite des autres systèmes appliqués dans le monde, M. Salgueiro, ingénieur, a exposé les facteurs dont il faudrait tenir compte au moment d'établir un système intégré d'informations géoscientifiques (SIGEO) qui permettrait d'enregistrer et de rechercher les résultats des études effectuées sur les océans et les continents. Le système doit posséder une structure relativement souple qui permettrait de tenir compte des problèmes liés à la taxonomie, à la transformation, à l'entreposage, à la recherche, à la transformation, à la présentation et à la publication de données géophysiques concernant les Amériques du Nord et du Sud.

M. Argenal, ingénieur, a signalé qu'un réseau de mesures séismiques est en opération au Nicaragua depuis mai 1975 et que les résultats obtenus ont servi à déterminer les zones séismiques et à élaborer un code du bâtiment. Grâce à la collaboration des autres pays, le réseau de mesures séismiques pour l'ensemble de l'Amérique Centrale devrait fonctionner d'ici un ou deux ans. Il a en outre indiqué qu'il était impérieux de considérer les problèmes liés au traitement du grand nombre de données qui seront obtenues.

M. Guevara, ingénieur, a indiqué que l'on avait effectué peu de mesures gravimétriques au Honduras avant 1956 mais qu'un réseau de mesures gravimétriques de base a été créé depuis 1969. Les travaux effectués jusqu'en 1969 dans le domaine du magnétisme ont servi à produire, entre 1970 et 1974, des cartes magnétiques terrestres et isogoniques. On a publié en 1974 une carte géologique provisoire du Honduras. Il a enfin indiqué qu'une carte gravimétrique provisoire sera mise au point et fournira les données de base pour les prochaines études géologiques du pays.

Le père Ramírez a discuté d'un certain nombre de projets géophysiques en Colombie. Le premier est un projet exécuté conjointement par l'Institut de géophysique de l'Université de Javerina et l'Université du Wisconsin en vue d'étudier la structure des Andes occidentales colombiennes, zone séismique la plus active en Amérique du Sud. Le deuxième projet a trait à la publication de données géologiques et géophysiques recueillies au moyen des systèmes automatiques de documentation qui ont été étudiés par le groupe de géodynamique à Acapulco (Mexique) du 14 au 16 juin 1976. Quant au troisième projet, il s'agissait des profils de réflexion séismique marine et des mesures magnétiques effectuées au nord de la côte de la Colombie au cours d'une étude réalisée conjointement avec l'Institut français du Pétrole en avril 1976. D'autres projets mentionnés comprennent la poursuite du projet Narino de 1973, lequel porte sur des études pétrographiques qui ont été effectuées dans les Cordillères centrales et occidentales de la Colombie par l'Université de Glessen (Allemagne) en 1976. Des études de sédiments volcaniques de la partie est de l'océan Pacifique, au large de la Colombie, et des mouvements orogéniques de l'ère tertiaire de la Colombie, ont été publiées en 1975. De février à septembre 1976, une étude des variations géomagnétiques et de la conductivité électrique des régions situées à l'ouest de la Colombie a été effectuée en collaboration avec le Carnegie Institute de Washington. Les bulletins habituels font état de la surveillance séismique du volcan Galeras et le cheminement géophysique entre les 6e et 7e degrés de latitude Nord a été intensifié par l'installation de nouvelles stations magnétiques et gravimétriques en 1975. Une carte isogonique de 1975 de la Colombie est en voie de préparation. Voici les autres renseignements plus généraux qu'il a fourni: une nouvelle carte métallogénique de la Colombie a été publiée; la mise au point d'une nouvelle carte géologique sera terminée en 1976; et les États-Unis avaient publié, en 1975 et 1976, des cartes géophysiques et des ouvrages sur la région des Caraïbes; la brochure de vulgarisation sur les tremblements de terre, préparée par l'Institut de géophysique des Andes colombiennes à l'intention de l'IPGH, était prête à être distribuée en 1975.

M. Llinas, ingénieur, a signalé qu'à cause du grand tremblement de terre de 1946 et des grands projets de constructions entrepris récemment dans la République Dominicaine, il fallait incessamment étudier les risques séismiques, mettre au point un code du bâtiment et établir un réseau de mesures séismiques. Il a indiqué qu'on avait proposé officiellement d'installer un réseau de 3 ou 4 stations, dont le nombre pourra être augmenté par la suite. Il a enfin indiqué que le manque de cartes géologiques sûres nuit à l'interprétation des données gravimétriques.

M. Ocola a distribué des exemplaires du rapport sur la séismologie, la gravimétrie et le magnétisme du Pérou; c'est l'Institut de géophysique du Pérou qui l'a préparé et distribué. Il est d'avis que l'évaluation des risques séismiques est le principal problème auquel doivent faire face les pays de l'Amérique cen-

trale et du Sud. La théorie de l'évaluation des risques séismiques que l'on a adoptée est fondée sur la méthode de Cornell, laquelle exige une bonne connaissance de l'activité séismique et de la technologie d'une région. On a maintenant terminé la mise au point d'une carte des risques séismiques de l'Amérique du Sud. Il a signalé un problème particulier posé par la description de grands tremblements de terre simultanés et de longue durée pour lesquels la définition ordinaire de la magnitude est inadéquate. Il a aussi décrit un catalogue destiné à éliminer les événements indépendants des tremblements secondaires aux grands tremblements de terre.

M. Fonseca a fait part des rapports qu'il a rédigés en collaboration avec MM. V. Grateron, M. A. Lopez Mussa et E. Gajardo au sujet de la gravimétrie, du magnétisme et de la séismologie au Venezuela. Puis, il a exposé à grands traits l'historique de la recherche gravimétrique dans ce pays et de la mise en place du réseau gravimétrique national qui vient d'être compensé grâce au programme SILAG. En ce qui concerne la carte des anomalies de Bouguer, il a signalé qu'en plus des mesures au sol, certaines données recueillies par des sociétés pétrolières pour la région de la mer des Caraïbes ont été intégrées dans la série de données même si elles n'ont pas été rattachées au continent. D'autres mesures viendront compléter la couverture gravimétrique. Pour dresser la carte correspondante des anomalies à l'air libre, on a utilisé des lectures gravimétriques prises à des intervalles de 4 km pour fins géodésiques. La carte des anomalies de Bouguer doit être publiée en 1976 à une échelle de 1/500 000.

Les cartes magnétiques du Venezuela sont rééditées à tous les 5 ans depuis 1955. Après avoir eu beaucoup de mal à trouver un endroit propice, on effectue actuellement des essais à Pozo Hondo où l'on espère mettre sur pied un observatoire magnétique national au cours de la prochaine année. Des cartes aéromagnétiques et radiométriques ont également été dressées pour certaines régions. M. Fonseca a signalé que le réseau national de stations séismiques transmet quotidiennement des enregistrements à l'Institut séismologique de Caracas qui publie, chaque mois, des bulletins et une carte séismiques du pays. La fondation au Venezuela pour la recherche séismique, établie en 1972, mène actuellement des études de risques séismiques pour l'ensemble de l'OEA en collaboration avec des organisations américaines et sud-américaines. D'autres réseaux d'instruments séismiques sont en voie d'établissement et des études sont réalisées par le personnel de FUNVISIS et des étudiants en génie géophysique.

M. Feininger a décrit la carte des anomalies de Bouguer de l'Équateur, dressée à partir de quelque 14 000 observations faites depuis 25 ans. Parlant des variations du champ de Bouguer dans le contexte des quatre grandes provinces physiographiques de l'Équateur, il a fait observer que la variation totale du champ de la pesanteur entre la plus faible valeur observée (−300 mgal dans la province de la Sierra) et la valeur la plus élevée (+160 mgal dans la province de la Costa) était supérieure à 450 mgal. Il a associé les anomalies positives de Bouguer observées dans la région de la Costa à la présence de la formation Pinon qui se compose principalement de basalte et de diabase avec intrusions peu fréquentes de gabbro et de péridotite. Quant aux anomalies négatives de la région de la Sierra, elles sont essentiellement attribuables aux racines profondes sous les Andes.

M. L. Sebert a décrit la cartographie comme l'un des instruments les plus utiles à la géophysique; il a indiqué qu'un certain nombre de projets cartographiques au sein de l'IPGH avaient un rapport immédiat avec les études géophysiques menées en Amérique latine, se reportant à la carte géologique de l'Amérique du Sud à une échelle de 1/2 500 000 et à la carte tectonique de l'Amérique du Sud à une échelle de 1/5 000 000. En ce qui concerne cette dernière discipline, il a qualifié de décevants les progrès réalisés jusqu'à maintenant, attribuant cet échec à un manque de fonds en dépit des efforts déployés par plusieurs personnes pour obtenir un appui financier, même partiel, par l'entremise de l'IPGH. Au nombre des projets pris en main par le Comité des cartes spéciales que préside M. Sebert, figurent la création et l'expansion de cartothèques en Amérique latine et les publications d'atlas nationaux et régionaux. Il a signalé qu'un colloque sur les atlas serait tenu dans environ deux ans. En guise de conclusion, il a formulé des propositions en vue d'obtenir un appui financier pour l'établissement de la carte tectonique de l'Amérique du Sud et la création des cartothèques.

M. Jordan a glissé quelques mots sur les divers projets et programmes qui ont été mis en œuvre pour faciliter l'échange de données dans le domaine de la séismologie et, se basant sur les résultats obtenus, il a proposé des améliorations futures à cette méthode d'information. Au sujet du *National Earthquake Information Service* administré par le *Geological Survey* des États-Unis, il a mis en relief les efforts volontaires qui ont été déployés à l'échelle mondiale et qui ont abouti à la mise au point d'une méthode efficace pour déterminer les épicentres de tremblements de terre. Il a néanmoins fait observer que les renseignements en provenance de l'Amérique latine ne circulent pas d'une manière qui permette de mettre en œuvre des études modernes de séismicité. Il a proposé que l'on mène des efforts concertés en vue d'améliorer les réseaux de communication et d'accroître le nombre de stations. Il a parlé d'un certain nombre d'améliorations qui pourraient être apportées au NEIS, appuyant sur l'amélioration des techniques d'enregistrement automatique, des systèmes de traitement des données et l'utilisation possible de satellites.

Au cours de la discussion qui a suivi, M. Radicella a recommandé qu'une proposition soit formulée en vue de promouvoir la formation dans le cadre du programme pendant les quatre prochaines années. M. Kausel a signalé que l'IPGH s'occupait d'ores et déjà de formation et que la publication de nouveaux journaux ne serait pas souhaitable étant donné que *Revista geofisica,* pourtant disponible, ne reçoit que très peu d'articles. Puis, les propos de M. Sáenz sont venus corroborer la nécessité d'obtenir des Latino-américains de plus nombreux articles à paraître dans les publications établies de l'Institut. Le Père Ramírez a décrit une expérience qui a été réalisée dans la transmission des données au moyen de photocopies d'articles sur la tectonique. M. Salgueiro a proposé que l'on se serve de la publication *Investigating the Earth* en essayant d'y intégrer la documentation latino-américaine, et que l'on se partage l'utilisation des observatoires en place et des méthodes actuellement employées pour échanger l'information. M. Llinas a souligné l'importance des bourses d'études, question que M. Kausel a lui aussi élaborée, et de la formation de futurs géophysiciens dès les cours primaire et secondaire en se servant de textes appropriés. Il appartiendrait alors à l'IPGH de déterminer qui a besoin de bourses d'études. M. Llinas a insisté une fois de plus sur le besoin des bourses d'études au niveau universitaire pour la formation des ingénieurs en géologie et en géophysique. M. Salgueiro a fait observer que des cours spécialisés en vue d'un baccalauréat se donnaient déjà à l'université du Chili, quoique l'IPGH pourrait

offrir des bourses d'études universitaires comme l'a proposé M. Giesecke. M. Kausel a fait remarquer que le programme d'enseignement de l'OAS a rarement servi à la formation de géophysiciens; ainsi, l'Institut pan-américain devrait-il faire figure de promoteur en encourageant la géophysique à des niveaux supérieurs. M. Sáenz a alors demandé si l'enseignement prodigué aux opérateurs en gravimétrie et en séismologie se comparait avantageusement aux cours offerts par l'École de cartographie à Panama. Énumérant certaines lacunes des spécialistes de l'observation gravimétrique, M. Monges a insisté pour que l'on mette sur pied un cours de formation et que l'on rédige un manuel. M. Llinas s'est dit satisfait du programme de formation que M. Kausel avait exposé et a insisté sur la nécessité de faire progresser les cours dans ce domaine à tous les niveaux d'enseignement. M. Guevara s'est lui aussi prononcé en faveur de l'enseignement de la géophysique tant aux niveaux élémentaires qu'aux niveaux supérieurs. M. Argenal a pour sa part réclamé une large diffusion de l'information sur les bourses d'études. M. Radicella a présenté une proposition pour que la Commission élabore un programme coordonné de formation technique et scientifique, et pour que celui-ci soit intégré dans le programme de la Commission pour 1977-1981. M. Salgueiro a ajouté qu'il serait souhaitable de mentionner également les publications, notamment celles que la Commission a entre les mains mais qui ne sont pas encore publiées. M. Sáenz a fait observer que le manuel mentionné par M. Salgueiro est actuellement publié dans *Geofisica*. En réponse à une question de M. Sáenz, M. Radicella a précisé que les cours de formation offerts aux observateurs devraient être indiqués en toute lettre dans la proposition et que le mot « information » devrait couvrir le sujet soulevé par M. Salgueiro. La proposition a été acceptée.

M. Kausel, à qui revenait la tâche de clôturer la réunion, a remercié tous ceux qui avaient participé à l'organisation et à la tenue du colloque.

Résumé de la huitième séance
Table ronde sur les programmes et les priorités de la Commission géophysique

M. Kausel a tout d'abord fait référence à la réunion des autorités de la Commission géophysique qui a eu lieu à Lima; les objectifs qui avaient été établis ont servi de base à la discussion qui a suivi. La discussion a été divisée en six thèmes et, pour chacun d'eux, on a choisi un orateur. Une période de discussion a suivi la présentation de chacun des thèmes. À la suite du premier exposé, *Principaux thèmes de recherche*, les présidents des trois comités ont pris la parole à tour de rôle.

M. Radicella, président du Comité sur la physique solaire-terrestre, a parlé des ressources naturelles, présentant la Terre comme un véhicule spacial pourvu de ressources limitées mais d'une population croissante. Selon lui, l'atmosphère excerce une influence dominante sur l'écologie et les activités humaines. Trop peu d'études ont été menées sur les climats en Amérique latine pour permettre la prévision des récoltes. Il importe en effet d'étudier les conséquences des régions à forte densité de population sur le climat, dont les effets de la population en tant que telle, ainsi que l'état des communications en Amérique latine, notamment l'utilisation de satellites et de techniques micro-ondes.

M. Cabezas, président du Comité des océans et atmosphères, a parlé de l'étude des courants marins exceptionnels qui circulent sur la côte pacifique de l'Amérique du Sud et de ses effets sérieux sur l'économie des pays adjacents. Un projet est en voie de réalisation au Pérou et s'étendra aux îles Galapagos. M. Cabezas a également dit quelques mots au sujet de la réunion qui doit se tenir à Montevideo.

Enfin, le président du Comité de la lithosphère, le Père Ramírez, a dit pourquoi son comité avait choisi les risques séismiques comme principal thème de recherche et a mis en évidence la nécessité de dresser des cartes des épicentres et des mouvements terrestres en vue de l'établissement des codes du bâtiment.

Dans son exposé, M. Guevara a mis l'accent sur la séismicité. M. Ocola a pour sa part mis en relief la contribution des études gravimétriques et géomagnétiques à la recherche fondamentale menée en vue de l'évaluation des risques séismiques. M. Salgueiro a indiqué qu'il était nécessaire que l'on entreprenne, au plus tôt, la mise sur pied d'un réseau d'information intégré, à l'intention des disciplines géoscientifiques. M. Argenal a soutenu l'importance des études géomagnétiques aériennes en ce qu'elles permettent d'obtenir rapidement une couverture de presque toute l'Amérique du Sud. M. Malavassi a souligné la nécessité de compléter des projets en cours et l'importance de se pencher sur des problèmes pratiques tels que la construction paraséismique et les courants océaniques. En réponse à M. Salgueiro, M. Sáenz a examiné la manière dont les fonds de la Commission sont répartis équitablement.

De ces discussions, ont pu être dégagés les principaux thèmes de recherche pour les quatre prochaines années; on a aussi réaffirmé le besoin d'un appui en faveur des systèmes de données, des cartes thématiques et de la formation.

M. Kausel a présenté le deuxième sujet au programme, *Mécanismes de sélection et de contrôle*, et a exposé les grandes lignes des méthodes qui devraient être utilisées pour soumettre des projets à l'IPGH par l'entremise de la Commission géophysique, au moyen de la formule révisée actuelle.

Au cours de la discussion, M. Godoy a insisté sur l'importance de l'historique des projets comme critères d'évaluation. M. Radicella s'est dit d'accord avec M. Godoy, ajoutant que le compte rendu des enquêteurs devrait lui aussi être inclus dans l'évaluation.

M. Kausel a entamé la présentation du troisième thème qui consistait à déterminer si la géologie devrait constituer un comité distinct de la Commission géophysique. Répondant à M. Feininger, M. Kausel a indiqué que le Comité de la gravimétrie et des marées terrestres faisaient partie de la Commission de cartographie pour des raisons conventionnelles, mais qu'aucun projet n'était en cours dans ce domaine. M. Sáenz a indiqué que ce comité était fusionné avec celui de la géodésie. M. Malavassi s'est pour sa part rallié à l'idée d'un comité de géologie, tandis que M. Fonseca a déploré l'absence d'une représentation de la tectonophysique et de la volcanologie. M. Ocola s'est dit opposé à toute nouvelle subdivision de la Commission. En réponse à M. Geller qui a fait valoir la nécessité d'une meilleure administration des ressources disponibles par l'entremise de l'IPGH, M. Ocola a soutenu que l'augmentation du nombre de comités s'accompagnerait d'une hausse des coûts de la Commission. M. Fonseca a convenu que l'information géologique pourrait être intégrée dans les comités actuels. M. Kausel, donnant la réplique à M. Ocola, a allégué que la géophysique était depuis toujours distincte de la géologie et que nombre d'arguments pourraient soutenir la thèse d'une Commission géologique. M. Graterol a approuvé la création d'un comité géologique qui, selon lui, faciliterait les études de risques séismiques et l'interprétation des cartes des anomalies de

Bouguer. MM. Monges et Fonseca ont fait savoir qu'ils s'opposeraient à la formation d'un comité géologique si les géologues entendaient par là constituer une commission distincte. M. Mazzini a insisté sur les problèmes de dualité qui se poseraient au sein de l'IPGH si un comité géologique était formé. M. Kausel a émis l'idée selon laquelle un géologue pourrait être nommé à la vice-présidence de la Commission et travailler de concert avec les présidents de comités. La création d'une Commission géoscientifique a également été proposée comme solution; toutefois, cette option poserait encore plus de problèmes. MM. Woollard et Salgueiro ont soutenu que la création d'autres comités ne ferait que disperser l'organisation.

Votant sur la question, les participants ont rejeté en majorité la proposition visant à créer un comité géologique.

Mme Shea a présenté le quatrième sujet à l'ordre du jour: les centres d'information sur les données. Dans le cadre de son exposé, elle a allégué que l'absence de centres de données nationaux ou régionaux en Amérique latine rendait difficile le développement de la recherche géophysique dans ces pays parce que, si diverses bases de données ont été constituées par disciplines, il n'existe en Amérique latine aucune installation centrale convenablement située où puissent être traitées les données de nature globale ou régionale. En outre, elle a exprimé l'avis qu'une certaine stagnation se manifestait au niveau de la cueillette de données comme telle, car il n'existait aucun mécanisme qui permette aux usagers de contribuer à l'enrichissement du fichier. À son avis, l'Amérique latine remédierait peut-être à cette pénurie si elle mettait en service, à petite échelle, des centres ou des instituts où une grande collection d'enregistrements existe déjà. Ce travail pourrait s'effectuer discipline par discipline, chaque centre ayant une compétence particulière. En guise de conclusion, elle a énuméré les diverses normes à respecter en termes d'espace, de personnel, etc., pour l'établissement d'un petit centre de données.

Dans la discussion qui a suivi, M. Woollard a exposé ce qu'il en coûterait pour administrer un bon centre de données et en extraire de l'information. Il a précisé qu'il était difficile d'obtenir des fonds, ajoutant qu'aux États-Unis, aucun organisme ne s'occupait de financer un tel projet. M. Radicella s'est dit d'accord avec M. Woollard et a affirmé qu'il fallait chercher à concentrer les données au niveau régional, puis à les rassembler au niveau national. M. Tanner a renchéri sur les propos de M. Woollard en rappelant aux participants les coûts d'établissement du *World Data Centre A*, et a proposé que l'on débute modestement en réunissant des index de couverture des données. Le Père Ramírez a donné des exemples illustrant l'excellente réaction qu'a enregistrée son institut en ce qui concerne leurs listes et index de référence qui ont été publiées. M. Salgueiro a indiqué que la Commission devrait s'employer en premier lieu à étudier dans son ensemble l'état actuel des systèmes d'information en Amérique latine et la nécessité de mettre sur pied des centres régionaux de données. En réponse à M. Woollard, M. Svendsen a indiqué que les centres régionaux posaient un gros problème de mise à jour des données. M. Woollard a convenu avec lui qu'il était difficile d'optimiser le rendement des centres régionaux. En intervention, M. Ocola s'est exprimé en faveur des centres d'envergure nationale proposés par M. Salgueiro, et a émis l'opinion que tous les pays devraient disposer d'un système d'information normalisé, et que la tâche de le mettre sur pied devrait être entreprise sur le champs. Mme Shea a fait état des problèmes liés à la communication, alléguant qu'il était difficile de déterminer quelles données existent déjà. M. Giesecke a pour sa part fait observer que l'OAS finance déjà la mise sur pied des centres d'information scientifique et technologique. En réponse à M. Kausel, il a également parlé des principaux problèmes auxquels s'est heurté CERESIS, tels que la circulation irrégulière des rapports séismiques. M. Radicella a alors formulé une proposition en faveur d'un inventaire des données géophysiques. M. Brussoni a avancé l'idée de faire participer l'industrie à la création des centres de données. Mme Shea a mentionné que le NSF pourrait constituer une source de contribution supplémentaire. M. Cabezas a indiqué qu'à la lumière de l'expérience vécue par le Comité océanographique, le manque de fonds avait pour effet d'empêcher la mise sur pied de centres de données.

Aux propos de M. Salgueiro selon lesquels l'établissement d'inventaires devrait incomber aux sections nationales qui œuvrent dans des domaines spécialisés, M. Giesecke a ajouté que l'on aurait avantage à utiliser l'expérience que les divers conseils nationaux ont acquise dans la cueillette des données. M. Tanner s'est prononcé en faveur de l'établissement d'index dans un premier temps. M. Radicella a signalé la possibilité d'organiser un colloque ou un atelier avec le concours du NSF; cette proposition a été soumise au Comité des résolutions. M. Woollard a fait savoir que le NSF était en mesure de contribuer à l'organisation d'un atelier.

Le cinquième thème à l'étude, *les cartes thématiques*, a été présenté par M. Tanner qui a proposé qu'un membre de la Commission géophysique soit appelé à faire partie d'un comité spécial des cartes thématiques, au sein de la Commission cartographique. M. Sáenz a parlé des diverses façons de coordonner les travaux des différentes commissions.

Chargé de présenter le sixième projet au programme, *la formation*, M. Giesecke a analysé le concept de formation en fonction des différents niveaux d'éducation. Il a mis en relief la nécessité de diffuser davantage de renseignements par le truchement des publications en espagnol, visant surtout les journaux qui traitent de la pratique de la géophysique (par exemple, des études de la séismicité induites par réservoirs), dans la double perspective d'informer les populations d'Amérique latine et de promouvoir la participation des spécialistes étrangers. Selon M. Giesecke, il est essentiel que les établissements de recherche latino-américains procèdent à des échanges de géophysiciens et que l'on multiplie les occasions à cette fin par l'entremise de l'IPGH. À son avis, il faudrait viser à une utilisation régionale maximale des installations en place en Amérique latine. Enfin, il a qualifié de hautement bénéfiques les cours que l'institut panaméricain a organisés, tels que le cours de gravité, le cours de lecture d'ionogrammes, le cours d'utilisation des séismographes.

Resumen de la primera sesión
Ceremonia de apertura

El Dr. Blanchette, Presidente de la Sección Nacional y Embajador canadiense ante la Organización de Estados Americanos, inauguró oficialmente el simposio dando la bienvenida a los delegados en Ottawa. En su alocución, señaló que éste era el 7mo. seminario que Canadá celebraba en una de las disciplinas del IPGH (Instituto Panamericano de Geografía e Historia). Luego procedió a describir la estructura del IPGH y las actividades de sus cuatro comisiones mediante las cuales el IPGH proporciona una gama de actividades relativas a la difusión de conocimientos en América Latina y presta ayuda a las naciones en diversos aspectos de sus programas nacionales.

El Dr. Whitham, Director-General de la Dirección de Física Terrestre, dió la bienvenida a los delegados en nombre del Ministerio de Energía, Minas y Recursos, de Ottawa, Canadá. Describió la estrecha colaboración que su organismo mantenía con el IPGH desde hacía unos 15 años, lo que motivó la participación canadiense en el establecimiento de la Red de Normalización de la Gravedad en América Latina. El Dr. Whitham luego se refirió a los cambios de actitudes de la sociedad respecto a la ciencia, especialmente la geofísica; hizo notar, concretamente, el mayor énfasis puesto sobre la investigación orientada hacia la obra de misión, particularmente en el campo de los estudios ambientales. Finalmente, señaló que los organizadores han tratado de desarrollar un programa bien acabado con objeto de ofrecer una perspectiva equilibrada de las contribuciones aportadas a la geofísica por los científicos empleados por el gobierno, universidades y compañías de prospección privadas.

El Ing. Sáenz, Secretario General del IPGH, esbozó la historia y estructura del IPGH, sus relaciones con la OEA y el modo de operación de la Comisión de Geofísica dentro del IPGH. El instituto coordina y promueve estudios en las diversas disciplinas mediante programas desarrollados y revisados cada cuatro años. Era necesario ahora iniciar el desarrollo de programas para el período 1977-1981. Formuló la esperanza de que el simposio produciría un plan maestro para la Comisión de Geofísica que atendiese en particular los problemas de los países menos adelantados en geofísica. El Ing. Sáenz transmitió el agradecimiento de la Comisión a todos los que estuvieron a cargo de organizar el simposio.

El profesor Garland debatió en su charla temática la extensa participación social y económica que tuvo y tendrá la geofísica en la sociedad. La primera parte de su charla se concentró en las razones históricas del desarrollo de numerosas disciplinas bien conocidas actualmente en geofísica. Al describir la participación actual de la geofísica en los problemas humanos, sociales y económicos, examinó temas tales como los movimientos relativamente lentos de la corteza terrestre, fenómenos sísmicos, inclusive la zonificación, los avisos de alerta respecto a los tsunami, sismicidad inducida y pronóstico, fenómenos volcánicos, problemas energéticos, y problemas relativos a los minerales, petróleo y al ambiente. Luego describió la contribución de la geofísica en las cuestiones actuales dentro de estos sectores de problemas y concluyó subrayando la importancia de la cooperación internacional en geofísica haciendo mención del importante papel desempeñado por la Unión Internacional de Geodesia y Geofísica en los asuntos mundiales poniendo énfasis en la necesidad constante de una activa contribución por parte de la misma, así como de otras organizaciones tales como el IPGH.

El profesor Radicella señaló que el profesor Garland no discutió asuntos relativos a la investigación oceanográfica y atmosférica, tema que esperaba ocuparía a los participantes de la conferencia durante los últimos días de la semana.

Resumen de la segunda sesión antecedentes

El Dr. Kausel, Presidente de la Comisión Geofísica, esbozó brevemente la actividad geofísica realizada en la América Latina e hizo notar el nivel de actividad alcanzado por disciplinas tales como meteorología, geología y geofísica prospectiva. La gravimetría ha prosperado gracias al interés de instituciones geográficas, pero este campo todavía requiere más estudio en lo que se refiere a la interpretación de los resultados. En sismología, destacó la obra de CERESIS, pero puso de relieve la necesidad de capacitar a personal en este campo, dada la importancia de los estudios relativos a los riesgos de movimientos sísmicos, la necesidad de mejorar las comunicaciones respecto a los eventos sismícos y la necesidad de elaborar métodos para pronosticar la actividad sísmica, campo que todavía esta en su infancia. Discutió brevemente algunas investigaciones que se estaban llevando a cabo en América Latina, aunque estimaba que el número de investigadores que trabajaban en América Latina es reducido. Señaló la urgente necesidad de la capacitación y subrayó que deberá mejorarse la infraestructura del personal que opera a nivel medio, así como incrementar el número de investigadores. Si tenemos en cuenta las contribuciones a la bibliografía geofísica, la cantidad relativa de la investigación llevada a cabo en la América Latina es desproporcionadamente baja. Subrayó, finalmente, la necesidad de mejorar los sistemas de información geofísica.

Al discutir la presentación del Dr. Kausel, los Ingenieros Giesecke y Brussoni señalaron que, en vista de que los investigadores latinoamericanos tardan en hacer conocer los resultados de sus investigaciones, todavía falta publicar gran cantidad de información.

El profesor Woollard presentó un panorama muy variado del estado de la investigación geofísica en América Latina. En su exposición, relacionó la investigación con el progreso de la explotación de recursos naturales, problemas sociales y económicos, utilización de tierras y problemas científicos. Se describió a América Latina como un continente rico en recursos. Como tal, una de las funciones más fructíferas de la investigación es tratar de comprender la explotación de sus depósitos de minerales. Con una zona principal de subducción situada en la costa este de América Latina, esta vasta región es obviamente una de las principales áreas del mundo en que se realiza dicha investigación geofísica. Los peligros naturales, tales como volcanes y terremotos, constituyen en numerosas regiones de América Latina un gran motivo de preocupación. La investigación geológica y geofísica (sismológica) se ha concentrado en desarrollar un banco de datos adecuado con miras a comprender la ocurrencia de estos fenómenos en el contexto del tipo tectónico existente en América Latina es una región de densas selvas y montañas escarpadas, el Dr. Woollard subrayó que el uso de la tierra debía ser encarado con previsión e hizo notar que los programas geofísicos destinados a fomentar un inventario de tierras bien fundado han sido modestos hasta la fecha. Finalmente, señaló que quedan miles de problemas fundamentales por resolver en América Latina. Son muchas las perspectivas, pero lamentablemente los geofísicos demasiado escasos. Dicha investigación será, sin duda, extremadamente importante a largo plazo para el desarrollo energético, la prospección de minerales y los problemas ambientales y sociales.

El Dr. Lomnitz habló con franqueza sobre educación en geofísica en América Latina, subrayando que las opiniones emitidas eran las suyas propias y no las de cualquier otra organización o individuo. Hizo una reseña del desarrollo de la educación universitaria en América Latina desde sus orígenes cuando se limitaba primordialmente al ejercicio de la medicina, el derecho y la ingeniería, a través de su visión más enfáticamente política de mediados de los años 1900 hasta el reciente énfasis puesto sobre la educación en las profesiones no científicas dentro de las universidades privadas. Luego señaló que en una sociedad

donde los dirigentes se vuelven cada vez más conscientes de la importancia de los científicos dedicados a las ciencias geofísicas, la carencia de profesionales capacitados coloca a América Latina en un estado de dependencia lamentable respecto a científicos extranjeros. En consecuencia, afirmó, se necesita un nuevo estímulo, un estímulo que debe venir desde dentro si se quiere encontrar una solución satisfactoria a los problemas sociales y económicos de largo alcance que involucran a las ciencias geofísicas. Como un ejemplo, el Dr. Lomnitz citó el proyecto RESMAK en México, que ha conducido al desarrollo de una extensa red de estaciones sísmicas ligada por un sistema telemétrico que atraviesa toda la nación, cuyo diseño básico y gran parte de la tecnología nacieron en México. Por más importante que sea este desarrollo, señaló que se necesita mucho más ayuda de las grandes corporaciones y que es imperioso desarrollar la actividad de las sociedades profesionales latinoamericanas.

El Sr. Tanguay describió el programa de desarrollo de la ACDI en América Latina como uno que está dirigido para proporcionar un ambiente mejor, así como un mejor uso de los recursos renovables. Señaló que alrededor del 12% del presupuesto de la ACDI está destinado a la América Latina con un gasto total de aproximadamente 60 millones de dólares anuales repartidos en unos 100 proyectos. Con mucho, la mayor proporción de éstos está dirigida hacia la agricultura (50), pero otros campos incluyen educación (25), salud (15), infraestructura social (3), y transporte (3). También señaló que aproximadamente 50 proyectos se encuentran en la etapa de planificación. Indicó que los proyectos dentro de la gama de las ciencias geofísicas han tenido lugar en los campos de detección remota y prospección de minerales en varios países, pero en vista de la obvia necesidad de desarrollo en los campos de la agricultura, etc., la ciencias geofísicas no pueden recibir la alta prioridad que se podría esperar.

El ingeniero Salgueiro y el profesor Radicella señalaron la necesidad de descubrir nuevas formas de cooperación científica que tomen en cuenta el nivel de conocimientos técnicos y realidades de los países involucrados. Ambos consideraban que se debía dar prioridad a la educación en todo programa de desarrollo.

El Sr. Feller presentó una lista de proyectos por países que se llevarían a cabo bajo el programa científico de cooperación latinoamericana cuyo objeto es ayudar a los científicos estadunidenses que desean ampliar sus programas nacionales de investigación cooperando con colegas de América Latina y las Antillas. Las actividades involucradas incluyen investigación cooperativa en ciencias básicas o aplicadas, seminarios orientados hacia la investigación y visitas científicas para el desarrollo de programas o proyectos a corto plazo. La lista de proyectos actualmente en marcha en ciencias geofísicas es impresionante y cubre virtualmente todos los aspectos del campo. El número de instituciones estadunidense involucradas es cuantioso y procede de la mayoría de las regiones del país. El Sr. Feller también hizo notar que la geofísica marina está bien representada en el programa y que se han patrocinado viajes de reconocimiento en varios buques de investigación en aguas adyacentes a América Latina.

Respondiendo a una pregunta del Ingeniero Malavassi, el Sr. Feller esbozó los medios a través de los cuales el NSF podía ayudar a un país latinoamericano a organizar un curso en geofísica ayudando a los investigadores americanos involucrados en proyectos mixtos con miembros de la universidad pertinente.

Resumen de la tercera sesión
Objetivos y metodología de programas norteamericanos seleccionados

El Dr. Vaníček presentó una ponencia sobre la interrelación de la geodesia y la geofísica. Su ponencia presumía al auditoria familiarizado con la geofísica, pero no con la geodesia. Durante su exposición dividió la geodesia en tres partes: Posicionamiento, campo gravitatorio terrestre y variaciones temporales en posición y campo gravitatorio. Las posiciones (horizontal y vertical) de puntos sobre la superficie terrestre pueden ser determinadas o bien mediante la agrimensura o las técnicas por satélite. Cada técnica tiene sus ventajas, pero en general, los métodos de base terrestre producen mejores resultados en distancias cortas (es decir, algunas decenas de kilómetros), mientras que las técnicas por satélite son claramente superiores en distancias del orden de los mil kilómetros. El conocimiento del campo de gravedad tiene numerosos usos en geodesia y su aplicación principal es quizás la determinación de la desviación de la vertical y la forma del geoide. Las variaciones temporales de posición y gravedad constituyen parámetros importantes de la geodinámica contemporánea. El Dr. Vanícek subrayó que en ninguna parte es evidencia más dramáticamente la relación simbiótica entre geodesia y geofísica que en este punto y que esto conducirá a una mayor cooperación entre geodestas y geofísicos.

El Dr. Gibb describió el Servicio Gravimétrico de Canadá dirigido por la Dirección de Gravitación y Geodinámica de la Dirección de Física Terrestre, Ottawa. El objetivo primordial del Servicio es el de completar un croquis de reconocimiento gravimétrico junto con observaciones sobre la gravedad a intervalos de hasta 15 km o menos. Esbozó brevemente la historia de las mediciones gravimétricas en el Canadá, comenzando con las primeras mediciones de péndulo, y concluyendo con una descripción del programa moderno notablemente acelarado. Informó que aproximadamente 80% de la masa continental, plataformas continentales y mares continentales de Canadá han sido estudiados mediante cuatro técnicas de reconocimiento básicas: terrestre, superficie de hielo, subterránea y superficie del mar, que requieren diferentes medios de transporte y una variedad de instrumentos que satisfagan las especificaciones del programa cartográfico nacional. Asimismo describió la norma de referencia para observaciones de gravedad relativa realizadas en Canadá que han sido convertidas recientemente a la Red de Normalización Internacional de Gravedad de 1971 (IGSN71). La Red de Gravedad Nacional de Canadá está conectada a 20 estaciones de IGSN71 ubicadas en Canadá. Finalmente señaló que, desde enero de 1976, los principales hechos de las 345.000 gravimétricas se almacenaron en el Banco Nacional de Datos de Gravedad de Ottawa, del que se puede recuperar información en una variedad de formatos. El Servicio gravimétrico publica una serie de Mapas Gravimétricos (escala 1:500.000) y los datos son emitidos en el momento oportuno mediante el sistema de archivo abierto de la Dirección de Física Terrestre.

El Dr. Niblett afirmó que la geografía de Canadá ha proporcionado una oportunidad excepcional a los canadienses en la investigación del geo-magnetismo, porque el país contiene el polo magnético norte y forma el mejor laboratorio natural del mundo para estudiar la actividad geomagnética y la estructura de la magnetosfera en las regiones aurorales y polares. Reseñó brevemente las primeras observaciones y logros realizados por marinos e ingenieros del ejército británico durante el siglo XIX respecto al establecimiento de la red canadiense de observatorios

magnéticos y del desarrollo de estudios geomagnéticos en el contexto nacional. El Dr. Niblett describió la investigación geomagnética realizada en Canadá bajo los siguientes capítulos: observatorios magnéticos, estudios geomagnéticos y cartas magnéticas, paleomagnetismo y magnetismo rocoso, inducción electromagnética y estudios teóricos. Aunque el núcleo de su charla se refería a las actividades realizadas en la Dirección de Física Terrestre, se hizo también mención de actividades llevadas a cabo en otras instituciones de Canadá. Entre los hechos salientes descritos por el Dr. Niblett podemos mencionar las anomalías de conductividad inusualmente altas en el Artico y Canadá occidental, es estudio de las posiciones del polo Precámbrico y las trayectorias del desplazamiento del polo terrestre, el reconocimiento magnético aéreo de Canadá realizado a baja altura y los reconocimientos aéreos a gran altura con fines de tabulación.

El Dr. Berry señaló que la mayoría de los terremotos ocurren al borde de las placas litosféricas y que una porción significativa son intensos y dañinos. Por consiguiente, una de las razones principales para estudiar la sismicidad es el peligro de movimiento sísmico que definió como la probabilidad que ocurra cierto grado de movimiento terrestre sísmico durante un período específico, para luego definir el riesgo de movimiento sísmico como las consecuencias del movimiento terrestre medido en términos de pérdidas y daños a la propriedad por unidad de áerea y por año. Dividió los cálculos del período de movimiento sísmico en períodos a largo, intermedio y breve plazo para los cuales, según el grado de conservación deseado, se podía establecer un conjunto de especificaciones en términos del diseño de construcción. Cuanto más elevado sea el grado de conservación, tanto más sofisticados serán los métodos de evaluación de los edificios y ciudades con objeto de minimizar las pérdidas de vidas humanas. El pronóstico de riesgo o peligro a largo plazo implica claramente la puesta en ejecución de códigos de edificación y planificación del uso de la tierra. Actualmente el pronóstico a corto plazo es, a lo sumo, un proceso muy incierto por carecerse de teorías suficientes para definir el proceso del temblor de tierra de modo que los modelos sobre los cuales se basa el pronóstico puedan establecerse con arreglo a un grado razonable de certeza. De manera análoga, señaló el Dr. Berry, en Canadá no somos capaces de hacer pronósticos intermedios. El proceso de predicción a largo plazo está razonablemente establecido en Canadá y se ha trazado un mapa de riesgos que proporciona una buena base para un código de construcción razonable.

El Dr. Jessop dividió los estudios geotérmicos en Canadá en tres partes: geotérmica fundamental, potencial de energía geotérmica y aspectos térmicos del gelisuelo. La geotérmica fundamental se ha venido realizando en Canadá durante más de treinta años. Sus objetivos han sido medir el flujo calorífico y la generación de calor a través de Canadá y su interpretación en el contexto del régimen estructural tectónico canadiense. Los estudios de energía geotérmica son relativamente recientes en Canadá. Esta aparición tardía, comparada a la de los otros países, es probablemente una manifestación de la hasta ahora abundante provisión de otras formas de energía. El gelisuelo es un fenómeno peculiar en los países del Artico. Los aspectos térmicos del gelisuelo han tomado importancia en los últimos años debido al comportamiento de los materiales congelados cerca de los gasoductos, pozos de petróleo, edificios, etc. El Dr. Jessop señaló que hay lugares en el norte de Canadá donde la extensión del gelisuelo sobrepasa los 600 m.

El Dr. Lambert describió la manera en que se combinan diversas mediciones geofísicas en Canadá para estudiar la deformación de la corteza terrestre. Aunque no exista un programa nacional de estudio de estabilidad de la corteza centrado en un organismo único, con todo, ha habido un esfuerzo concertado en Canadá para desarrollar un programa mediante la participación de cuantos organismos gubernamentales diferentes sea posible en ciertos sectores específicos de problemas. Hizo notar que una deficiencia notable es la carencia de esfuerzo coordinado en el área costera del oeste tectónicamente interesante, pero que actualmente se están tomando medidas para corregir esta situación. Indicó que es posible realizar progresos sin recurrir a adelantos técnicos importantes en la instrumentación, afirmando que la mayoría de los instrumentos mencionados en su charla están disponibles comercialmente. Asimismo, hizo notar que un volumen considerable de datos recolectados para otros propósitos pueden utilizarse para estudios de estabilidad de la corteza. Dadas estas condiciones, indicó, a menudo sólo es necesario identificar las regiones de interés geofísico para asegurar que se dispondrá de una amplia gama de datos.

El Dr. Simkin presentó una ponencia sobre los volcanes de América Latina. En su exposición debate planteó tres aspectos de la situación: a) evaluación de la frecuencia regional o posibilidad de las erupciones; b) descripción de los peligros debidos a los volcanes, y c) las diversas maneras en que el hombre puede solucionar estos riesgos. Aunque las erupciones no pueden evitarse, el Dr. Simkin señaló que se puede hacer mucho para evaluar lo que se puede esperar de un volcán y cuándo esperarlo. Esto depende de buenas comunicaciones y el Dr. Simkin indicó que a su parecer el IPGH podría ayudar en este sentido. Los historiadores pueden compilar historias de erupciones, los sismólogos pueden controlar o verificar las regiones volcánicas y alertar a los geólogos respecto a posibles erupciones, los geodestas pueden compilar datos sobre movimientos, los geólogos pueden compilar "mapas de riesgos" de terremoto, y así sucesivamente. Al compilar la información suministrada por los expertos de estas disciplinas, el Dr. Simkin cree que podríamos lograr una mejor compresión de la distribución y ocurrencia de las erupciones volcánicas con grandes beneficios para la América Latina.

El Dr. Harlow describió un "Sistema de vigilancia para volcanes". Este sistema consiste en un registrador automático del movimiento sísmico y de un inclinómetro conectado por satélite a una estación central capaz de evaluar los datos registrados con el fin de pronosticar la ocurrencia de las erupciones volcánicas. Afirmó que las pruebas de la primera versión del sistema en Guatemala han sido estimulantes, al punto de que se está construyendo una segunda versión. Aunque el gasto de capital inicial pueda ser cuantioso, la eficiencia del sistema en terminos de utilización de mano de obra justificará fácilmente los costos básicos. Con la capacidad de este equipo, opinó el Dr. Harlow, que los científicos estan en una situación mucho más privilegiada respecto al pronóstico de la ocurrencia de las erupciones.

Resumen de la cuarta sesión
Objetivos y metodología de programas norteamericanos seleccionados

El Dr. Darnley habló de las razones de la necesidad de que la investigación de la prospección minera sea realizada por el gobierno. En su presentación también discutió el tipo de investigación que debe realizarse y presentó un modelo para organizar esa in-

vestigación. El Dr. Darnley afirmó que en su punto de vista era esencial que el gobierno tuviera una participación mucho mayor en las exploraciones para asegurar que los programas de exploración tengan por objeto satisfacer las necesidades nacionales, en un período en que la proporción de nuevos recursos respecto al consumo esta probablemente disminuyendo. Señaló que las prácticas actuales permiten a las compañías privadas guardar información confidencial valiosa ya que de otro modo perjudicarían su posición competitiva. El Dr. Darnley consideraba que esto no era en el mejor interés de la sociedad, argumentando que se estaría mejor servido poniéndose los datos a disposición de los organismos gubernamentales; de este modo aumentarían su capacidad de llevar a cabo los estudios necesarios para desarrollar políticas nacionales y nuevas técnicas de exploración minera. El Dr. Darnley prosiguió describiendo su concepción de una organización ideal que suministrase al gobierno el liderato necesario para dirigir los programas de exploración. En la última parte de su charla describió los trabajos de investigación geofísica realizados actualmente por la Dirección de Levantamiento Geológico de Canadá.

El Sr. Lindseth describió la ciencia de la geofísica petrolera como una "microgeofísica" que trataba de los detalles más intrincados dentro de la delgada capa sedimentario de la superficie de la tierra. El instrumento preferido es el método sísmico por su capacidad de proporcionar un cuadro claro de la estructura detallada necesaria para un programa de prospección petrolera exitoso. Se utilizan, aunque menos frecuentemente, otros métodos, y a menudo, sólo con fines de reconocimiento. Luego pasó a describir los dos adelantos principales que en su opinión condujeron a todas las demás mejoras en la exploración sísmica: la elaboración de registros reproducibles y la elaboración numérica de datos. El Sr. Lindseth entonces objetó vivamente a la sugerencia hecha por el Dr. Darnley de que el esfuerzo de la exploración se concentre en un organismo gubernamental, afirmando que la historia y la experiencia han demostrado que este enfoque es mucho menos eficaz que un enfoque multifacético y de mayor creatividad que surge naturalmente de situaciones competitivas que involucran a varias organizaciones o compañías privadas. Señaló que aunque haya ganadores y perdedores en una situación determinada, las inexorables demandas de la competencia fuerzan a las organizaciones a seguir adelante y pasar al problema siguiente sin agonizar públicamente sobre lo que pudo haber fallado. Este ambiente positivo, afirmó, ha sido en gran parte la causa del éxito de Canadá en el campo petrolero.

El Sr. Pemberton comenzó su exposición sobre los desarrollos en la industria privada respecto a la exploración minera diciendo que la industria representaba casi 9% del PNB de Canadá y cerca de un tercio de sus exportaciones. Con estos datos de entrada, expresó su pesar por la pérdida de las relaciones que existían anteriormente entre gobierno e industria. Señaló que es absolutamente esencial que el gobierno deje a la industria una porción justa de las recompensas con objeto de estimular a las compañías mineras a reinvertir sus ganancias para construir una industria todavía más sólida. Además, el Sr. Pemberton señaló los numerosos desarrollos en materia de instrumentación y metodología que han sido los precursores de la industria de la prospección en Canadá. Esta metodología ha sido promovida, en gran medida, por la naturaleza compleja del sector. Los objetivos son variados y los descubrimientos requieren métodos que difieren de una meta a otra y de una región a otra. Las técnicas de interpretación están lejos de ser simples y en última instancia están sujetas a juicios individuales que en muchos sentidos hacen que la exploración sea tanto un "arte" como una "ciencia".

El Dr. Ballard hizo una reseña del estudio sobre la inclinación o levantamiento del "Caimán medio en la parte central del pliegue sinclinal del Caimán". La primera fase de investigación del programa involucraba un viaje de reconocimiento geofísico multiparamétrico e hidrográfico en la región, lo que proporcionaría información detallada para estudios posteriores. Más tarde, en 1976, se realizó un estudio de campo, combinando el reconocimiento por barco de superficie y submarino, dentro del valle de la dislocación del levantamiento y de sus pendientes laterales. Se tomaron excelentes fotografías de porciones de la característica tanto desde el submarino como desde cámaras sumergidas desde el buque hasta el fondo del mar. Se recolectó una excelente serie de muestras incluso algunos basaltos frescos que rebotaron y se partieron sobre la cubierta del buque después de su recuperación. El Dr. Barrard informó que se estaban haciendo planes para añadir otros tres levantamientos adicionales durante 1977 y 1978. El primero implicaría al submarino ALVIN utilizado en el segundo viaje de exploración y después el batiscafo TRIESTE II realizaría una serie de inmersiones en el valle de dislocación. Finalmente, el tercer viaje de reconocimiento a comienzos de 1978 implicaría un estudio sísmico detallado del pliegue sinclinal utilizando equipo de perfilado sísmico multicanálico de alta resolución fabricado recientemente.

Resumen de la quinta sesión
Sistemas de información en geofísica

El Sr. McConnell describió el Banco Nacional de Datos de Gravedad de la Dirección de Física Terrestre del Ministerio de Energía, Minas y Recursos, Ottawa, que proporciona servicios de almacenamiento y recuperación para los datos de gravedad adquiridos directamente por el Ministerio o contribuidos por otros organismos gubernamentales, universidades y la industria de exploración petrolera y minera. El banco de datos también incluye la información numérica y documentación describiendo la Red Internacional de Normalización de la Gravedad-1971 y la Red de Gravedad Latinoamericana, administrada conjuntamente con los servicios científicos y técnicos suministrados a la Comisión Internacional de Gravedad y la Comisión Geofísica del IPGH. En su presentación, el Sr. McConnell también describió la organización y contenidos del banco de datos y su interacción con los sistemas de programación utilizados para reducir, editar, almacenar, actualizar, recuperar y determinar los datos referentes a la gravedad.

El ingeniero Salgueiro subrayó la importancia del trabajo descrito por el Sr. McConnell para el establecimiento de los bancos de datos en América Latina y el intercambio de ideas e información en el seno de la Comisión Geofísica.

El Dr. Wilcox describió la Biblioteca de Gravedad del Ministerio de Defensa de los Estados Unidos y presentó los mapas regionales de gravedad y topográficos para la América del Sur. El archivo de gravedad del Ministerio de Defensa contiene actualmente los resultados de unos once millones de mediciones distintas de la gravedad. De éstas, unos seis millones están almacenadas en cintas magnéticas en un archivo automatizado que lleva el nombre de Anomalía del Punto de Gravedad que sirve como la base al almacenamiento automatizado y recuperación de datos de la Biblioteca de Gravedad del Ministerio de Defensa. Los cinco millones de observaciones restantes se mantienen en un archivo no automatizado de contingencia. Otros archivos de la

biblioteca están clasificados por índice de autores, estación base, anomalía media, elevación media y mapa gravimétrico. La biblioteca tiene capacidad para producir información en una variedad de formatos, incluyendo mapas de graficación especiales. El Dr. Wilcox pasó entonces a describir los cuatro mapas (estructura regional, elevación media, Bouguer y aire libre) que había compilado a tiempo para ser presentados durante la reunión. Los mapas de elevación y gravedad fueron compilados de valores promedios 1° x 1°. El mapa de estructura regional fue compilado para asistir en la interpretación de los mapas gravimétricos. Durante el curso de la ponencia del Dr. Wilcox, el Ingeniero Guevara describió el trabajo gravimétrico y geológico realizado en Honduras y la necesidad de que el gran volumen de datos sea manejado por expertos. El Ingeniero Salgueiro expresó su deseo de aprovechar el sistema de datos y la programación descrita por los Sres. Wilcox y McConnell y la conveniencia de tener un solo centro común de computación de datos gravimétricos en América Latina.

El Sr. Svendsen describió el Sistema del Centro Mundial de Datos refiriéndose particularmente al Centro Mundial de Datos A, ubicado en Boulder, Colorado. Este centro presta servicios a gran número de disciplinas en los campos de la física solar-terrestre y la geofísica de la litosfera. Expuso que el grado de éxito alcanzado en las diversas disciplinas era variable y que en algunos casos la recolección de datos recién acababa de comenzar. Opinó que, en conjunto, el mejor papel se había alcanzado en el campo del geomagnetismo. El centro de datos recibe y almacena los datos en una amplia variedad de formatos y se está tratando de editar la mayoría de los datos, aunque con un volumen tan grande el proceso está lejos de haber alcanzado la perfección. Los datos son distribuidos a los clientes de todas partes del mundo en una amplia gama de formatos. La mayor demanda es de copias de microfilm de registros analógicos (por ejemplo, magnetogramas). El Sr. Svendsen también se refirió a la excelente cooperación que recibió el Centro Muncial de Datos A de los países latinoamericanos.

El Sr. Callahan describió la Organización Meteorológica Mundial refiriéndose especialmente a la porción de la red que involucraba a América Latina. La OMM opera un completo sistema de comunicaciones capaz de transmitir enormes cantidades de observaciones meteorológicas a centros regionales y mundiales para su análisis y síntesis, con objeto de proporcionar pronósticos de tiempo varias veces al día. La red en América Latina y las Antillas es extensa y va mejorando constantemente. La red tiene actualmente más de mil estaciones encargadas de hacer observaciones en tierra y más de cien que toman observaciones estratosféricas. Muchas de las estaciones están equipadas actualmente con radiotransmisores FAX que permiten el envío de fotografías y otros formatos de datos visuales.

El Dr. Lachapelle presentó un método combinado de colocación mínimo-cuadrático y fórmulas integrales (de Stokes y Vening Meinesz) utilizado para pronosticar desviaciones de la vertical y ondulaciones geoides sobre la base de un conjunto de coeficientes geopotenciales, llamadas, GEM8 y de datos de superficie de gravedad. Comparó las desviaciones pronosticadas con los valores astrogeodésicos correspondientes para los puntos en Canadá y encontró que concordaban perfectamente siendo las diferencias rms de 1,26″ y de 1,48″, respectivamente. Comparó las ondulaciones pronosticadas computadas utilizando el modelo GEM8 con los valores derivados del efecto doppler por satélite y encontró que la diferencia rms era de 2,62 m. Una comparación similar con los valores computados utilizando un modelo de datos de gravedad de superficie GEM8 y combinando con alturas geoides derivadas de efecto doppler dieron por resultado una diferencia de 3.77 m. El Dr. Lachapelle sugirió que este resultado sorprendente surge probablemente de diferencias sistemáticas en las regiones cordilleradas del oeste de América del Norte. Cuando se eliminaron los puntos de esta región, la diferencia rms se redujo a 2,74 m y 2,67 m respectivamente para el GEM8 gravimétrico y el GEM8 geoide, respectivamente. Concluyó que estas diferencias expresan una cobertura de gravedad comparativamente baja en el oeste de Canadá.

Resumen de la sexta sesión
Sistemas de información en geofísica

El Ingeniero Mazzini describió un programa para estudiar los cambios de gravedad seculares en los Andes, un proyecto cooperativo del Servicio de Hidrografía Naval y la Universidad de Buenos Aires, realizado en 1973.

Se levantaron tres perfiles: del norte, centro y sur. Se dieron los datos de estos perfiles y de sus características generales, junto con la interpretación de los resultados obtenidos. El Sr. Mazzini sugirió que las variaciones en gravedad entre los resultados de 1973 con los medidores LaCoste y Romberg y las mediciones anteriores se deben probablemente a errores de calibración en el instrumento Worden 51 utilizado en los levantamientos previos.

En el debate que siguió a la ponencia del Sr. Mazzini, el Dr. Ocola se refirió a trabajos similares que se están llevando a cabo en el Perú. Tanto él como Mazzini subrayaron la necesidad de conocer las características del instrumento y la correcta identificación de las estaciones reocupadas. El profesor Woollard señaló que no estaba convencido de que los errores de calibración fueran la causa de las variaciones de gravedad. Sugirió que las variaciones se correlacionaban espacialmente con cambios en la estructura del basamento y de aquí los tipos tectónicos diferentes.

El ingeniero Monges informó sobre los estudios de variaciones seculares de gravedad realizados en México y sobre perfiles en la América Central y del Sur. En la ciudad de México se había observado una variación de gravedad de 0.065 mgal por año. En Guatemala fue posible reocupar estaciones después del terremoto reciente y registrar cambios significativos en gravedad. Este resultado sirvió de estímulo en los programas de remedición en las zonas de México con tendencia a los terremotos. En la América del Sur los cambios de gravedad entre 1961 y 1973 calculados en varias localidades fluctuaban entre un cambio total de 0.15 y 0.33 mgal.

En la discusión que siguió a la presentación del ingeniero Monges, el ingeniero Argenal inquirió si había alguna correlación entre la variación secular en gravedad y el drenaje del valle central de México. No se encontró ninguna correlación. El profesor Woollard reiteró entonces su opinión de que estos cambios de gravedad son realmente cambios seculares. En apoyo de su tesis citó la evidencia de las mediciones de comprobación en México y los Estados Unidos. Concluyó diciendo que la gravedad es una manera económica de verificar zonas en que se sospechan movimientos verticales antes de la renivelación.

El ingeniero Guevara preguntó si había alguna variación en la gravedad en Honduras después del terremoto de Guatemala. No se encontró ninguna.

La Dra. Shea describió el sistema de intercambio de datos utilizado en la disciplina de la física solar-terrestre. El medio elegido es el sistema del Centro Mundial de Datos. Desde el Año

Geofísico Internacional ha surgido en la disciplina un extenso sistema de información e intercambio de datos a escala mundial. Los científicos pueden obtener esta información de dos maneras. Los contribuyentes tienen derecho a sacar datos de valor equivalente de un centro de datos sin cargo alguno. Los no contribuyentes deben pagar los costos de reproducción asociados con el proceso de recuperación. La existencia de este sistema ha facilitado la predicción de tormentas solares que interrumpen las telecomunicaciones Los científicos están estudiando intensamente los posibles efectos de las actividades y ciclos solares en nuestros sistemas metereológicos.

El Dr. Smart presentó un breve panorama general de la física solar-terrestre y de los sucesos de protones solares. Señaló que muchos latinoamericanos no estaban familiarizados con estos acontecimientos ya que el campo magnético terrestre restringe el flujo de las partículas solares a las regiones polares. En su debate, el Dr. Smart señaló que no existe ninguna técnica para pronosticar las erupciones solares siquiera una o dos horas por adelantado. Sin embargo, desde el momento que se produce una erupción solar, existen programas de computarización muy vastos y completos para pronosticar el carácter de las emisiones de las diversas gamas energéticas varios días después de la erupción. Este tipo de información tiene diversos usos, entre los cuales podemos mencionar las aplicaciones a las comunicaciones y los posibles efectos sobre el tiempo o pautas climáticas a corto y a largo plazo. El Dr. Smart señaló, asimismo, que se está preparando para América Latina un manual especial con los parámetros geofísicos básicos necesarios para la aplicación de la investigación en numerosas áreas de la física solar-terrestre. Se espera que el manual esté publicado en 1977.

El Dr. Giesecke, en calidad de director de CERESIS, subrayó el carácter especial de los datos sísmicos y la necesidad de que el público tenga rápido acceso a la información sísmica después de los terremotos para la evaluación del peligro o riesgo de movimiento sísmico. Con este motivo, varios centros locales de información son más convenientes que una instalación central. Los centros de información deben estar actualizados y la información distribuida sin las grandes demoras que actualmente son tan comunes. Hasta la fecha se han publicado pocas ponencias. Los estudios preliminares indican que los Centros Mundiales de Datos no están recibiendo el 20-25% de los hechos registrados. Subrayó los aspectos internacionales de los datos sísmicos y los beneficios del libre intercambio de información para las relaciones entre los países. El Dr. Giesecke pasó entonces a discutir los problemas de comunicación, ya que no todas las redes operan veinticuatro horas al día. Algunas se encuentran en lugares remotos y cuentan solamente con personal temporario. Los boletines informativos han resultado extremadamente útiles como registros permanentes, pero muchos observatorios todavía no han emitido ninguno. El Dr. Giesecke también señaló que existe la necesidad de normalizar la numerización de los acelerogramas de datos.

En el debate que siguió a la ponencia del Dr. Giesecke, el ingeniero Salgueiro manifestó que veía la necesidad de un sistema de información sismológica latinoamericana (SILAS) que integrase todos los estudios sísmicos. El diseño de dicho sistema debía estar a cargo de CERESIS que el Dr. Giesecke considera ha recibido un nivel adecuado de apoyo internacional de los países miembros.

El ingeniero Fonseca dió los informes relativos a Venezuela sobre gravimetría, magnetismo y sismología preparados por él mismo y los ingenieros V. Graterol, M. A. López Mussa y E. Guajardo. Trazó la historia de las investigaciones en materia de gravedad en Venezuela y el desarrollo de la red de gravedad nacional que quedó ajustado recientemente mediante el programa de SILAG. Respecto al mapa Bouguer, informó que, además de las mediciones terrestres, se han incorporado al conjunto de datos algunos datos de la compañía petrolera del área del mar del Caribe, aunque dichos datos no estaban ligados al continente. Se proyectan más mediciones para completar la cobertura en materia de gravedad. Las mediciones de gravedad para fines geodésicos en intervalos de 4 km solamente han sido utilizados para preparar el mapa de anomalía de aire libre correspondiente. El mapa de anomalía Bouguer se publicará en 1976 en escala 1:500.000.

En el caso de Venezuela se han preparado mapas magnéticos cada 5 años desde el año 1955. Después de considerables dificultades para encontrar un emplazamiento adecuado, se están realizando pruebas actualmente en Pozo Hondo, donde se espera poder establecer un observatorio magnético nacional el próximo año. Se han preparado también para algunas zonas mapas aeromagnéticos y radiométricos. El ingeniero Fonseca informó que la red nacional de estaciones sísmicas transmite diariamente en sus registros al Instituto de Sismología de Caracas, donde se publican boletines sísmicos mensuales y un mapa sísmico del país. La Fundación Venezolana de Investigaciones Sismológicas, fundada en 1972, está preparando estudios sobre riesgos sísmicos mediante la OEA en colaboración con organizaciones estadunidenses y suramericanas. Se encuentran también en construcción otras redes de instrumentos sísmicos y estudios llevados a cabo por personal de FUNVISIS y estudiantes de ingeniería geofísica.

El Dr. Feininger describió el mapa de anomalía Bouguer del Ecuador, que había sido compilado en base a unas 14.000 observaciones realizadas en los últimos 25 años. Describió las variaciones en el campo de Bouguer en el contexto de las cuatro principales provincias fisiográficas del Ecuador. En el proceso hizo notar que el relieve total en el campo de gravedad era superior a 450 mgal, fluctuando desde una baja de casi 300 mgal en la provincia de La Sierra, hasta una alta de más de 160 mgal en la provincia de La Costa. Correlacionó las anomalías positivas Bouguer en la región de La Costa con la ocurrencia de la formación Piñón, que consiste principalmente en basalto y diabasa con inyecciones poco frecuentes de gabro y peridotita. Las anomalías negativas en la región de la Sierra son una manifestación principal de la profunda raíz subyacente a los Andes.

El Sr. L. Sebert describió la cartografía como uno de los importantes servicios de apoyo a la geofísica y señaló que existe una serie de proyectos cartográficos que está realizando el IPGH relativos a los estudios geofísicos de América Latina. En este último contexto, se refirió al mapa geológico de América del Sur en una escala de 1:2.500.000, y al mapa tectónico de América del Sur en una escala de 1:5.000.000. Describió su desilusión respecto al progreso del último por la falta de fondos a pesar de los esfuerzos de varios particulares para prestar siquiera una ayuda financiera parcial a través del IPGH. Otros proyectos a cargo del Comité de Mapas Especiales presidido por el Sr. Sebert incluyen la formación y desarrollo de bibliotecas cartográficas en América Latina y la publicación de atlas nacionales y regionales. Señaló que se celebrará un simposio sobre atlas dentro de unos dos años. Concluyó su charla presentando las resoluciones que solicitaban apoyo para la preparación del mapa tectónico de América del Sur y para el desarrollo de bibliotecas cartográficas.

El Sr. Jordan describió los diversos proyectos y programas utilizados para facilitar el intercambio de datos en el campo de la sismología, cuya experiencia le sirvió de base para sugerir futuras mejoras al proceso. Al describir el Servicio Nacional de Información sobre Terremotos operado por la Dirección Geológica de los Estados Unidos, hizo notar el esfuerzo voluntario mundial que había conducido a un método eficaz para determinar los epicentros de los terremotos a escala mundial. Sin embargo, señaló que el flujo de información procedente de América Latina no es adecuado para estudios modernos de sismología. Sugirió que se concentrasen los esfuerzos para mejorar los sistemas de comunicaciones, así como para aumentar el número de estaciones. Discutió una serie de posibles mejoras al NEIS haciendo resaltar las técnicas automatizadas de registro perfeccionadas, mejores sistemas de elaboración de datos y el posible uso de satélites.

Resumen de la septima sesión
Reseña y revisiones de los programas y prioridades de la comisión geofísica

El ingeniero Mazzini esbozó brevemente el proyecto intitulado "Perfil Sudamericano de Mediciones de la Marea Terrestre" que empezaría con un programa de capacitación en Tucumán, en octubre de 1977. Solicitó apoyo para este proyecto el cual esta copatrocinado por el Observatorio Real Belga y la Universidad de Tucumán en la Argentina.

El ingeniero Brussoni hizo una reseña de la geofísica en el Uruguay. El gobierno uruguayo realizó un programa importante sobre gravedad y perforaciones entre 1948 y 1958, con objeto de determinar la estructura del basamento. En 1954 se establecieron 26,000 estaciones gravimétricas. El Servicio Geográfico Militar publicó los primeros mapas geomagnéticos y, con la Universidad Nacional de Buenos Aires, desarrolló la red nacional de gravedad. El PICH. Apoyó la publicación de datos y mapas de gravedad. Desde 1966 se han venido realizando sobre la plataforma continental observaciones sísmicas y magnéticas. Se está por terminar una red sismológica y se han comenzado desde hace dos años cursos regulares universitarios de geofísica. El ingeniero Brussoni informó, asimismo, que se está realizando una importante investigación relativa de registros sísmicos registrados entre 1887 y 1940.

Basado en su estudio de otros sistemas realizados en el mundo, el ingeniero Salgueiro esbozó los factores que deberían tenerse en cuenta para establecer el Sistema de Información Integrado de Geociencias (SIGEO) para almacenar y recuperar los resultantes de estudios realizados sobre los océanos y continentes. El sistema debería estar estructurado para tener en cuenta, de una manera flexible, los problemas asociados a la taxonomía, elaboración, almacenamiento, recuperación, transformación, presentación y publicación de información geofísica en las Américas.

El ingeniero Argenal informó que desde mayo de 1975 funciona en Nicaragua una red sísmica y que los resultados han sido utilizados para desarrollar zonas sísmicas y un código de construcción. Dentro de uno o dos años, estará funcionando, junto con otros países una red sísmica para toda América Central. El ingeniero Argenal señaló que urge examinar los problemas creados por el volumen de datos que se elaborarán.

El ingeniero Guevara informó que solamente unas pocas mediciones de gravedad se han realizado en Honduras antes de 1956, pero desde 1969 se ha desarrollado la red básica de gravedad. El trabajo magnético realizado hasta 1969 se ha utilizado para producir mapas isogónicos y del magnetismo terrestre para 1970 a 1974. En 1974 se publicó un mapa geológico preliminar de Honduras. Finalmente, señaló que se producirá un mapa gravimétrico provisional basado en más estudios geofísicos para determinar la estructura geológica.

El padre Ramírez presentó un informe sobre el número de proyectos geofísicos realizados en Colombia. El primero es un proyecto conjunto del Instituto Geofísico de la Universidad de Javerina y la Universidad de Wisconsin para estudiar la estructura de los Andes Colombinos Occidentales, la zona de mayor actividad sísmica de América del Sur. El segundo proyecto trataba de la difusión de información sobre geología y geofísica mediante sistemas de bibliotecas automatizadas, tal como fuera debatido por el Grupo de Trabajo II en la Reunión Internacional de Geodinámica celebrada en Acapulco, México, del 14 al 16 de junio de 1976.

El tercer proyecto versaba sobre los perfiles de reflexión de maremotos y mediciones magnéticas observadas en la costa norte de Colombia en un estudio mixto realizado por el Instituto Francés de Petróleo en abril de 1976. Otros proyectos incluían una continuación del proyecto Nariño de 1973 sobre estudios petrográficos realizado en la cordillera central y occidental de Colombia por la Universidad de Glessen, Alemania, durante 1976. En 1975 se publicaron estudios sobre sedimentos volcánicos en la costa oriental del Pacífico en Colombia y los períodos orogénicos del Terciario en Colombia. Se organizó una investigación de la conductividad eléctrica y las variaciones geomagnéticas en Colombia occidental durante el período febrero a septiembre de 1976, en colaboración con el Instituto Carnegie de Washington. El control sísmico del volcán Galeras se publica en boletines regulares y la geopoligonación entre 6°N y 7°N fue aumentada mediante estaciones magnéticas y de gravedad adicionales en 1975. Se está preparando un mapa isogónico para Colombia para el año 1975. De manera más general, afirmó que se ha presentado un mapa metalogénico de Colombia, que aparecerá un nuevo mapa geológico en 1976, que en 1975 y 1976 se han publicado en los Estados Unidos mapas universal y geofísicos para la región del Caribe y que desde 1975 existía un folleto de divulgación sobre terremotos preparado por el Instituto de Geofísica de los Andes Colombianos para el IPGH.

El ingeniero Llinas informó que como resultado del gran terremoto de 1946 y el auge reciente de la construcción pesada en la República Dominicana, existe la urgente necesidad de realizar estudios de riesgo de movimientos sísmicos, de un código de construcciones y de una red sísmica. Señaló que se ha hecho una propuesta formal para una red de tres o cuatro estaciones, para establecer posteriormente estaciones adicionales. Finalmente declaró que la interpretación de los datos de gravedad se ha demorado por falta de un mapa geológico fiable.

El Dr. Ocola distribuyó copias del informe de sismología, gravimetría y magnetismo en el Perú, preparado por el Instituto de Geofísica del Perú al que pueden solicitarse ejemplares. Consideró que el principal problema referente a América Central y del Sur es la evaluación del riesgo de movimiento sísmico. La teoría de la evaluación del riesgo sísmico postulada aquí está basada en el método Cornell que requiere buenos conocimientos de la actividad sísmica y de la tectónica de una región. El mapa de riesgo sísmico para América del Sur ya se ha preparado. Informó que un problema concreto es la descripción de grandes terremotos múltiples de larga duración para los cuales la definición normal de

magnitud es inadecuada. También describió un catálogo para eliminar eventos independientes de las sacudidas que siguen a terremotos de mayor magnitud.

Resumen de la octava sesión
Discusión de mesa redonda de los programas y prioridades de la comisión de geofísica

El Dr. Kausel inauguró la discusión haciendo referencia a la reunión de las autoridades de la Comisión Geofísica en Lima que establecía los objetivos que sirvieron de base a la discusión que siguió. Esta discusión se dividió en seis temas y para cada tema se seleccionó un orador de apertura. Se asignó un período de discusión al término de las presentaciones de los temas. El primero de estos debates trataba de los "Temas centrales de investigación" expuesto por cada uno de los presidentes de los tres comités.

El profesor Radicella, presidente del Comité de Física Solar-terrestre, discutió los recursos naturales en términos de la Tierra como vehículo espacial con limitados recursos pero una población creciente. La atmósfera era un factor importante por su influencia sobre la ecología y las actividades humanas. Los estudios climáticos en América Latina son insuficientes para el pronóstico del rendimiento de la cosecha. Se necesita efectuar estudios sobre los efectos climáticos de las regiones densamente pobladas, comprendidos los efectos de la población y el estado de las comunicaciones en América Latina, incluso el uso de satélites y técnicas de microonda o hiperfrecuencia.

El Capitán Cabezas, Presidente del Comité sobre Océanos y Atmósferas, discutió el estudio de las corrientes marinas anómalas por la costa oriental del Pacífico de Sudamérica y de sus graves efectos sobre las economías de los países adyacentes. Actualmente existe un proceso en ejecución en el Perú, y este proyecto será extendido hasta incluir las islas Galápagos. Se describió una reunión que será celebrada en Montevideo.

Finalmente, el Presidente del Comité sobre la Litosfera, padre Ramírez, discutió la selección del tema "Riesgos Sísmicos" como tema central de investigación de su comité y la necesidad de mapas de epicentro y tectónicos para el desarrollo de códigos de construcción.

En la discusión el ingeniero Guevara respaldó el énfasis puesto sobre la sismicidad. El Dr. Ocola subrayó la contribución de los estudios gravimétricos y geomagnéticos a la investigación fundamental para la evaluación del riesgo sísmico. El ingeniero Salgueiro señaló la necesidad de comenzar tempranamente la tarea de desarrollar un sistema de información integrado para las geociencias. El ingeniero Argenal defendió la importancia de los estudios geomagnéticos aéreos para la cobertura rápida a casi toda América del Sur. El ingeniero Malavassi subrayó la necesidad de completar los proyectos existentes y la importancia de resolver los problemas prácticos tales como el código sísmico y las corrientes oceánicas. Respondiendo al ingeniero Salgueiro, el ingeniero Sáenz reseñó la manera equitativa en que se distribuyen los fondos de la Comisión.

Todo ello llevó a la adopción de los temas centrales de investigación para los próximos cuatro años, estipulándose que debía mantenerse el apoyo para los sistemas de datos, mapa temáticos y capacitación.

El segundo tópico del programa, "Selección y Mecanismos de Selección y Control", fue presentado por el Dr. Kausel quien esbozó los procedimientos para presentar los proyectos al IPGH mediante la Comisión Geofísica, utilizando la fórmula corriente revisada.

En la discusión, el ingeniero Godoy subrayó la importancia de la temprana historia de los proyectos como criterio para su evaluación. El profesor Radicella estuvo conforme e instó a que se incluyeran también en la evaluación la actuación de los investigadores.

El tercer tópico fue presentado también por el Dr. Kausel, la cuestión de si la geología debía constituir un comité separado en la Comisión Geofísica. En respuesta al Dr. Feininger, el Dr. Kausel señaló que el Comité sobre Gravimetría y Mareas Terrestres estaba comprendido en la Comisión Cartográfica por razones clásicas, pero que no existían proyectos activos en este sector. El ingeniero Sáenz señaló que el Comité estaba combinado con el de geodesia. El ingeniero Malavassi apoyó la idea de un comité de geología, y el ingeniero Fonseca habló sobre la falta de representación de la tectonofísica y la volcanología. El Dr. Ocola habló contra la medida de subdividir aún más la comisión. El Sr. Geller señaló la necesidad de una mejor administración de los recursos disponibles mediante el IPGH. El Dr. Ocola afirmó que el incremento del número de comités aumentaría los costos de la comisión. El ingeniero Fonseca convino en que la información geológica debía integrarse en los comités ya existentes. En respuesta al Dr. Ocola, el Dr. Kausel esbozó la separación histórica de la geofísica y la geología e indicó que la moción de crear una comisión distinta de geología había recibido apoyo. El Dr. Graterol estuvo de acuerdo con la formación de un comité geológico para asistir a los estudios del riesgo sísmico y la interpretación de los mapas de anomalía de Bouguer. Los ingenieros Monges y Fonseca se opusieron a la formación de un comité geológico si ello significaba que los geólogos deseaban formar una comisión separada. El ingeniero Mazzini señaló que un comité de geología podría acarrear problemas de dualidad en el seno del IPGH. El Dr. Kausel sugirió que se podría nombrar a un geólogo vice-presidente de la comisión para que actuase junto con los presidentes del comité. Alternativamente, pero más difícil que formar un comité para geología, se podría formar una comisión de geociencias. El profesor Woollard y el ingeniero Salgueiro hablaron en favor de que no se dispersara la organización con la formación de más comités. Puesta la moción a votación, la mayoría rechazó el establecimiento del nuevo comité de geología propuesto.

La Dra. Shea introdujo el cuarto tópico "Centros de Información de Datos". En su charla subrayó que la carencia de grandes centros de datos o centros regionales de datos en la América Latina es una traba al desarrollo de la investigación en geofísica en América Latina porque los bancos de datos de diversas disciplinas han dejado América Latina sin ninguna instalación central adecuada convenientemente ubicada para trabajar con datos globales o regionales. Más aún, la Dra. Shea pensaba que el mismo proceso de recolección de datos tendía a estancarse por falta de mecanismos de entrada de parte de los usuarios. Sugirió que América Latina podía subsanar esta falla quizás comenzando a establecer en pequeña medida centros o institutos que almacenaran una colección significativa de registros. Esto podría realizarse en base a una determinada disciplina de acuerdo a los conocimientos técnicos del centro en cuestión. Concluyó enumerando varios criterios respecto al espacio, personal, etc., para establecer uno de estos centros de datos.

En la discusión que siguió, el profesor Woollard esbozó los costos de administrar un centro de datos efectivo y de recuperar

datos del mismo. Subrayó la dificultad de obtener fondos y la carencia de organismos de financiación para esta obra. El profesor Radicella estuvo de acuerdo y habló de la necesidad de desarrollar concentraciones regionales de datos y llevarlos hasta niveles nacionales. El Dr. Tanner ratificó las observaciones del profesor Woollard refiriéndose a los costos de establecer un Centro Mundial de Datos "A" y sugirió un comienzo modesto reuniendo índices de cobertura de datos. El padre Ramírez dió ejemplos de la buena acogida que obtuvo su instituto a sus publicaciones de listas y referencias. El ingeniero Salgueiro señaló que la primera obra de la Comisión debería ser un estudio general del estado actual de los sistemas de información en América Latina y la necesidad de centros de concentración de datos. Respondiendo al profesor Woollard, el Sr. Svendsen señaló que el gran problema de los centros regionales era la actualización de los datos. El profesor Woollard convino en que era difícil lograr que los centros regionales fuesen eficaces. El Dr. Ocola habló en favor de los centros de concentración nacional sugeridos por el ingeniero Salgueiro, quien instó a que se dispusiera de un sistema de información normalizado para todos los países y a que se le estableciera de inmediato. La Dra. Shea habló de las dificultades relativas a la comunicación y la identificación de los datos ya existentes. El ingeniero Giesecke habló de los fondos ya proporcionados por la OEA para el establecimiento de los centros de información científica y tecnológica. También discutió, en respuesta al Dr. Kausel, los principales problemas enfrentados por CERESIS, tales como el flujo irregular de informes sísmicos. El profesor Radicella propuso una resolución en favor de un inventario de datos geofísicos. El ingeniero Brussoni habló de hacer participar a la industria en la formación de centros de datos. La Dra. Shea mencionó al NSF como posible fuente adicional de ayuda. El Capitán Cabezas señaló que la experiencia del Comité Oceanográfico indicaba que la falta de fondos impedía la formación de centros de datos.

El ingeniero Salgueiro afirmó que la formación de inventarios debía ser responsabilidad de los sectores nacionales y estar en manos de especialistas, mientras que el ingeniero Giesecke señaló que se debía utilizar la experiencia adquirida en la recolección de datos por los diversos consejos nacionales. El Dr. Tanner apoyó la idea de confeccionar índices como primera medida. El profesor Radicella planteó la posibilidad de organizar un simposio o seminario con la ayuda del NSF. La Resolución del profesor Radicella fue sometida al Comité de Resoluciones. El Dr. Woollard señaló que existía la posibilidad de que el NSF diese su apoyo para un seminario.

El quinto tópico, "Mapas temáticos", fue introducido por el Dr. Tanner quien recomendó se nombrara a un miembro de la Comisión de Geofísica para integrar el comité especial sobre mapas temáticos de la Comisión Cartográfica. El ingeniero Sáenz discutió los medios para llevar a cabo la coordinación entre comisiones. Aunque no se nombró ninguna representación del Comité, se convino en que la Comisión de Geofísica debía mantener un estrecho contacto con el Comité.

Finalmente, el Dr. Giesecke introdujo el sexto tópico, "Capacitación". Analizó el concepto de capacitación respecto a los diferentes niveles de educación. Mencionó la necesidad de extender la información disponible mediante publicaciones en español, particularmente en revistas que tratasen de la práctica de la geofísica, tales como investigaciones de sismicidad inducidas por embalses, tanto para informar a los latinoamericanos como para promover la participación de especialistas extranjeros. Existe también la necesidad de proporcionar mediante el IPGH mayores oportunidades para el intercambio de profesionales geofísicos entre las instituciones de investigación latinoamericanas. El Dr. Giesecke consideraba que debía buscarse la máxima utilización regional de las instalaciones existentes en América Latina. Finalmente, consideró que los cursos organizados por el IPGH, a saber, sobre la gravedad, lectura de ionogramas, operación de sismógrafos, etc., habían resultado altamente beneficiosos.

En la discusión que siguió, el profesor Radicella sugirió que se pasara una resolución sobre el fomento de la capacitación como parte del programa durante los próximos cuatro años. El Dr. Kausel señaló que la capacitación era ya una de las responsabilidades del IPGH y que no debían publicarse nuevas revistas ya que existía la Revista Geofísica aunque contenía pocos artículos. El ingeniero Sáenz ratificó las observaciones respecto a la necesidad de tener más artículos de latinoamericanos en publicaciones ya conocidas del IPGH. El padre Ramírez describió un experimento en la transmisión de datos utilizando fotocopias de artículos sobre tectónica. El ingeniero Salgueiro discutió el uso del libro "Investigando la Tierra" y el intento de utilizar este material latinoamericano, así como el uso mutuo de instalaciones de observatorio, y los métodos existentes de intercambiar información.

El ingeniero Llinas habló de la necesidad de becas que el Dr. Kausel también planteó en los niveles primario y secundario de enseñanza con textos apropiados. El IPGH debía identificar a los becarios. El ingeniero Llinas insistió en la necesidad de otorgar becas a nivel universitario para capacitar a ingenieros en geología y geofísica. El ingeniero Salgueiro señaló que ya existían cursos universitarios de primer ciclo en la universidad de Chile, aunque el IPGH podía patrocinar cursos para graduados tal como lo había sugerido el ingeniero Giesecke. El Dr. Kausel señaló que el proyecto de la OEA raramente había sido utilizado para capacitar geofísicos, de modo que el IPGH debía tomar la delantera en la promoción de la geofísica a los niveles superiores. El ingeniero Sáenz inquirió sobre si la capacitación de operadores en gravedad y sismología era adecuada en comparación con la capacitación de la Escuela de Cartografía de Panamá. El ingeniero Monges esbozó algunas de las deficiencias de los observadores de la gravedad e insistó a la formación de un curso y un manual de capacitación. El ingeniero Llinas expresó su satisfacción con el proyecto de capacitación esbozado por el Dr. Kausel e instó a que se prosiguiera con la capacitación en todos los niveles. El ingeniero Guevara también habló en apoyo de los cursos de capacitación a nivel básico y superior. El ingeniero Argenal abogó por la amplia difusión de la información sobre becas. El profesor Radicella sometió una resolución de que la Comisión preparase un plan técnico y científico coordinado para ser incluido en el programa de la Comisión para 1977-81. El ingeniero Salgueiro señaló que también debían mencionarse las publicaciones, particularmente las que estaban a cargo de la Comisión, aunque todavía no estuviesen publicadas. El ingeniero Sáenz indicó que el manual indicado por el ingeniero Salgueiro está en curso de publicación en "Geofísica". En respuesta a una citación de observadores debía mencionarse específicamente en la resolución y de que la "información" debía cubrir el tema planteado por el ingeniero Salgueiro. La resolución fue aceptada.

Las palabras de clausura de la reunión estuvieron a cargo del Dr. Kausel, quien expresó su agradecimiento a los encargados de organizar y dirigir el simposio.

APPENDIX II/ANNEXE II/APENDICE II

RESOLUTIONS/RÉSOLUTIONS/RESOLUCIONES

Resolution No. 1

The Committee for Solid Earth Geophysics

Considering:

the importance of studies related to the protection and safety of the public and public buildings in Latin America,

Recommends:

that high priority be given to the planning and implementation of studies on seismic risk and building codes.

Resolution No. 2

The SILAG Working Group

Considering:

the importance of unified gravity control networks in providing a reference standard for gravity surveys and secular variation studies,

Recommends:

1. that various agencies responsible for national gravity standards in Latin America implement programs to strengthen the existing national gravity networks by
   (a) where necessary, extending the networks to provide uniform coverage in previously unsurveyed areas,
   (b) extending the networks to include stations at key ports where marine gravity surveys have been or are likely to be tied and
   (c) re-observing the national gravity networks at least every 10 years to provide basic data for secular variation studies,

2. that national agencies collaborate to carry out the international gravity ties specified by SILAG to ensure datum and scale consistency between countries.

Resolution No. 3

The SILAG Working Group

Considering:

the importance of the research related to gravity tides in the South American continent, that the regional nature of the project requires the joint effort of all the countries in the continent and that the results are important to studies of secular changes,

Recommends:

that PAIGH encourages the execution of the South American Transcontinental Project in Gravity Tides which has been proposed by Argentina's National Section and which is based on a recommendation of the IUGG.

Resolution No. 4

The SILAG Working Group

Considering:

that the maintenance and extension of gravity networks permits the use of uniform standards for data acquisition, preservation and reduction, and also considering the arguments that are included in Recommendation No. 2 from the SILAG Working Group during its meeting in November 1975 in Panama City,

Recommends:

the organization of the first training course in gravimetry in Panama's Canal Zone, at IAGS headquarters, designed to prepare Latin American personnel for carrying out field observations and instrument maintenance according to a specialized program adapted to the requirements for developing national gravity programs and following the procedures set out in a handbook for gravity measurements to be completed in the immediate future.

Resolution No. 5

Dr. T. Simkin, Smithsonian Institution

Considering:

the serious hazards posed by volcanoes to many parts of Latin America and the need for a better understanding of volcanoes to reduce this hazard

Recommends:

1. that historical records of ancient eruptions existing in church and village records be gathered and placed in data banks such as the Smithsonian Volcanological data file.
2. that monitoring of potentially active volcanoes be carried out by
   a) suitable high gain seismograph stations
   b) installation of benchmarks and periodic geodetic surveys
   c) recording temperature changes by remote infrared measurements or use of thermocouples in fumarolic regions
   d) periodically analysing groundwater and fumarolic gases for chemical changes
   e) recording unusual animal behaviour
3. that geological "risk maps" be prepared based on historic and geologically dated eruptions and be made available to government and other agencies responsible for disaster relief continency plans
4. that the use of the science event alert network of the Smithsonian Institution be considered as a method of alerting volcanologists to impending or active volcanism.

APPENDIX III/ANNEXE III/APENDICE III

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APPENDIX IV/ANNEXE IV/APENDICE IV

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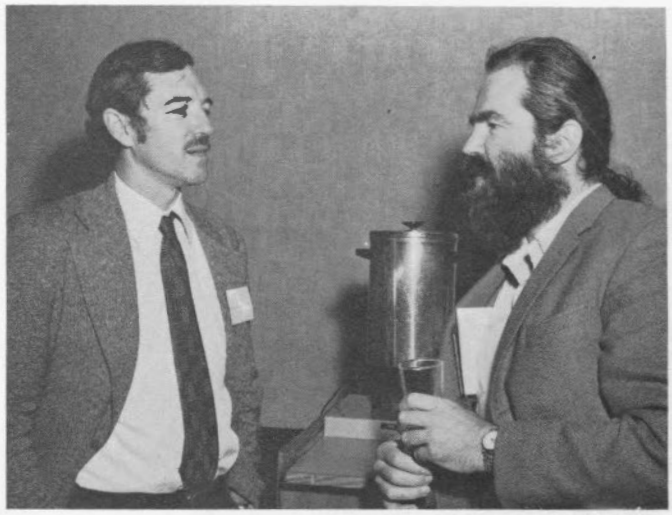
Left to right — First row: M. Berry, J. Jordan, J. Ramírez, K. Whitham, J. Guevara, J. Guevara Jr., A. Fonseca, S. Salgueiro, R. Salgueiro
Second Row: P. Serson, R. Argenal, E. Malavassi, K. Svendsen, V. Graterol, R. Geller, R. de Godoy
Third row: V. Mazzini, A. Brussoni, L. Ocola, L. Wilcox
Back row: T. Feininger, P. Van Dusen, M. R. Dence, J. G. Tanner

J. A. Sáenz and J. E. Ramírez



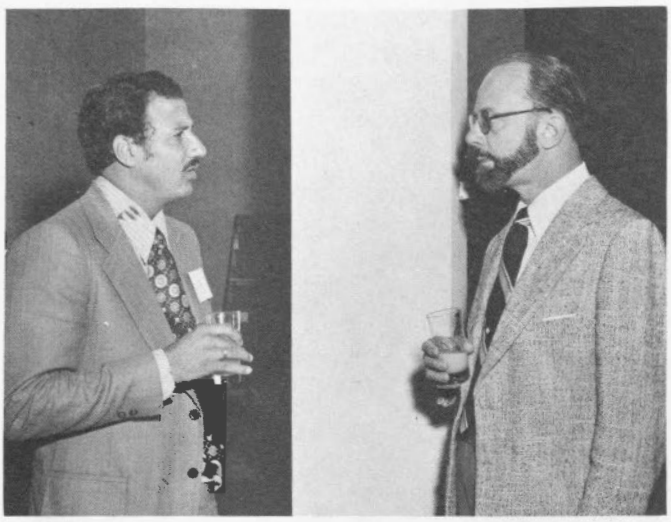
M. R. Dence and T. Simkin

V. Mazzini, A. Brussoni, G. P. Woollard, J. Monges

G. Lachapelle, M. A. Shea and L. Wilcox

V. Graterol and G. P. Woollard

G. P. Woollard, R. K. McConnell, R. C. de Godoy and V. Mazzini (background — J. G. Tanner and G. Lachapelle)



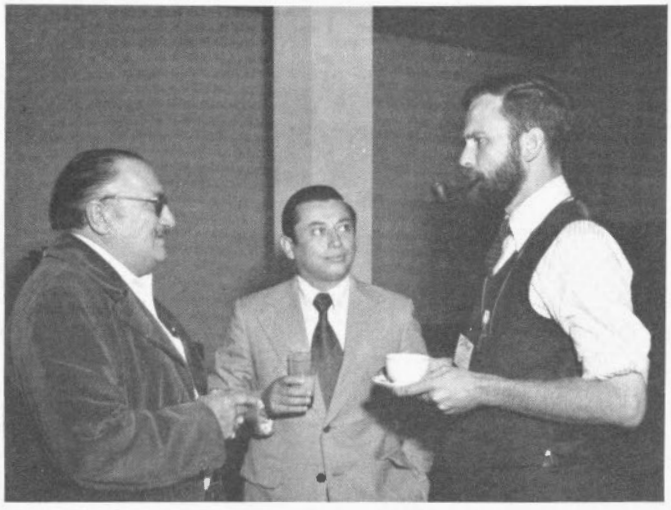
R. Llinas and R. Geller

E. Kausel and J. G. Tanner
(background — J. Monges and T. Feininger)

P. Cabezas, J. E. Ramírez, A. E. Blanchette, K. Svendsen
(background — M. R. Dence)

A. Giesecke and R. Salgueiro
(background — T. Simkin and M. R. Dence)

E. Malavassi and S. Radicella



J. Monges, P. Cabezas, T. Feininger

Left to right — First row: L. Ocola, R. Salgueiro, M. A. Shea, J. J. Guevara, R. Argenal, S. Radicella, J. A. Sáenz, E. Kausel, J. G. Tanner, P. Cabezas, J. E. Ramírez, A. Giesecke, G. P. Woollard.

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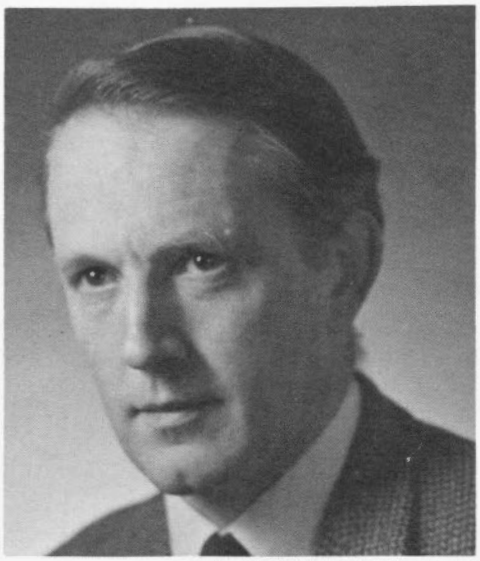
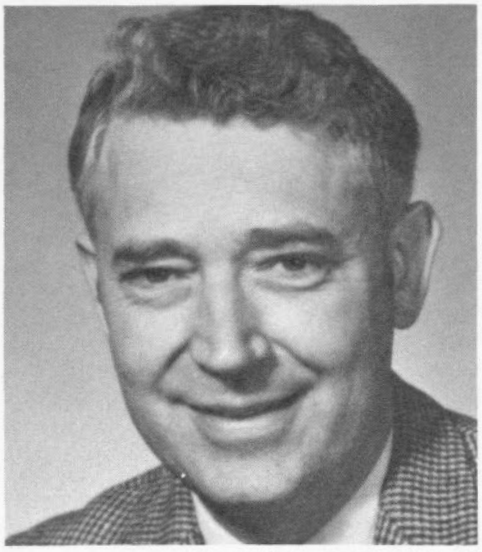
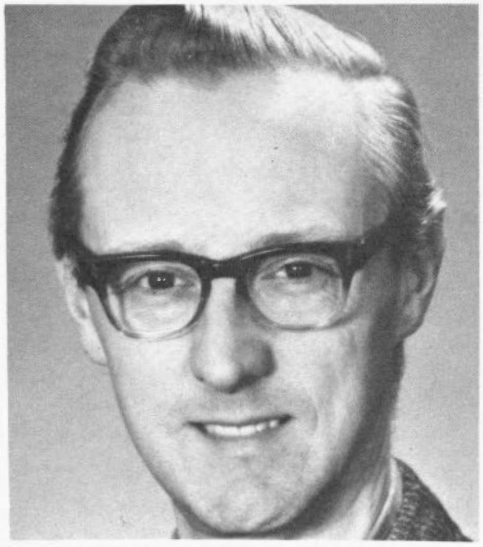


A. G. Darnley

R. O. Lindseth

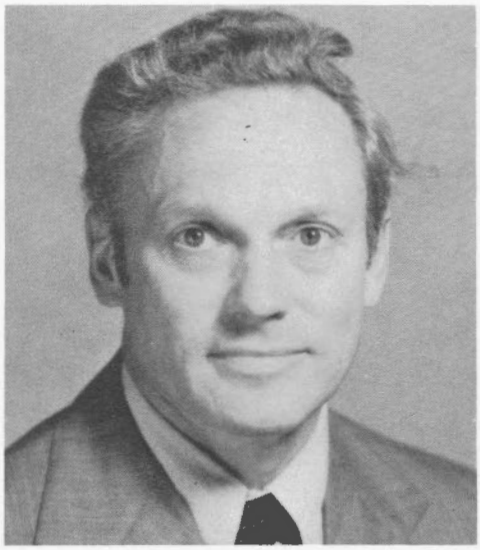


E. R. Niblett



A. Jessop

L. Sebert



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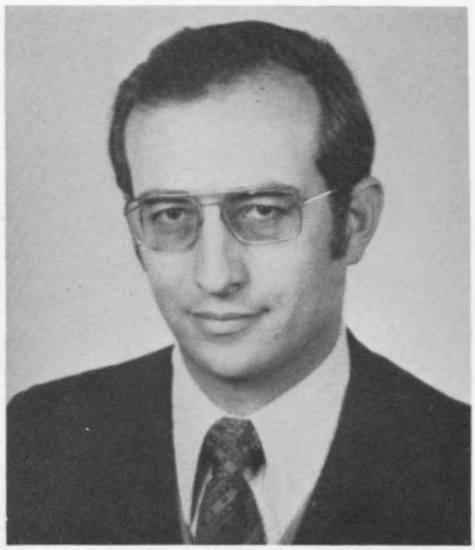
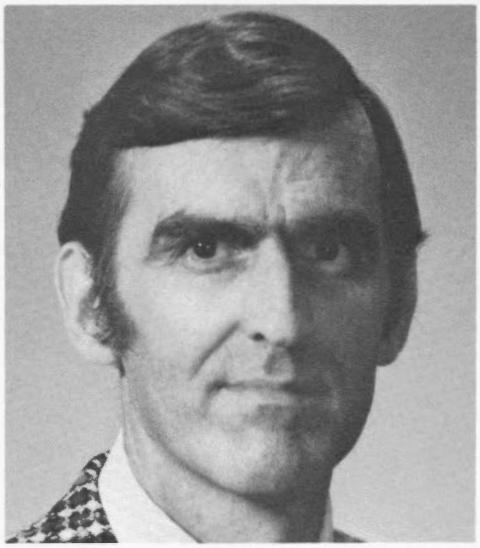
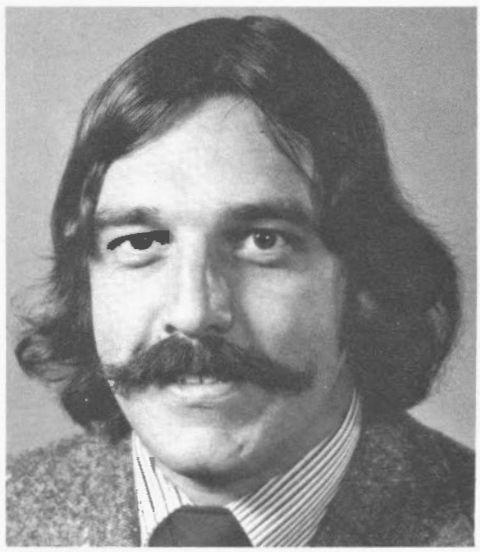


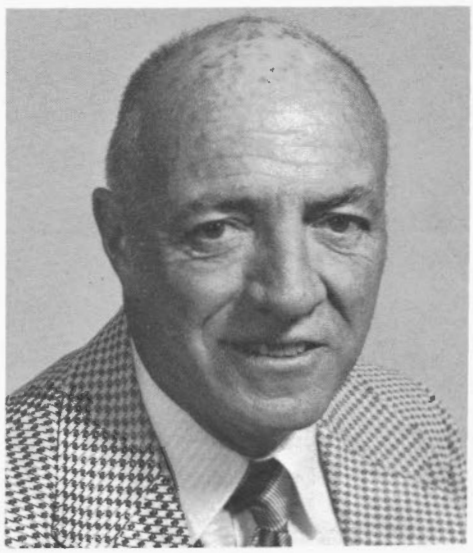
E. Feller



R. A. Gibb



M. D. Thomas



W. S. Callaghan

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