PROPOSALS TO THE SURVEYS & MAPPING BRANCH FOR GEODETIC RESEARCH

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GEODETIC STRAIN-POLYGONS

Proposal

It is proposed that the Geodetic Survey undertake the construction of geodetic polygons consisting of piers in a network of 1 to 2 km legs in areas of seismic hazard and that frequent remeasurement of the polygons is routinely done to detect anomalous relative displacements of the ground.

Background

In most countries the programs on the study of earthquakes contain as a key activity the routine observation and reduction of highest precision geodetic surveys so as to detect anomalous movements of the ground. In many, the geodetic work is in part dedicated to the earthquake program with a number of precisely surveyed small geodetic nets in areas of possible movement that are routinely resurveyed at yearly or less intervals. In others, as in Canada, anomalous movements have been detected but as an accident arising from normal geodetic activity for survey control purposes.

A dedicated program of earthquake studies could contain many elements but notably; routine resurvey of horizontal and vertical control at smaller intervals of time in seismic areas than in relatively aseismic areas; high priority reduction and early release of survey data from seismic areas; the construction and routine resurvey of geodetic polygons primarily for measurements of ground displacement.

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Earth Physics Branch is currently conducting a number of experiments in the La Malbaie - Baie St. Paul region of Quebec (see accompanying map) to study seismic structure, geodynamics and geomagnetic field variation. This area is one of the most seismic areas in Canada having experienced about 5 magnitude 7 or greater earthquakes since the 16th century. The purpose of the study is therefore to obtain information on the peculiarities of the structure of the region, and, in the light of recent theoretical work on the causes of earthquakes, to evaluate a number of possible precursory effects as predictive parameters for future earthquakes.

The seismic experiment consists of a number of seismographs deployed in the area for 6 weeks, during June and July 1974 to observe local seismicity. The seismic network will be calibrated by 3 large explosions.

The geomagnetic variation work is the extension of work initially undertaken by the University of Toronto to determine the electrical structure of the region. It will determine the feasibility of identifying precursory magnetic effects for earthquakes.

The activities of geodynamics group are:

(1) to continuously monitor the strain and tilt field of the surface at sensitivities sufficient to measure tidal signal amplitude to better than 10%. A possible location, an abandoned mine near St. Urbain (see map) is being evaluated and if satisfactory a triangular array of longitudinal strainmeters and an orthogonal array of tiltmeters will be installed this summer.

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(2) Gross tilt can be measured by re-occupation of prepared sites using a transportable tiltmeter and will be used for mapping changes of tilt exceeding 2×10^{-6} radians. The present coverage is shown on the map.

(3) Gravity survey to detect ±3 μgal changes in gravity with time will be undertaken at the same sites as (2).

The Geodetic Polygons

Two possible locations for the proposed geodetic polygons are shown on the map, although after examination in the field other locations may be better. The program, if undertaken, will require:

(1) Selection of sites

(2) Monumenting

(3) a time interval of at least 6 months to allow the concrete to cure

(4) Initial measurement

(5) Repeated measurement at intervals to be determined - one year would appear to be a reasonable initial interval.

The schedule would call for site selection and monument construction -summer and fall of 1974 - with initial measurement summer 1975.

Location

Although the polygon program is independent of the geodynamics program in the La Malbaie area an important aspect is to relate the displacement changes measured in the polygon over distances of 1 km or so with the strain and tilts measured continuously at high sensitivity over the short period but indeterminate sensitivity at long periods (a. 1 year) in the permanent geodynamics site. Therefore the two should be located as close together as practicable.

Measurement

To achieve the high accuracy required to identify the small displacements expected (a few parts per million), a large redundancy in data and a number of different measurments should be made. A mekometer can measure leg lengths, precise levelling monument height and angular measurements should be made between monuments. All have the potential precision of 1 part in a million or better and with the data redundancy and corrections for tidal and other effects an accuracy of a few parts in ten million can be perhaps achieved.

Future developments

The initial polygons will be in some measure an evaluation of geodetic techniques in studying ground movements of seismic areas and depending on the outcome, economically and technically, the number of polygons in Quebec and British Columbia may be increased.

LEVELLING RESEARCH

Proposal

It is proposed that the Geodetic Survey undertake a fundamental study of the errors and accuracy of levelling techniques in order to resolve inconsistencies in water level and precise geodetic levelling techniques.

Background

Precise geodetic levelling is a highly evolved scientific technique that attempts to estimate all sources of error, systematic and random, by a physical model. As such it has been the most precise method of transfer of level available. But it has so far proved impossible to test the physical model against some independent or alternative levelling procedure to ensure that all sources of systematic error are recognized. There has been recently a number of studies comparing geodetic land-based levelling with water transfer of level at the continental margins that show divergences greater than the calculated internal errors in both techniques. The physical model for precise levelling is probably more securely based than that of water levelling in oceans so that the error is widely held (by land based geodesists and some oceanographers but by no means all) to arise in the water levelling technique. It is possible that a systematic error occurs in precise geodetic levelling of large magnitude that is unrecognized. Both types of levelling supply basic data for the study of earth movements and the observed signals are generally little above noise level. It is therefore important for geodynamics, quite apart from geodesy, to recognize the limits on accuracy of the separate techniques.

In North America there is in the Great Lakes area a unique opportunity to compare levelling by independent methods at high levels of accuracy. Precise levelling can be carried out in closed nets around the Great Lakes independently of water level transfers that can be measured between stations for distances exceeding 700 km in both NS and EW direction.

The importance of the program is shown by recent approach by the President of American Association of Petroleum Geologists to Dr. C.H. Smith encouraging its activation.

Levelling Programme

The programme should make use of the longest distances available for water transfer of level. The longest distances on a single water body occur on the HURON/MICHIGAN system with distances of 540 km NS and 660 km EW. The programme involves the recognition of some ten benchmarks around the lake to which access is readily available by both water level stations and geodetic levelling networks. The requirements for the benchmark, apart from access are local stability and several excentres each. If it is necessary to locate the benchmark in areas where ground movements can be expected through ground water changes then this effect and any others must be considered.

These benchmarks are then independently levelled by (i) a Geodetic levelling network that is freely adjusted for the benchmarks and (ii) by water level transfer allowing for all meteorological and oceanographic effects that can be conveniently modelled. The significant differences in elevation of the benchmarks as independently determined, if any, are examined for possible systematic errors in the two techniques.

The major problem is the expense of geodetic levelling. The first phase therefore is to collect existing information, identify benchmarks common to both the geodetic levelling and contemporaneous water level stations, and carry out a levelling analysis using this old data in as complete a manner as possible. With the information obtained from this procedure the most economical geodetic network to complete the analysis can be made. Thus a complete new network of geodetic levelling is not a necessary feature of the programme. New levelling will probably be required however to complete existing levelling so as to produce a tight, well structured network for rigorous analysis.

Proposal

It is proposed that the Geodetic Survey carry out astronomic levelling in an area of high gravity gradients to provide a basic framework for evaluating procedures and establishing specifications for local gravimetric geoid determinations.

Background

The effect of geoidal height (i.e. the separation between the equipotential surface coinciding with the "mean sea-level" and a reference surface) on the scale of geodetic network has been known for a long time. Earlier its effect was partly reduced by the choice of local reference surfaces, while the remaining part contributed to the systematic scale error. Until recently the inclusion of geoidal height into proper reduction procedure was hindered by the large uncertainty of geoidal heights obtained from gravimetric and/or astro-geodetic methods. In order to show the magnitude and the variations of the neglect of geoidal height in reducing distances, a recently determined gravimetric geoid was recontoured to show the error expressed as ppm (see Figure 1).

Recently a number of developments renewed the interest in geoid computations.

The developments are:

1. Direct determination of x,y,z coordinates of a station makes possible the "inverse" application of geoidal height, that is to determine station elevation without levelling. If the rectangular station coordinates are available, say from satellite observations, and the geoidal height is

known, then the station elevation referred to a given reference ellipsoid can be calculated. It is clear that the accuracy of this elevation is dependent upon both the accuracies of the station coordinates and the geoidal height. If and when satellite technique provides meter accuracy for station position then the need for submeter accuracy in geoidal height is clearly demonstrated. This method has much to recommend it in remote or other operationally difficult areas.

2. Intolerably large scale error in geodetic network. The conventional ("direct") use of geoidal height is in reducing distances and directions measured on the topographic surface to the reference surface. The importance of the proper reduction procedure using geoidal height is shown by the time spent on datums, geoid and related topics at a recently held symposium (May, Fredericton, N.B.) sponsored, amongst others, by the International Association of Geodesy to discuss the redefinition of the North American Datum.

3. The question of continental against global reference surfaces: The major argument to use a continental as opposed to a global reference system is that the former fits better locally. Most other arguments (uniformity for navigational purpose, satellite work, gravity data reduction, etc.) favor a global reference surface. It can even be argued that a "better local fit" theory for a continental reference surface may be based on false arguments: early geoid determinations (mostly from satellite) indicated very smooth variation in the geoid and supported the idea of using locally fitting surface and ignoring the geoid in reducing distance measurements. However recent geoid determination (surface gravity, or combination solutions) indicate a more irregular geoid locally suggesting that no continental-sized area can be

approximated in such a way as to avoid taking the geoid into account in reducing land survey data.

Obviously a global reference system will result in larger geoidal heights locally, but once the geoid height is routinely included in the reduction of distances, the larger geoidal heights will not cause any problems.

4. New instrumentation such as the gyroscope require that deflections of the vertical can be computed at selected points.

Practical, computer-oriented techniques and sufficient gravity data exist to compute the regional geoid to a relative precision of 1 - 2 metres for the largest part of Canada. The lack of complete world-wide land gravity coverage, however, does result in an overall global or systematic error of about 5 metres. The procedures in use at the Earth Physics Branch also involve satellite in addition to land gravity data. The computer routines are complete with error analysis to put bounds on the accuracy of the computations. We lack, however, the practical techniques (with error analysis) to compute the geoid locally. Perhaps the most serious aspect of this shortcoming is the lack of specifications to establish the distribution of gravity stations needed for the computations. The study proposed here is intended to remedy this situation.

The Field Programme

It is proposed that the Geodetic Survey of Canada provide astro-geodetic deflections at intervals of 5 - 15 km along a profile some 200 km in length. The required gravity measurements within the area (see below) will be carried out by the Gravity Division. As the requirement for knowledge of the local geoid is becoming an increasingly more urgent matter, it seems important to begin planning the study in 1974 so that a start can be made in 1975.

The choice of area for the study is subject to agreement, although it would seem preferable to locate it as near to Ottawa as possible. Other factors affecting the choice of location are:

1. The area should contain horizontal gravity gradients greater than 1 mgal/km.
2. A good network of roads should be available for the gravity work.
3. Good vertical control is required for the gravity work.
4. Areas of high relief are to be avoided initially because of operational, computational and other problems.

The Research Programme

The research programme will consist largely of the analysis and evaluation of the field data either directly or through models of the gravity field. Implicit in this will be critical field tests of the developments from the research. Basically this research will be carried out by one scientist at the Earth Physics Branch. Some additional support could be gained from the employment of a Postdoctorate Fellow in physical geodesy at the Earth Physics Branch. However, candidates and other factors considered, it is not likely that a PDF could be engaged before 1976. A "one scientist" research project is estimated to take 3 - 5 years to complete to the point where the procedure is routine. An immediate start would imply a finish somewhere between 1978 and 1980.

If the time framework is too great for the needs of Surveys and Mapping Branch (and on the assumption S & M wishes to take part in the project) some speed-up could be achieved by assigning one of their personnel to the research phase of the project. Provided any such individual work full time on the project and was assigned to work at the Earth Physics Branch for the duration of the project, we could envisage a saving in time of as much as 18 months. Aside from that of time, other possible advantages of such a suggestion include a better understanding of the respective requirements of the two branches, better communication in future and the indirect benefit to other research activities such as the application of inertial guidance platforms to surveying problems of interest to both branches.

EMPLACEMENT OF FUNDAMENTAL GEODETIC POINTS AT THE PZT SITES

Proposal

It is proposed that the Geodetic Survey erect permanent, first order control points in the close vicinity to the present PZT (Photographic Zenith Tube) sites near Calgary and Ottawa that will form part of any national geodetic control network.

Background

The PZT defines latitude and longitude within an astronomical coordinate system at the present time of unsurpassed precision. At their location there is a record of changes extending over decades.

Satellite-doppler is being installed at the same locations during 1974 to operate continously as part of the international TRANET programme and similarly gives position of great precision but to an earth centered coordinate system.

In the future techniques based on additional satellite systems (GLOBAL, GEOLE) will probably be located in the same sites because of prior existence of the PZT's. Also quite independent systems of measurement of position will probably be deployed when, and if, they become practicable like Very Long Baseline Interferometry.

A restructuring of the fundamental geodetic network of Canada and North America is imminent although no system has yet obtained general approval. Whatever the system, it is advantageous for future research into control networks and earth movements to have the network extended to the vicinity of the PZT's so that any changes in the

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definition of the nets in the future can be related to the observation of continuously recording high precision instruments.

Programme

All that is required is that geodetic piers be constructed within the boundaries of the PZT sites and that these piers be surveyed in at highest practicable precision to the control network.

One possible advantage, depending on the adopted network definition is that these piers can form part of the network with positional constraints given by the geodynamics instruments located there.

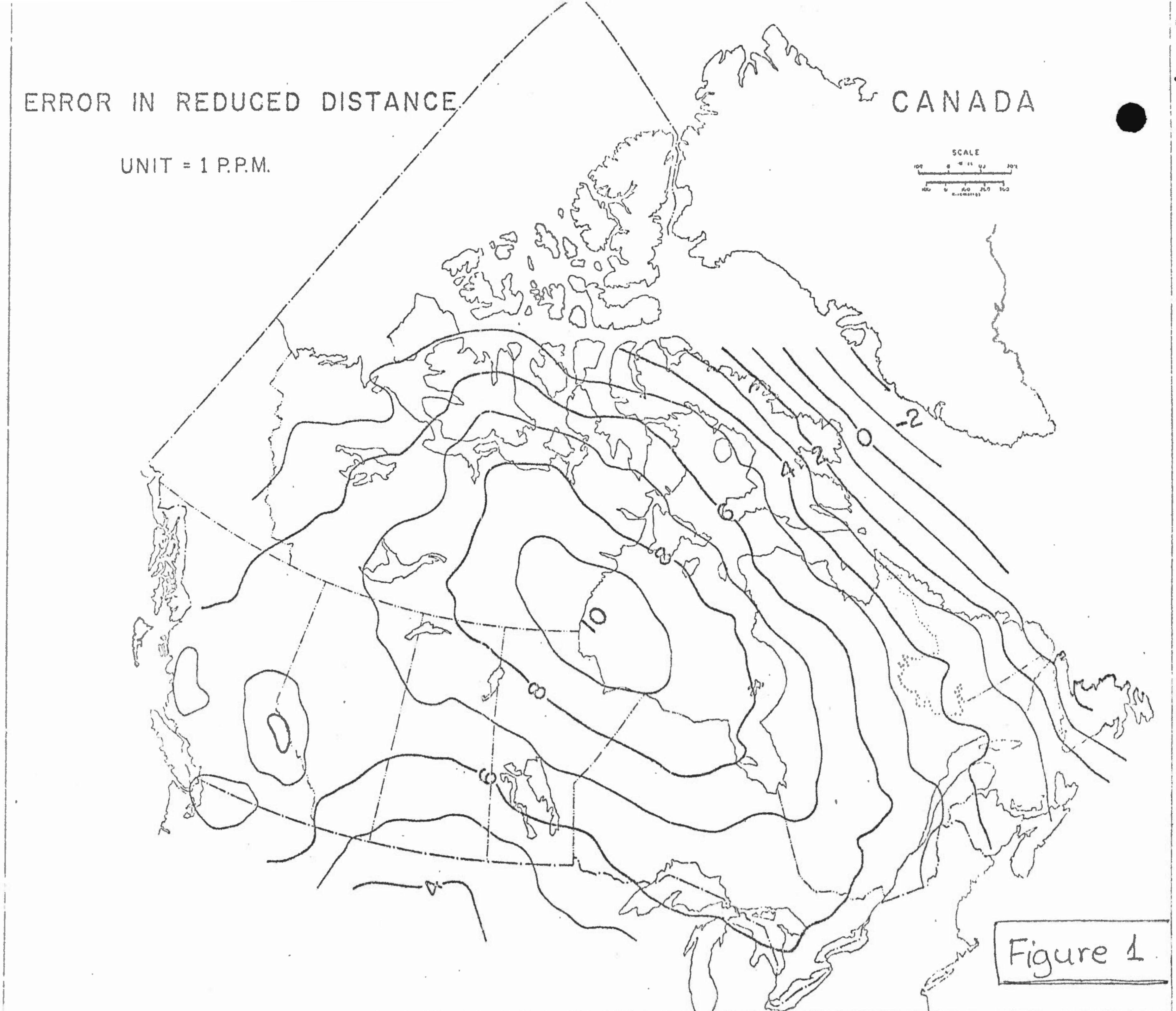
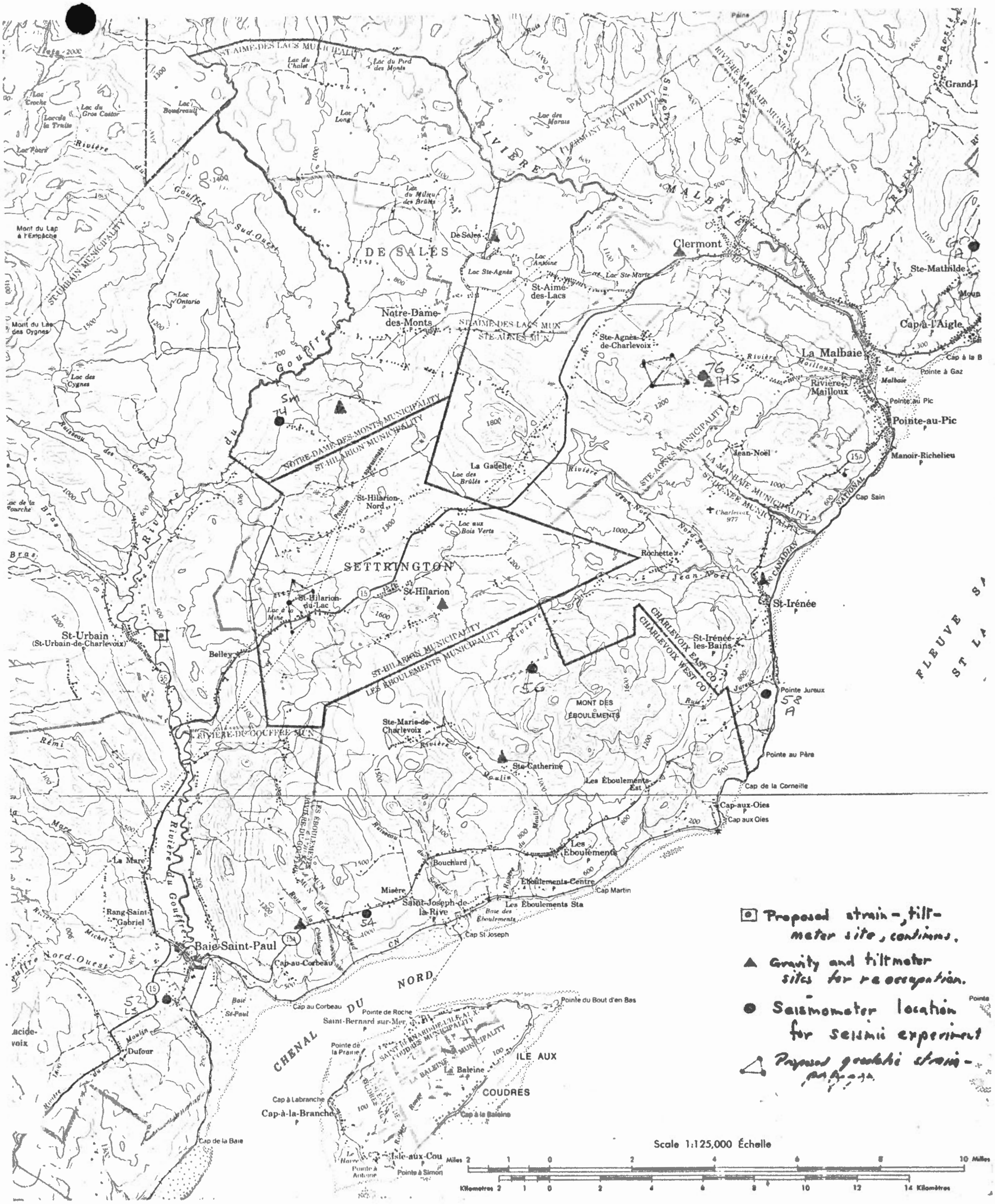


Figure 1



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Rivière-Mailloux
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CLERMONT MUNICIPALITY
RIVIERE MALBAIE MUNICIPALITY
CHARLEVOIX EAST CO
CHARLEVOIX WEST CO
RIVIÈRE MALBAIE
Rivière du Gouffre
Scale 1:125,000 Échelle
Miles 2 1 0 2 4 6 8 10 Milles
Kilometres 2 1 0 2 4 6 8 10 12 14 Kilomètres
Proposed strain-, tilt-meter site, continuous.
Gravity and tiltmeter sites for reoccupation.
Seismometer location for seismic experiment
Proposed geodetic strain-polygon.