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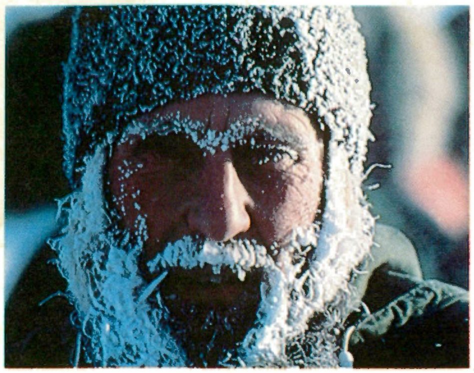
COUVERTURE: *Les plongeurs Joe MacInnis et Emory Kristoff, de la National Geographic Society, inspectent un instrument de mesure du flux de chaleur, qui a été installé sous la glace arctique lors du projet LOREX, expédition polaire d'EMR. J.R. Weber, chef du projet, nous décrit l'expédition multidisciplinaire, au printemps de 1979, dans son article intitulé: «Exploration du fond sous-marin de l'Arctique.»*

Exploring the Arctic Seafloor

Pack ice provides the platform for LOREX, a drifting research station which traverses the Arctic Basin over its longest mountain range



LOREX leader J.R. (Hans)/Weber, born in Switzerland, obtained degrees in electrical engineering from the Swiss Institute of Technology and Physics from the University of Alberta. He came to Canada in 1953 to join the Arctic Institute of North America's Baffin Island expedition to the Penny Ice Cap, and during the International Geophysical Year carried out glacier studies in Ellesmere Island. After joining the Dominion Observatory, now EMR's Earth Physics Branch, in 1960, Weber carried out gravity surveys at sea, over the Arctic Islands and Arctic Ocean, and led two geophysical expeditions to the North Pole. He helped develop techniques to measure glacier thickness and for precise navigation in the polar region, and he invented instruments for measuring ocean tilt and wind-induced tilt changes of sea ice.

By J.R. Weber

A map of the floor of the Arctic Ocean looks like a free-form ashtray, shallow as oceans go, seldom as deep as 5000 m. It is crossed by three more or less parallel submarine mountain ranges, like ridges to hold a giant cigar. The central, and longest, ridge, the Lomonosov Ridge, passes close to the geographical north pole. It is 1800 km long and rises 3000 m above the floor of the Arctic Ocean. It bisects the ocean basin, between the Canadian and Siberian continental shelves, and separates the Amerasia and Eurasia basins (Fig. 1).

This great ridge has been the subject of speculation since it was discovered during the winter of 1948-49 by Russian scientists who named it Lomonosov after the 18th century Russian scientist-poet-grammarian.

Some geophysicists theorize that the Lomonosov Ridge was once part of the Barents continental shelf and was rafted to its present position by the process of seafloor spreading. This would have happened 40 to 70 million years ago, possibly at the same time that the North Atlantic opened up. Others suggest that the ridge was formed by other processes.

This speculation is not only academic. Understanding the mechanics of the formation of the ridge will help unravel the tectonic history of the Arctic Ocean. Ultimately, it should help scientists locate areas rich with natural resources like hydrocarbons and other minerals.

A major, multidisciplinary, polar expedition to investigate the nature and origin of the Lomonosov Ridge was conducted by EMR in the spring of 1979. The expedition was code-named LOREX 79, for the Lomonosov Ridge Experiment 1979.

The plan was to establish three stations on the pack ice upstream of the Lomonosov Ridge and let the Transpolar Current, the same current that carried the explorer Fridtjof Nansen's *Fram* across the Arctic Ocean from 1893 to 1896, transport them across the ridge. The hope was that at least one of these stations would drift across its entire width. The timing was critical, as was the initial location of the camps.

The expedition had only a three-month window of work time. The polar night ends when the sun appears above the horizon on March 21, and daylight conditions become sufficiently bright to land aircraft from March 15. The ice begins to melt June 15, and the platform of our camp could crack and begin to disintegrate after that date. We estimated two weeks at each end of the period for the establishment and the evacuation of the camps. This left April and May for the scientific program.

The optimum location for the camps was 100 km from the North Pole and 900 km from Alert, where the ridge is narrow and the chances of drift right across it highest.

These careful calculations, plus some good luck, paid off. The main camp drifted 160 km, across the entire width of the ridge from the Amerasia to the Eurasia basin over the 60-day period of scientific work. One of the satellite camps drifted to within 12 km of the geographical North Pole.

Airlifting, over such a long distance, the staggering quantity of 250 tons of supplies and equipment required for an operation the size of LOREX was an enormous logistics problem. It was solved with the assistance of the Canadian Armed Forces 435 Squadron of the Tactical Airlift School, Edmonton, which paradropped the bulk of fuel and supplies at the LOREX site. Their Lockheed C-130 Hercules aircraft flew 16 missions from Thule, Greenland for the job. The balance of equipment, supplies and personnel was flown out of Alert in 19 flights using the newly developed De Havilland Dash-7 STOL aircraft. At the end of the operation in June the same Dash-7 carried out the evacuation of all personnel and equipment to Alert.

The population of the LOREX camps varied from 30 to 36. Surveys over the ice were by helicopter, and transport between the camps and to Alert by Twin Otter aircraft. Radio navigational aids gave the aircraft their geographical position at all times to an accuracy of about 1 km.

Geoscience studies were conducted at the main camp, while oceanographic studies were carried out at the satellite camps. Satellite camp Iceman was the site for physical oceanography including salinity, temperature, depth and current measurements, and acoustics, or sound propagation studies. Satellite camp Snowsnake housed the chemical oceanographers, responsible for nutrients and trace element sampling and carbonate chemistry.

Concurrently with LOREX the multidisciplinary expedition FRAM 1, described by Robin Falconer in the following article, was operating some 600 km away in the vicinity of the Nansen-Gakkel Ridge. From planning to execution, the two expeditions kept in close touch. This resulted in excellent logistics and scientific cooperation and culminated in a one-day special session at the joint meeting of the Canadian and American Geophysical Unions in Toronto in May 1980. The session was entirely devoted to the LOREX and FRAM 1 scientific results.

The preliminary results of the LOREX geoscience studies, which follow, received their first public exposure at this joint scientific meeting.

Bathymetry

Over 250 individual depth soundings and gravity measurements and some 600 km of echo soundings and gravity recordings were obtained. A 100 m contour map (Fig. 2) of the ocean floor was compiled from these results and from the data collected from the two previous North Pole expeditions. The shallowest and deepest depths recorded were 956 m over the ridge crest and 4306 m in the Fram Basin, respectively. The average slope of the Makarov flank from near the base to near the crest of the ridge is as steep as 14°, whereas the corresponding slope of the Fram flank does not exceed 6°. The Fram Basin is more than 300 m deeper than the Makarov Basin. Comparison of this contour map with the General Bathymetric Chart of the Oceans (GEBCO, 5th edition, 1979) shows the ridge crest between 18 and 34 km further south than on the GEBCO map.

Figure 2 shows the drift tracks of the LOREX main camp and the two satellite camps, Iceman and Snowsnake, as well as those of the 1967 and 1969 expeditions.

Satellite Transit Navigation

All three stations were equipped with Transit Satellite receivers. Positions were computed on-line at the main station, whereas the raw satellite data from Snowsnake and Iceman were collected every few days and processed at the main camp on a HP 2100 computer. By computing the positions from satellite passes simultaneously for all three stations it was possible to determine the horizontal positions of the station to better than 50 m (Fig. 2) and the geoidal heights to better than 50 cm.

Plumbline deflection measurements

Star observations were made with a Wild T-4 theodolite at the main camp and at Iceman. The plumbline deflections were computed from the difference between the astronomically determined drift path

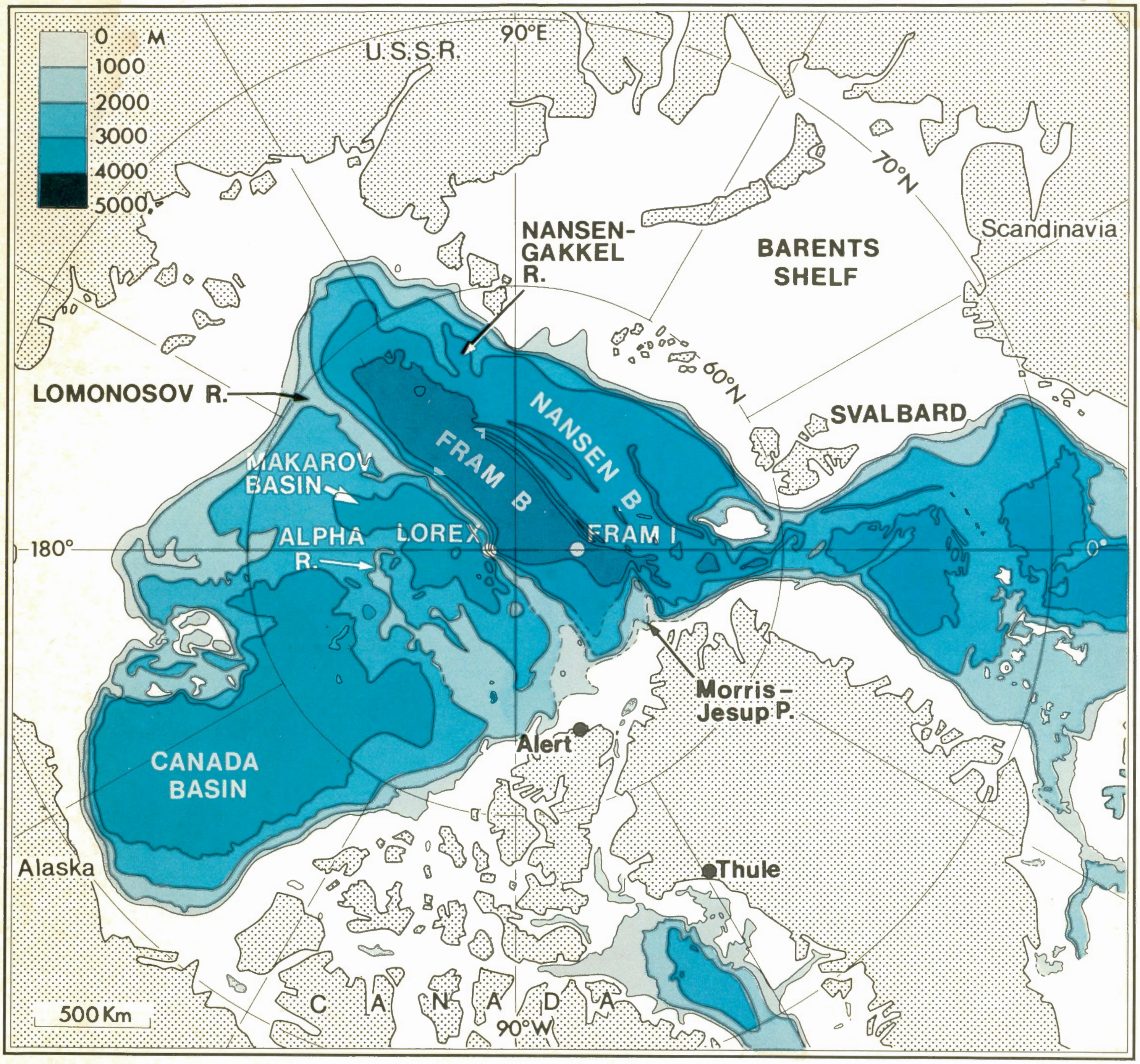


Figure 1. *Arctic Ocean seafloor features* *Éléments naturels du fond sous-marin de l'Arctique*

and the transit satellite drift path. The deflections ranged in magnitude from 30 to 60 microradians, and pointed towards the ridge crest for stations located over the ridge, and away from the ridge crest for stations located over the ocean basins. These measurements complement gravity measurements and tell us more about the density structure of the ridge.

Marine Geology

A high resolution, shallow seismic reflection profiler, consisting of a 10-cubic inch compressed air gun, was located at the main camp. Its powerful sound waves mapped the top 1200 m of the ocean floor, showing the ridge to consist of fault blocks whose tops are covered with a thin layer, less than 75 m, of unconsolidated sediments (Fig. 3). Since these stratified sediments lie conformably upon (parallel to) the irregular fault block tops, they appear to have been deposited before the faulting process started. Sea floor photographs show that these sediments are presently being eroded by the current (Fig. 4).

Strong pulsating water currents with velocities in excess of 12 cm per second (cm/s) sweep across the ridge crest; this has been confirmed by the data obtained from self-recording current meters moored to the ocean floor near the ridge crest and recovered 50 days later. The shallow seismic measurements further reveal a total absence of unconsolidated

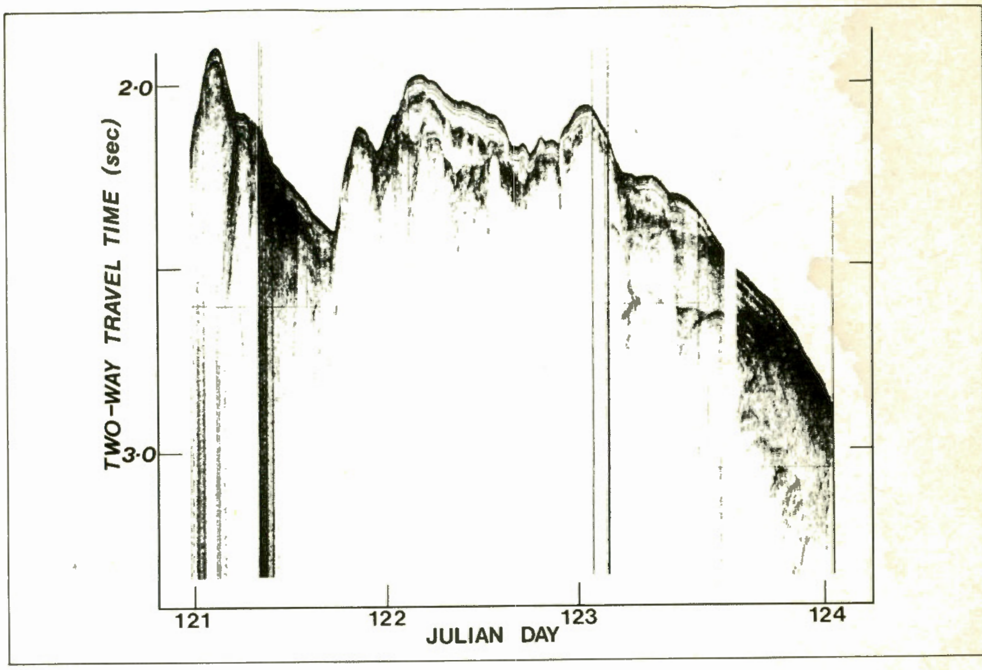


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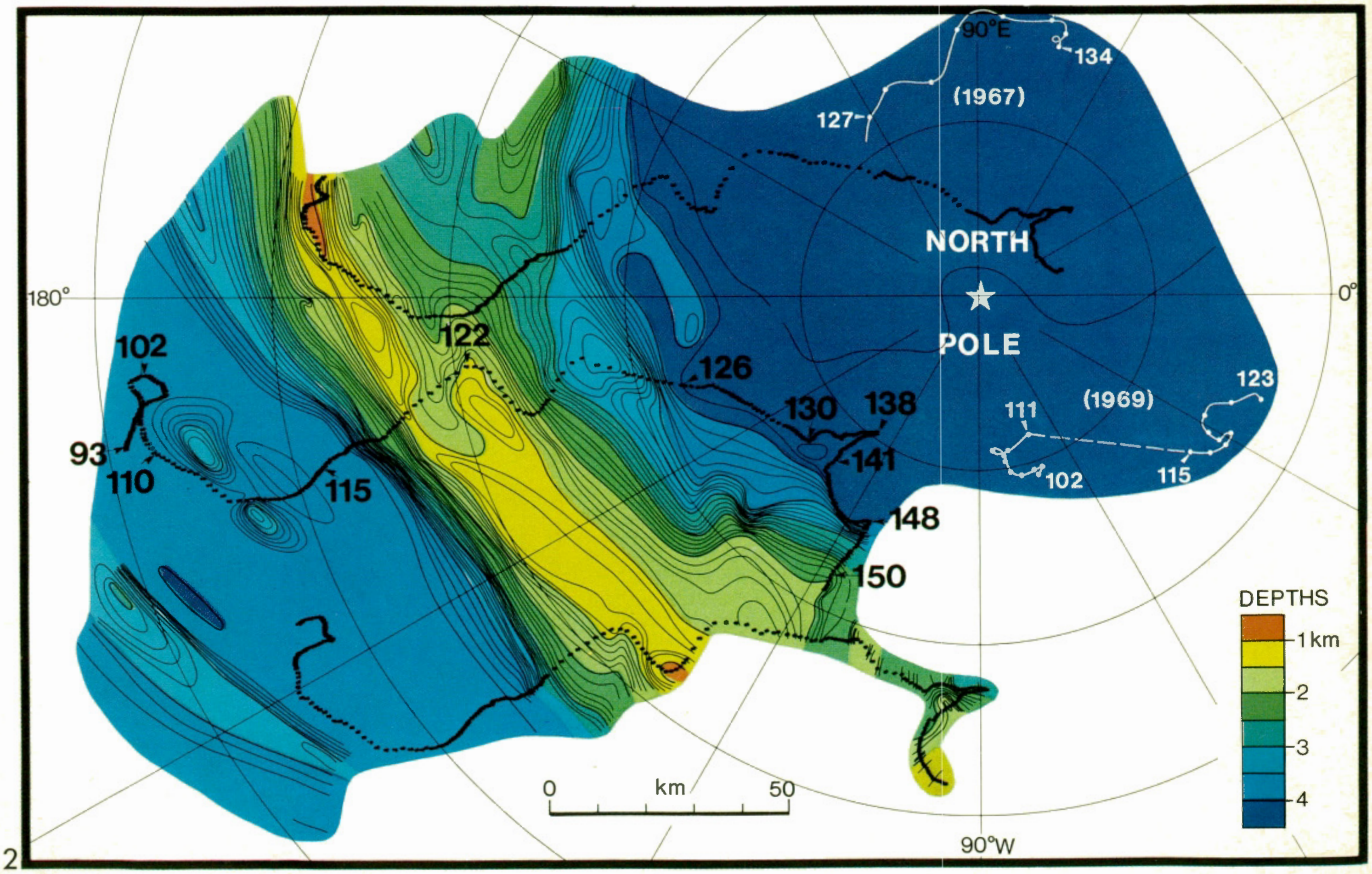
Figure 2. *Bathymetry of the ocean floor recorded on LOREX 79 as it crossed the Lomonosov Ridge. The dots on the LOREX drift tracks, spaced at three-hour intervals, show the variable speed of the drift, ranging from zero to 1100 m/hr, at which the ice drifted over the 60-day period. The numbers indicate Julian days*

Bathymétrie du fond océanique enregistrée au cours de LOREX 79 au moment où le camp dérivait au-dessus de la dorsale de Lomonossov. Les points sur le tracé de dérivation de LOREX, mesurés à des intervalles de trois heures, indiquent la vitesse variable de dérivation de la banquise, qui s'inscrit dans une fourchette de 0 à 1100 m/h, au cours des 60 jours qu'a durés l'expédition. Les chiffres renvoient aux jours du calendrier



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sediments on the Makarov flank, and more than 1100 m of well stratified flat-lying unconsolidated sediments, that infill the Makarov and Fram basins and abut unconformably against the ridge flank.

Forty-two sediment cores, up to 1.7 m long, were recovered from the two basin floors and from the ridge. In light of our knowledge that the sedimentation rate in the Arctic Ocean basins is about 1 mm per 1000 years, the sediments collected will provide insight about oceanographic conditions and the history of the ice cover during the last 1-1/2 million years. A preliminary analysis of a core from the ridge crest shows spores and microfossils as old as 350 million years. One of the microfossils, the Dinoflagellate Luxadinium Propatulum, originally inhabited water depth of about 200 m and became extinct about 80 million years ago.

The results of the sub-bottom profiling and of the core analysis strongly support the hypothesis that the ridge was part of a continental shelf less than 100 million years ago.

Intermediate reflection seismic

Intermediate seismic reflection profiling was conducted at the main camp. A cross-shaped geophone array picked up the echo of explosives detonated at its centre. Preliminary results confirm a layer of approximately 1 km thick horizontally stratified sediments under-lying both ocean basins adjacent to the ridge flank. Both the rock below the unconsolidated basin sediments, and the core of the ridge adjacent to the flanks, also reveal a complex structure of reflecting layers. These reflections may arise from faulted sedimentary or sill or dyke structures that extend at depth, some distance beyond the ridge flanks into the adjacent ocean basins. Further analysis of the intermediate reflection seismic data should reveal the nature of the geological structure to a depth of at least 10 km.

Deep crustal refraction seismic

Deep crustal seismic results were obtained on two partially reversed refraction profiles along and across the ridge. The Makarov and Fram Basins are modelled with a 1 km thick sedimentary layer underlain by a material with a velocity of about 4.7 km per second (km/s) and a thickness of 3 to 4 km. The uppermost 6 to 7 km of the ridge core has a similar velocity and may be the same material, conceivably a vesicular oceanic basalt. Material with velocities in this range are, however, common elements of continental crust. Immediately beneath this layer on the ridge a thick layer of 6.6 km/s material is evident. The lack of any evidence for material of intermediate density, with velocities in the 5.5 to 6.3 km/s range, is anomalous if we assume conti-

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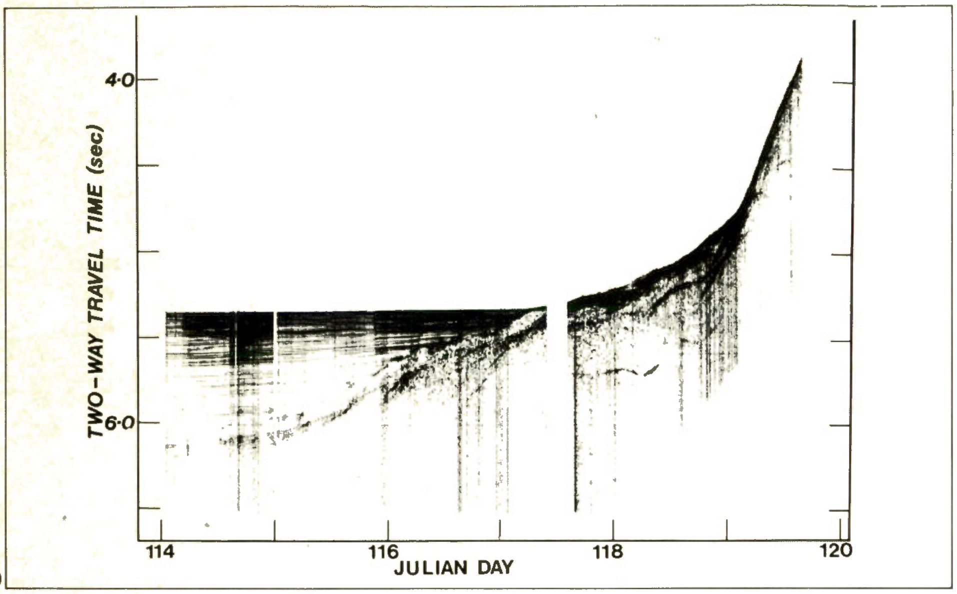

Figure 3. *Shallow seismic profiles, a. top of Lomonosov Ridge. b. edge of Makarov Basin*

Profils sismiques peu profonds, a) au sommet de la dorsale de Lomonossov et b) à la pointe du bassin de Makarov

S.M. Blasco, AGC, GSC, BIO/CGA, CGC, IOB

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Figure 4. *Seafloor photograph, taken in 1830 m of water, showing current erosion and associated coarse gravel pavement, and an outcrop of older semiconsolidated sediments in the bottom left. The compass vane is aligned in the direction of current flow towards the bottom right.*

Photo du fond océanique, prise à une profondeur de 1830 mètres, montrant l'érosion par le courant et le dallage de gravier grossier associé, ainsi qu'un affleurement de sédiments plus anciens, semi-consolidés, en bas, à gauche. L'aiguille de la boussole est alignée dans la direction du courant vers le bas, à droite

N.E. Fenerty, BIO/IOB

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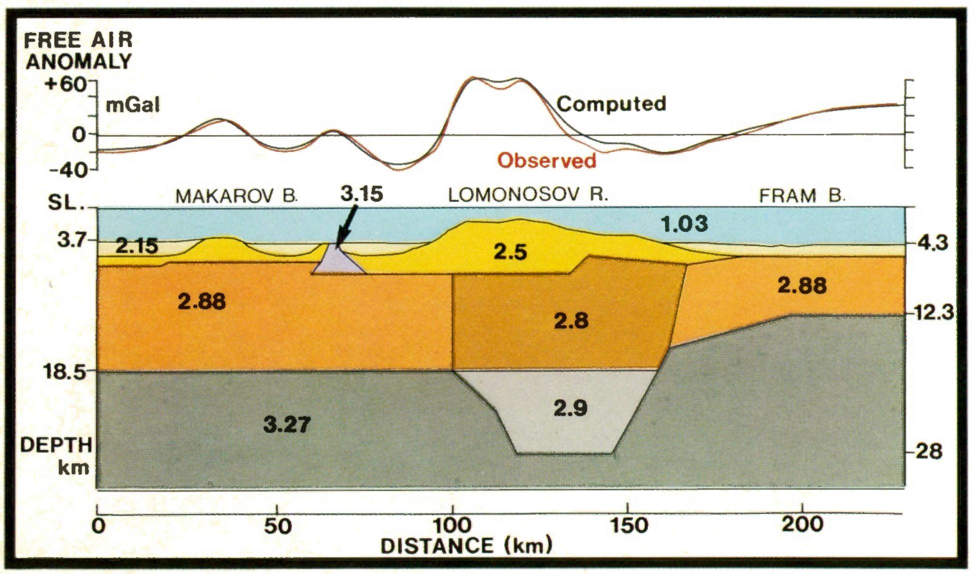

Figure 5. *Gravity crustal model of the area crossed by LOREX 79: Makarov Basin, Lomonosov Ridge, and Fram Basin*

Modèle gravimétrique de la croûte dans la région traversée par LOREX 79: bassin de Makarov, dorsale de Lomonossov et bassin de Fram nental-type crust. However this sequence of materials is quite typical for oceanic crust.

The crust-mantle boundary, as indicated by a sharp break from material with velocity of 6.6 km/s to 8.3 km/s, with a good upper-mantle reflection break, indicates crustal depths of 12.5 km for the Makarov Basin, 16 km for the Fram Basin and 28 km for the Lomonosov Ridge.

The implications of these preliminary results are (1) that while a thin veneer of continental sediments may be present, the core of Lomonosov Ridge, in the area of the survey, is composed of an oceanic sequence of rocks and (2) that the Makarov and Fram Basins were formed at different times.

Gravity

The free-air gravity anomaly (difference between observed and theoretical gravity at sea level) is characterized by a positive linear anomaly of between 60 and 85 milligal (mgal) centered over the ridge crest. This is flanked by two negative anomaly troughs of up to -50 mgal centered approximately along the 3900 isobaths on either side of the ridge. Further away from the ridge the free-air anomaly field is generally positive (~25 mgal) over the Fram abyssal plain and negative (~-20mgal) over the Makarov abyssal plain.

Stephen Blasco, Geological Survey of Canada, lowers a grab sampler through a hole in the ice platform

M. Stephen Blasco, de la Commission géologique du Canada, descend un carottier dans un trou foré dans la banquise

We have constructed a preliminary, very generalized, two-dimensional crustal model from bathymetry, and shallow, intermediate and deep seismic information available. This model explains the observed free-air anomaly in terms of density contrasts within the crust (Fig. 5). It shows the Lomonosov Ridge to have a root 28 km deep, imbedded in a higher density oceanic crust. The gravity high centered over the crest reflects the ridge bathymetry, caused by displacement of water by higher density rock. Since there is no seismic evidence for low density troughs deep enough to explain the gravity lows, the negative troughs on either side of the ridge must be caused by the density contrast between the root and the surrounding higher density crustal and mantle rock. The fact that the gravity anomalies are higher and the water depth greater in the Fram Basin implies that it has thinner crust (12.3 km) than the Makarov Basin (18.5 km).

The main LOREX camp in high winds and drifting snow at beginning of May 1979

Le camp principal LOREX, au milieu des vents violents et des rafales de neige, au début de mai 1979

Two implications follow from this preliminary gravity model: (1) the lower density of the root compared with the crust of the adjacent basin may indicate that the Lomonosov Ridge is a continental fragment, and (2) the thicker crust of the Makarov Basin may indicate it was formed before the Fram Basin.

Magnetic Studies

Magnetovariational and magnetotelluric fields were recorded at the three stations. The two main conclusions reached from these studies are, (1) the crust and upper mantle beneath the ridge are electrically similar to those beneath the adjacent basins, and (2) there is up to one kilometer of highly conductive sediments in the basins and almost none on the ridge.

Results from an aeromagnetic survey flown along and across some 500 km of the Lomonosov Ridge at a height of 300 m show a zone of anomalies of over 1000 nanoteslas, centered on the southern flank, parallel to the ridge crest. We conclude that the Lomonosov Ridge is composed of igneous rather than sedimentary rocks, or at least that it has had a considerable amount of associated igneous activity during its recent geological past.

Heat Flow

A total of 42 heat flow measurements were made by penetrating the sea bottom sediments with a 3 m long gradiometer probe. The probe was left in the ground for a minimum of 20 minutes while seven heat sensors, spaced equidistant along the probe, recorded the temperature gradient. In addition, over 300 thermal conductivity measurements were made with a hypodermic needle probe on 21 cores retrieved by the marine geologists. The resulting calculated heat flux from the interior of the earth is highest in the Fram Basin. This is consistent with an age of 40 million years for the margin of a basin containing an active spreading centre. The head flows measured on the Lomonosov Ridge are slightly higher than those in the Makarov Basin. If we assume a crustal thickness of 28 km for the ridge, the observed values correspond to a low heat production, as would be generated by a composition of sediments underlain by a basement of gneisses or granodiorites. This reasoning is consistent with the theory of a continental fragment originating from the Barents Continental Shelf.

Conclusions

Preliminary marine geological results support the theory that the Lomonosov Ridge was once part of the Barents Continental Shelf. Gravity and geothermal studies indicate that most of the ridge and its root is of continental origin, and deep crustal refraction seismic and magnetic studies imply that the ridge core may be composed of oceanic rocks. Preliminary refraction seismic interpretation seems to indicate that the crust of the Makarov Basin is thinner than that of the Fram Basin. On the other hand, gravity interpretation shows the reverse to be true. This discrepancy has not yet been resolved.

The next step in unravelling the geological history of the ridge is to synthesize the separate studies. In particular, analysis of the intermediate reflection seismic results from below the unconsolidated sediments, and their correlation with the deep refraction seismic data, promises to go a long way in unlocking the secret of Lomonosov's origin. □

Acknowledgements

The scientific program was conceived and developed by EMR's Earth Physics Branch, which had conducted two geophysical expeditions to the vicinity of the North Pole in 1967 and 1969. The logistic support of the expedition was provided by the Polar Continental Shelf Project of EMR.

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Satellite Navigation: David Wells, Dept. of Fisheries and Oceans, and Joe Popelar, Earth Physics Branch (EPB), EMR

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Heat Flow: Alan Judge, EPB

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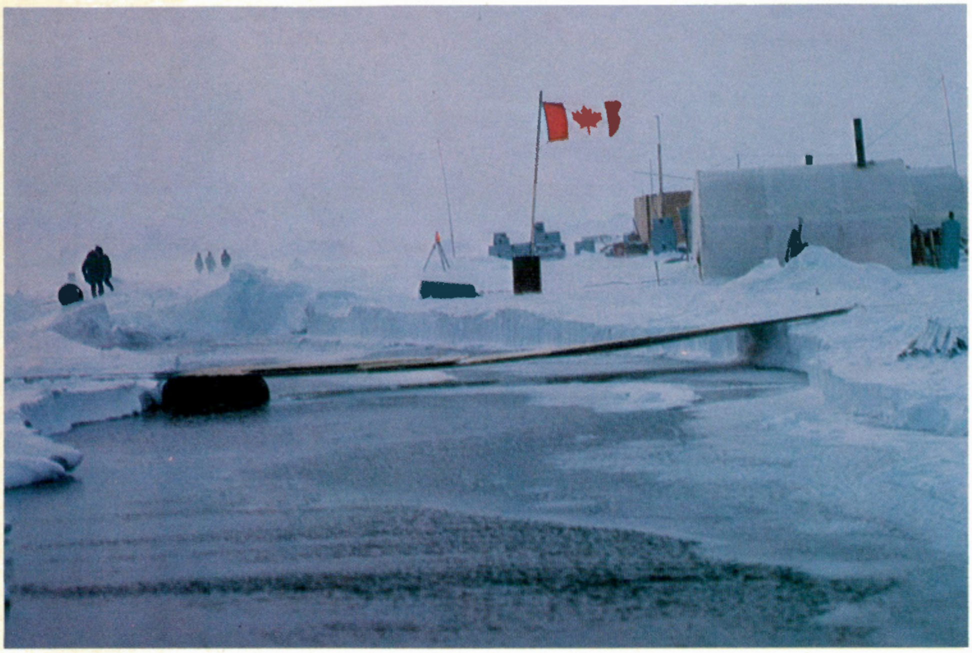
Camp Manager: Fred Alt, PCSP



A huge crack split the LOREX camp, May 1, 1979. The ice refroze in few days
Une fissure énorme a coupé le camp LOREX en deux, le 1er mai 1979. La glace a gelé à nouveau quelques jours plus tard

The main camp at end of April 1979 with LOREX spelled out in oil drums
Le camp principal à la fin d'avril 1979 avec le mot LOREX écrit à l'aide de bidons d'huile

FRAM
Second Drifting Research Station

While LOREX explored the Lomonosov, FRAM 1 floated over the Nansen Ridge

Au printemps de 1979, EMR a monté une importante expédition polaire multidisciplinaire en vue d'étudier la nature et l'origine de la dorsale de Lomonossov. Cette expédition fut baptisée LOREX 1979 (recherches sur la dorsale de Lomonossov 1979).

La dorsale est une chaîne sous-marine de montagnes qui s'élève à plus de 3000 mètres du fond de l'océan Arctique et s'étend sur une distance de 1800 kilomètres. Elle divise le bassin océanique en deux, entre le plateau continental canadien et le plateau continental sibérien, et séparant les bassins amérasien et eurasien.

Le principal camp LOREX et deux camps satellites furent montés vers la fin du mois de mars. Pendant 60 jours, la station LOREX a dérivé sur une distance de 160 km, sur un axe qui coupait transversalement la dorsale, qu'elle a ainsi complètement franchie. Durant cette période, 36 employés de l'EMR, scientifiques et personnel de soutien, ont effectué des études géoscientifiques et océanographiques.

Une autre expédition multidisciplinaire, le FRAM 1, s'est déroulée en même temps à une distance de 600 km du LOREX, près de la dorsale de Nansen-Gakkel. Des chercheurs américains, norvégiens, danois et canadiens y ont participé, et les deux expéditions sont restées en étroite liaison.

Les résultats préliminaires des études géoscientifiques, présentés dans ces articles, ont été livrés pour la première fois lors d'une session spéciale d'une journée, tenue dans le cadre de la réunion de l'Union géophysique canadienne et de l'*American Geophysical Union*, à Toronto, en mai 1980.

Ces articles sont disponibles en français.

By Robin Falconer

The famous Norwegian explorer Fridtjof Nansen in 1893 froze his ship, the Fram, into the ice to create a drifting research station. From it, he conducted the first scientific study of the Arctic Basin. In early summer 1979, another research project adopted the name of Nansen's ship, and while scientists on the LOREX project were studying the Lomonosov Ridge, FRAM 1 was drifting over the southern part of the Nansen Ridge, to the east (see map page 3).

FRAM 1 was a multi-nation, multidiscipline project with scientists from U.S.A., Canada, Norway and Denmark and studies ranging from below the seafloor to the upper atmosphere. The subsea structure was studied with gravity, magnetics, and seismics; the seafloor with dredges and corers. In the water, data on acoustics, chemistry, currents, biology and physical properties were gathered. The ice platform the camp was on was itself studied, as was life on the ice in the form of polar bears, and above the ice in metrology, air pollution and ionospheric radio propagation. Twenty scientific and support staff had only two months on the ice to cover this broad spectrum of science.

LOREX and FRAM were too far apart for frequent contact, but some acoustic propagation was done jointly and two men from LOREX made a one-day visit by Twin Otter aircraft to FRAM. The 1979 project was the first of a planned series of these eastern Arctic studies from drifting ice camps. FRAM 2 took place in March to May 1980 and FRAM 3 will follow in 1981. The U.S. Office of Naval Research initiated the program and does most of the logistics, but scientists from other nations and organizations participate and contribute.

On FRAM 1, the Canadian contribution was to use seismic methods to study the structure of the crust. Three scientists from the Geological Survey of Canada's Atlantic Geoscience Centre (AGC) at the Bedford Institute of Oceanography, Dartmouth, and one from Dalhousie University, formed two teams to run the program on the ice from March 11 to May 13, 1979. They measured sediment thickness with an airgun reflection system and the deeper structure by seismic refraction. Explosives were the sound source and they were deployed by helicopter up to 80 km from the camp. An ocean bottom seismometer (OBS) lowered by winch through the ice beneath the camp recorded the signals from the explosions.

Why study the crust at that point on the southern part of the Nansen Ridge? The Ridge extends from near Greenland across to the East Siberian shelf, and is a part of the globe-encircling system of ocean floor ridges along which plates of the earth's surface are separating and forming new seafloor, or new crust. To understand the evolution of the earth's crust, we need to know if its nature varies with the rate it formed. The Nansen Ridge is the slowest spreading ridge in the world, opening at the rate of 0.6 to 1.0 cm a year. This alone makes it especially important to study. In addition, the Ridge has the uniform parallel magnetic stripes typical of spreading ridges, but at the end nearest to Greenland the amplitude of the anomalies suddenly increases dramatically. Why? Does different thickness of the crustal layer produce the larger magnetic anomalies? Are different type of rocks the cause? There were no data to answer the questions.

On FRAM 1 we hoped to obtain the data by doing a series of refraction lines as the ice camp drifted. The predicted ice drift pattern was southwards from the western flank of the ridge, across the axis, then along the ridge and up onto the Greenland margin. In fact, immediately after the camp was established, the ice reversed the expected pattern, and went "backwards" to the north. It then stayed almost in place for several weeks and then slowly, but too slowly, drifted to the south. It never did reach the ridge axis or the Greenland margin during the two month duration of the project.

Nevertheless, scientific objectives were largely met. In eight refraction lines on the ridge flank we found that the crust is only three km thick — one of the thinnest oceanic crusts anywhere in the world. The camp only just reached the highly magnetic zone at the south end of the ridge

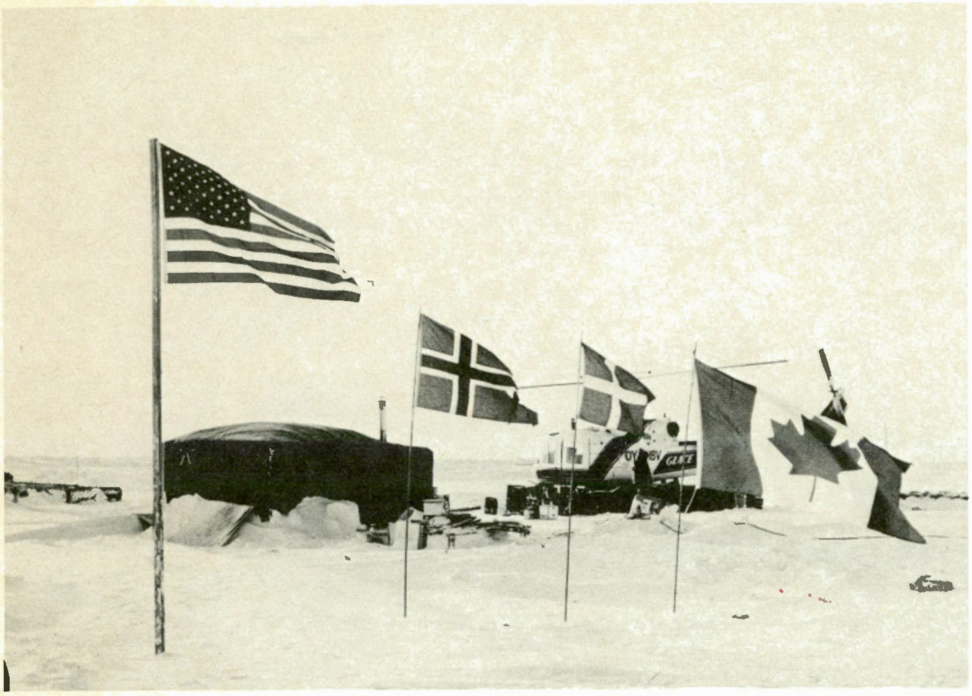
Dr. Falconer was until recently Head of the Eastern Arctic Offshore Group at EMR's Atlantic Geoscience Centre, Geological Survey of Canada, at the Bedford Institute of Oceanography in Dartmouth, N.S.

1 *Flags of the four participating nations on FRAM 1: U.S.A., Norway, Denmark, Canada*

Les drapeaux des quatre pays participant à l'expédition FRAM 1: États-Unis, Norvège, Danemark, Canada

2 *Helicopter view of FRAM 1 after the camp ice floe split on March 28, 1979*

Photo prise par hélicoptère, du camp FRAM 1 après la fissuration de la banquise le 28 mars 1979



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before May 15, the end of the project, and there was time left for only one refraction line. The results show that the crust is considerably thicker at this point than further north. This could explain the strong magnetic anomalies.

Why is it thicker there and so thin elsewhere? This will be the subject of speculation and models that will be published along with the data in a scientific journal.

AGC's Ruth Jackson and Don Locke returned to the ice again on FRAM 2, from March 19 to May 7, 1980. They ran more refraction lines, this time with groups from the U.S.A. that we had worked with north of Alaska in 1978. The FRAM 2 program was more restricted than FRAM 1, with only crustal studies, marine acoustics and some physical oceanography. The study area was the middle of the basin between the Nansen Ridge and the Lomonosov Ridge. The crust there is 50-60 million years old, but it also formed at a very slow spreading rate. Our objective was to compare it to the younger, 10-20 million year-old crust studied by FRAM 1 on the Nansen Ridge, to see if crustal properties change with time.

The ice drift in 1979 on FRAM 1 was too slow, and in 1980 on FRAM 2 it was too fast. Before the crustal studies could be fully completed, the camp was out of the deep water and up onto the Greenland margin. However, we did get enough data in the basin to contribute to understanding the crustal evolution. It is not yet analyzed but there are indications that the 50-million-year-old crust is thicker than the younger crust.□

More crustal studies, planned for the future, will within the next few decades bring our knowledge of the Arctic Basin up to our current understanding of other ocean areas. Most important is another geophysical expedition to the Polar Sea, to study the Alpha Ridge (Fig. 1), the least understood of the Arctic seafloor features. The expedition has been code-named CESAR 82, standing for Canadian Expedition to Study the Alpha Ridge, 1982. It is planned for the spring of 1982, the Centennial of the First International Polar Year in 1882. If approved, it will be organized by the Earth Physics Branch in cooperation with the Polar Continental Shelf Project, both of EMR. It will be similar to LOREX in size and composition.

In the meantime, Norwegian and Swedish scientists will work this summer north of Svarlbard from a Swedish icebreaker. FRAM 3, in 1981, still being planned, will emphasize physical oceanography, but EMR scientists will join it to do crustal studies. Later FRAM programs may revisit the Nansen Ridge.

Landsat et les gisements miniers

Par J.R. Bélanger

Depuis quelques années, grâce à l'avènement des satellites et aux nouveaux types de capteurs, la télédétection joue un rôle grandissant dans le domaine des sciences de la terre. Ainsi, la Commission géologique du Canada a entrepris des recherches afin d'évaluer le potentiel de la télédétection comme outil de travail dans les différentes activités portant sur l'étude géologique du Quaternaire. Parmi les diverses applications de la télédétection on retrouve l'étude des indicateurs géobotaniques, c'est-à-dire l'étude de la relation qui existe entre la végétation et les propriétés physiques et chimiques du sol sous-jacent.

Des études, entreprises par F.C. Canney et W.R. Hemphill, U.S. Geological Survey, en 1975, ont démontré que la concentration de certains minéraux dans le sol influence le type de végétation ainsi que le taux de chlorophylle présent dans les plantes. De plus, C.J. Tucker, U.S. National Aeronautics and Space Administration, a mis au point en 1979 certaines techniques en télédétection pour identifier les types de végétation et contrôler leur état physiologique. C'est donc à partir de ces données que des recherches ont été entreprises afin d'étudier l'influence de la végétation sur les paysages spectraux provenant des satellites Landsat et de voir jusqu'à quel point il est possible de remonter aux sources des dépôts métallifères en se basant sur la végétation.

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The use of remote sensing in mineral exploration is being evaluated at the Giological Survey of Canada. The research is based on the relationship between plant behavior and soil chemistry, and its influence on Landsat imagery. Preliminary studies applied in Thetford Mines area in Quebec show that high concentrations of heavy metals in the soil affect the growth of certain plants and it is possible to monitor this phenomena using Landsat imagery. The use of geobotanical indicators combined with remote sensing show interesting results and further studies are under way to apply this approach to other activities in Quaternary geology.

This article is also available in English

La région choisie pour mettre à l'épreuve la télédétection dans la recherche d'indicateurs géobotaniques est celle de Thetford Mines dans les Cantons de l'Est au Québec. Cette région offre un contexte idéal pour ce genre d'étude puisqu'on y retrouve une végétation abondante et variée ainsi que des affleurements de roches ultrabasiques parmi les plus importants au monde. Lors de la dernière glaciation, les couches supérieures de ces gisements ultrabasiques ont été érodées et transportées par les glaciers, formant ainsi, dans la région située au sud-est de Thetford Mines, une traînée de débris riches en nickel, chrome, cobalt, fer et magnésium. La figure 1 indique la source ainsi que la dispersion des débris dans les dépôts du Quaternaire. On a utilisé à titre d'exemple la concentration en nickel puisqu'elle représente la tendance générale de la dispersion.

L'approche utilisée dans l'étude des indicateurs géobotaniques consiste, en un premier temps, à comparer la composition des espèces végétales dans la zone contaminée avec celle de la zone extérieure; en second lieu de confronter les signatures spectrales de mêmes espèces situées dans l'une et l'autre zones.

Jusqu'ici, des études faites en laboratoire par A.N. Rencz et sur le terrain ont démontré qu'à l'intérieur des régions à haute teneur en métaux lourds, les arbres n'atteignent pas leur plein développement, le taux de chlorophylle est beaucoup moins élevé, les conifères sont plus nombreux et certaines espèces d'arbres, tel que l'érable à sucre, y sont absentes.

L'analyse basée sur la télédétection a été faite à partir de deux scènes MSS de Landsat: une prise le 26 juin, afin d'étudier la végétation en son plein épanouissement, et une seconde captée le 1er novembre, afin d'observer la même végétation à l'état dormant. Les scènes MSS proviennent des balayeurs multispectraux (Multi Spectral Scanners) montés à bord des satellites Landsat. Les capteurs MSS enregistrent les phénomènes situés à la surface du globe sur quatre différentes longueurs d'onde, correspondant au vert, rouge et deux proches infrarouges. Les niveaux de réflectance des objets sont envoyés sur terre sous forme digitale. La résolution des capteurs étant de l'ordre de 57 par 79 mètres, les scènes sont donc constituées de pixels (picture elements) rectangulaires, soit environ 7,360,000 par scène, et pour chacun des pixels on pos-

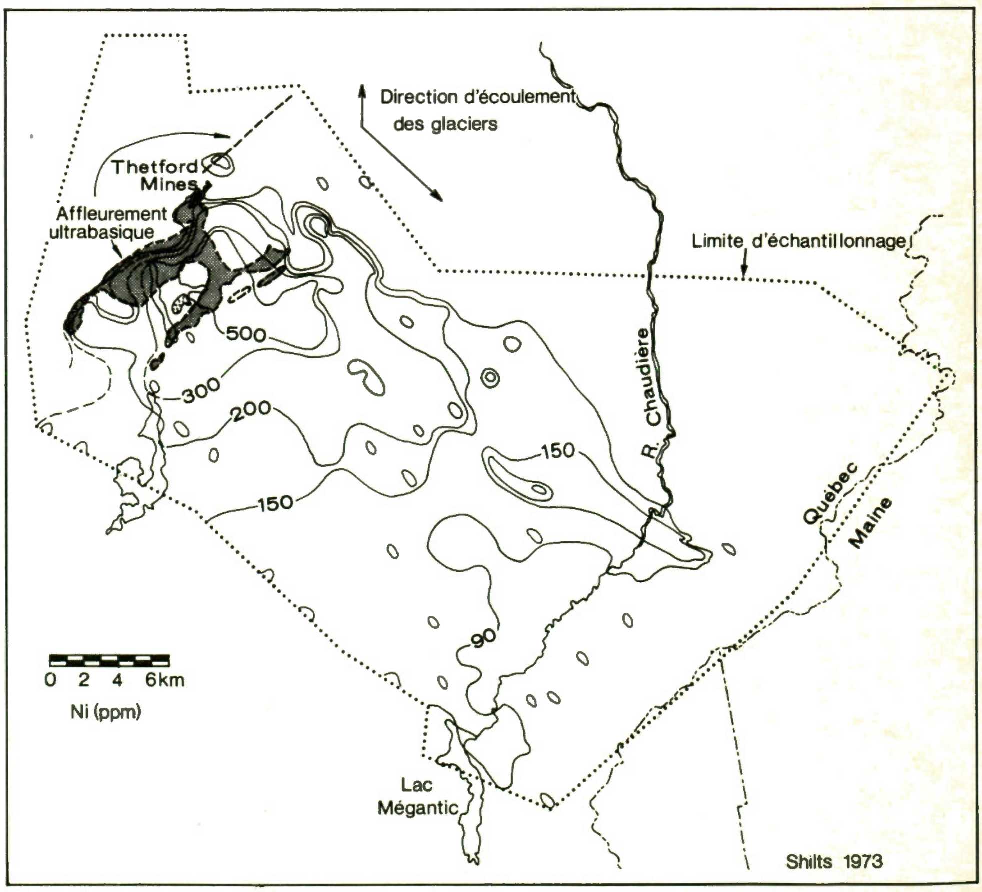


Figure 1. *Dispersion du nickel dans le till*

Dispersal pattern of nickel in till, W.W. Shilts, CGC, GSC

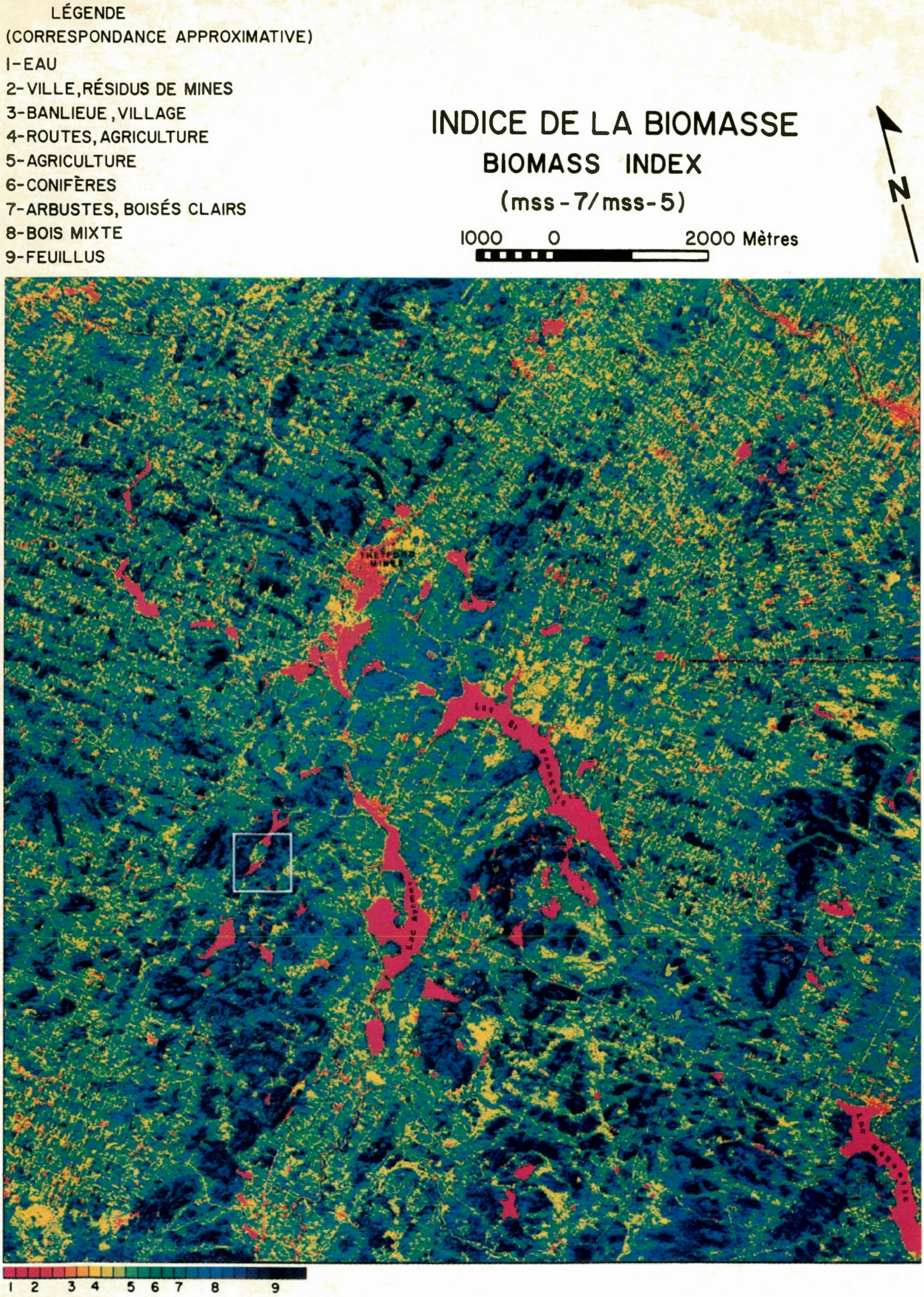

LÉGENDE
(CORRESPONDANCE APPROXIMATIVE)
1-EAU
2-VILLE, RÉSIDUS DE MINES
3-BANLIEUE, VILLAGE
4-ROUTES, AGRICULTURE
5-AGRICULTURE
6-CONIFÈRES
7-ARBUSTES, BOISÉS CLAIRS
8-BOIS MIXTE
9-FEUILLUS
INDICE DE LA BIOMASSE
BIOMASS INDEX
(mss-7/mss-5)
1000 0 2000 Mètres
N
THETFORD MINES
Lac St François
Lac Aylmer
1 2 3 4 5 6 7 8 9

Figure 2.

La mise au point d'indicateurs géobotaniques permettra aux satellites Landsat de fournir un concours précieux dans la localisation de nouveaux gîtes miniers.

sède des niveaux de réflectance pour quatre longueurs d'onde.

A titre d'exemples de documents utilisés pour l'analyse des signatures spectrales dans la recherche d'indicateurs géobotaniques, on donnera ici des histogrammes et une carte de l'indice de la giomasse. Les deux exemples sont basés sur les propriétés des balayeurs multispectraux MSS-5 et MSS-7 de Landsat. Le MSS-5 correspond au rouge (longueur d'onde de 600-700 nanomètres) et le MSS-7 correspond au proche infrarouge (800-1100 nanomètres). Ces longueurs d'onde se prêtent bien à l'analyse de la végétation, car plus la couverture végétale est dense plus elle absorbe de Mss-5 alors que plus la végétation est vigoureuse plus elle réfléchit le MSS-7. Donc à partir de ces données il est facile d'évaluer la densité de la végétation et sa condition physiologique.

Les histogrammes: les graphiques 1 et 2 montrent la répartition des pixels selon le niveau de réflectance du proche infrarouge pour les deux scènes Landsat. On peut observer que pour la scène d'été, la distribution des pixels est beaucoup plus étendue et que les niveaux de réflectance sont plus élevés que pour la scène d'automne. Cette variation est due au changement dans la réflectivité de la végétation; en effet, la végétation vigoureuse de la scène d'été réfléchit le proche infrarouge, tandis que la végétation sénescente de la scène d'automne tend à l'absorber davantage.

Le deuxième exemple se sert de l'indice de la biomasse pour faire ressortir les indicateurs géobotaniques. La carte de l'indice de la biomasse (Fig. 2) a été produite à l'aide d'un traceur couleur Applicon. Grâce à son fonctionnement analogue aux balayeurs multispectraux de Landsat, il est possible de reconstituer les scènes très rapidement sans passer par des moyens photographiques conventionnels. En effet, le traceur balaye la surface de la carte, et à l'aide de trois gicleurs, correspondant au jaune, bleu et rouge, vaporise des jets d'encre dont la densité est contrôlée par des programmes d'ordinateurs. Les cartes ainsi produites sont composées d'une multitude de jets d'encre correspondant à des pixels, de la même façon que les scènes Landsat.

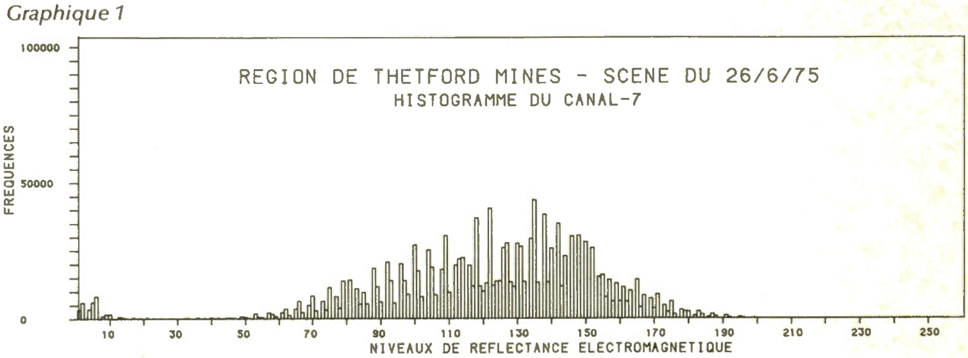
On obtient l'indice de la biomasse en établissant le rapport MSS-7/MSS-5, donc en accentuant le contraste entre la végétation dense et saine et la végétation clairsemée et malade. Sur la carte, les teintes rouges correspondent à un bas indice de la biomasse (peu ou pas de végétation), tandis que les teintes bleues correspondent à un indice élevé (végétation dense et vigoureuse).

Puisque les différents types de végétation n'ont pas tous le même indice de biomasse, même à l'état sain, il est donc possible de se servir de cet indice pour différencier certaines catégories de végétation. Ainsi sur la carte on peut faire la distinction entre les peuplements de conifères, de feuillus, d'arbustes et autres. Ces distinctions permettent dans un premier temps de comparer la répartition des essences d'arbres de la zone où le sol est enrichi de métaux lourds aux régions environnantes.

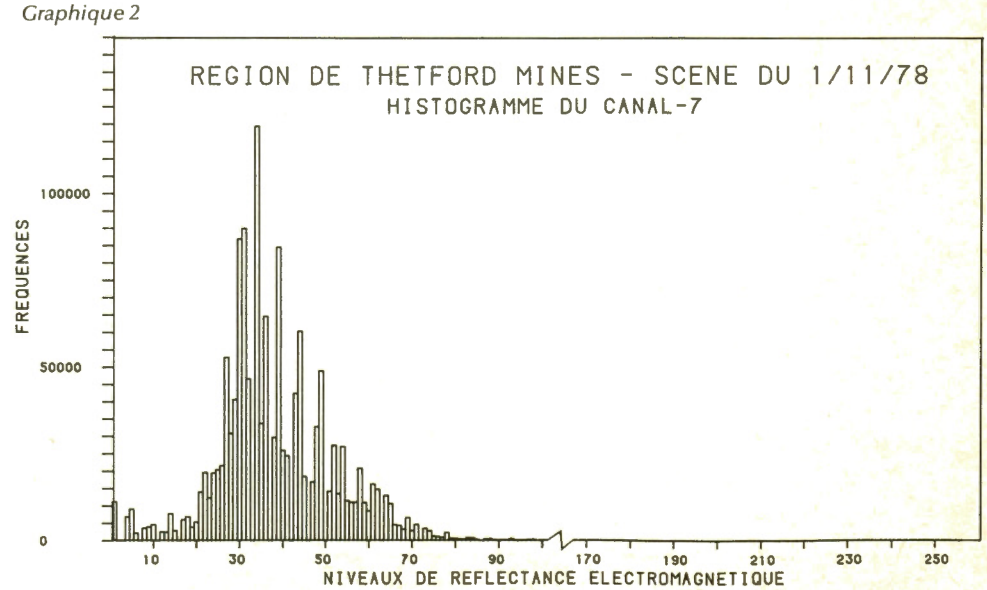
Dans un deuxième temps l'indice de la biomasse nous permet d'étudier les indicateurs géobotaniques en faisant ressortir certaines anomalies dans la végétation. Par exemple, en superposant la carte de l'indice de la biomasse à une carte topographique, on observe que les collines correspondent généralement à des teintes de bleu, c'est-à-dire à de hauts indices. Cependant la colline encerclée sur la carte indique un bas indice de biomasse. Après certaines recherches on a découvert que cette colline correspond à un affleurement de roches ultrabasiques dont la composition chimique est toxique aux plantes. D'autres recherches, ayant pour but d'étudier certaines anomalies de la signature spectrale des espèces végétales situées à l'intérieur de la traînée de débris ultrabasiques, sont présentement en cours. L'étude de ces anomalies nous permet d'orienter les recherches de prospection vers des endroits propices aux découvertes de gisements miniers.

Les indicateurs géobotaniques combinés à l'analyse spectrale des sols permettront d'utiliser la télédétection dans le Grand Nord canadien comme moyen auxiliaire non seulement dans la prospection minière mais aussi dans la cartographie des dépôts de surface. Bien que les capteurs situés à bord des satellites actuels ne permettent pas de pousser à fond les possibilités de cette science, principalement en ce qui a trait à l'étude des indicateurs géobotaniques, il reste que les premiers Landsat ont révolutionné le domaine de la télédétection. Il est à espérer que la prochaine génération de satellites apportera les raffinements nécessaires à de nouvelles découvertes dans le monde de la prospection.□

Graphique 1



Graphique 2



Canada Charts its Magnetic Field 1843-1980

Accurate magnetic charts are vital... Small coastal vessels and small aircraft still depend on magnetic compasses for navigation.

Les cartes magnétiques exactes sont essentielles. Malgré la présence de nombreux instruments de navigation, les petites embarcations côtières ainsi que les petits avions naviguent surtout avec des boussoles magnétiques. Par le biais de nombreux organismes, le gouvernement canadien publie des cartes nationales de déclinaison magnétique depuis 1922 et la Direction de la physique du Globe de l'EMR vient de publier celle de 1980.

Les cartes illustrent les variations séculaires du champ magnétique de la Terre ainsi qu'un déplacement caractéristique vers l'ouest que l'astronome anglais Edmund Halley a été le premier à remarquer en 1693.

L'article traite également des variations de l'intensité totale du champ magnétique de 1844 à 1975.

Cet article est disponible en français

By Ed Dawson and L.R. Newitt

Human genius has developed many navigational aids, but the magnetic compass remains a basic directional instrument to help chart our way across land, sea and sky. As a result, the deviation of a compass needle from true north, called magnetic declination (D), is one effect of the Earth's magnetic field that most people are familiar with. It is of such practical value to mariners and navigators that most countries make magnetic surveys and charts as a matter of course.

Charts are a convenient way of expressing, in the form of isolines, the data necessary for the practical needs of navigation. (Isolines are lines joining, for example, equal values of magnetic declination.) By necessity, most magnetic charts are based on data observed in different years, and they have to be corrected for the slowly varying changes of the Earth's magnetic field called the secular change, or secular variation. The latest magnetic declination chart, for 1980, has just been published by EMR's Earth Physics Branch (Fig. 2c).

Edward Dawson is Head, and Larry Newitt is a physical scientist with, the Geomagnetic Charts and Interpretation Section, Division of Geomagnetism, of EMR's Earth Physics Branch.

The earliest known reference to magnetic declination in Canada was made by Jean Alphonse in his world sailing guide in 1559. Alphonse, a pilot who accompanied the French explorer Roberval on his 1542-43 voyage in the St. Lawrence region, observed a declination of over 33° W for this area. In other words, his compass needle pointed 33° west of true north. Other explorers, listed in Table 1, also made magnetic measurements in their travels around Canada.

John Henry Lefroy, a young English subaltern, made the first systematic magnetic survey over a large part of Canada and greatly extended knowledge of the magnetic field. He came to Canada in 1842 to take charge of the newly established magnetic observatory at Toronto and, at the request of the Royal Society, to journey to the Hudson's Bay territories to make a magnetic survey of British North America. In 18 months, from 1843-44, Lefroy travelled close to 10 000 km, mostly by canoe, taking magnetic measurements under great difficulty at 314 locations. These measurements remained the authority for describing the magnetic field in Canada for many years.

In 1880, the Topographical Survey of Canada began the exploration and surveying of Dominion Lands. They used

TABLE I

Some Early Magnetic Declination Observations in Canada

Place	Latitude (N) °	′	Longitude (W) °	′	Date	Magnetic Declination °	′	Instrumental Error	Observer
Cumberland Sound	67	00	67	30	1587	30	W	5	Davis
Halifax	44	40	63	35	1604-12	15	15W	5	Champlain
Near Resolution Island	61	40	65	40	1615	23	40W	5	Baffin
Quebec	46	48	71	14	1642	16	W	5	Bressani
Fort Churchill	58	48	94	12	1725	21	00W	1.25	Middleton
Nootka	49	36	126	37	1778	18	45E	1	Cook
Repulse Bay	66	31	86	30	1812	48	33W	1	Parry
Cumberland House	53	57	102	19	1819	17	18E	1	Franklin

precision theodolites to take accurate bearings astronomically, and survey parties equipped with magnetic instruments used these bearings to take magnetic observations at little extra expense.

From Lefroy's survey until the early 1900's the objective of Canadian survey work was primarily practical with little emphasis on research related to magnetism.

In 1907, the Dominion Observatory in Ottawa, which later became the Earth Physics Branch (EPB), formed a Magnetic Division to promote studies and conduct systematic surveys of the magnetic field in Canada. About the same time, the Meteorological Service, which maintained Canada's only magnetic observatory at Agincourt, near Toronto, made several important surveys: in the subpolar regions in 1908-09, up the Mackenzie River in 1910, and of Hudson Bay and Strait in 1912. They also established another magnetic observatory at Meanook, near Edmonton, in 1916. Table 2 shows the compilation of magnetic measurements by decades on the EPB files.

TABLE 2

Magnetic Data Compilation, 1900 to 1979

Period	Number of Measurements
1900-1909	490
1910-1919	1080
1920-1929	3820
1930-1939	2550
1940-1949	2630
1950-1959	16610
1960-1969	22030
1970-1979	7410

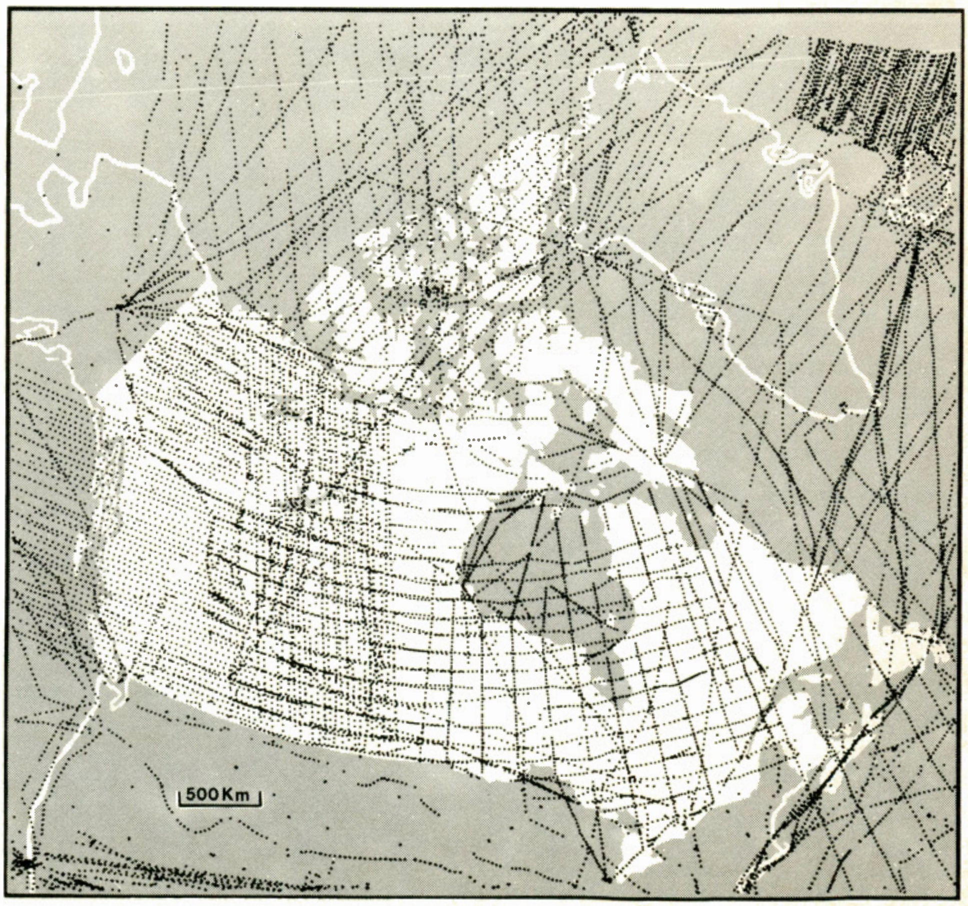
Since the geomagnetic field has both a magnitude and a direction, measurement consists of an observation at one place in one or more of the following components of the geomagnetic field: declination (D), inclination (I), total intensity (F), vertical intensity (Z) and horizontal intensity (H).

Before the 19th century, magnetic observations were too inaccurate and poorly distributed for compiling magnetic charts. Although Lefroy's magnetic charts (Fig. 2a) presented the first comprehensive data for Canada, he, busy with an active and varied career, did not publish them until 1883.

Topographical Survey published a declination chart of western Canada only in 1904, and in 1922 it published the first national declination chart of Canada. Since then ten other national declination charts have been published at regular intervals, by the Topographical Survey, the Surveys and Engineering Branch, the Dominion Observatory, and the Earth Physics Branch, as the responsibility for publishing them passed to each agency in sequence.

Since Lefroy's time there has been a constant improvement in the accuracy of the charts, from an apparent error of 1.3° in Lefroy's chart, to 0.5° in the D chart for 1980. These errors were determined by a least squares fit to differences between map values and observed values at 197 widely distributed points. (Due to its limited coverage, only 100 points were used to determine the apparent error in Lefroy's chart.) Much of the error in the earlier charts arose from lack of information in the northern parts of the country.

From 1922 to 1960 these charts were based on an average of 23 000 D – observations, some going back to Lefroy's time. Little account was then taken of transient variations, or short-term fluctuations of the magnetic field. From 1965 on, the abundance of aeromagnetic observations made it possible to produce charts based only on recent data. Over 40 percent of the measurements listed in Table 2 are



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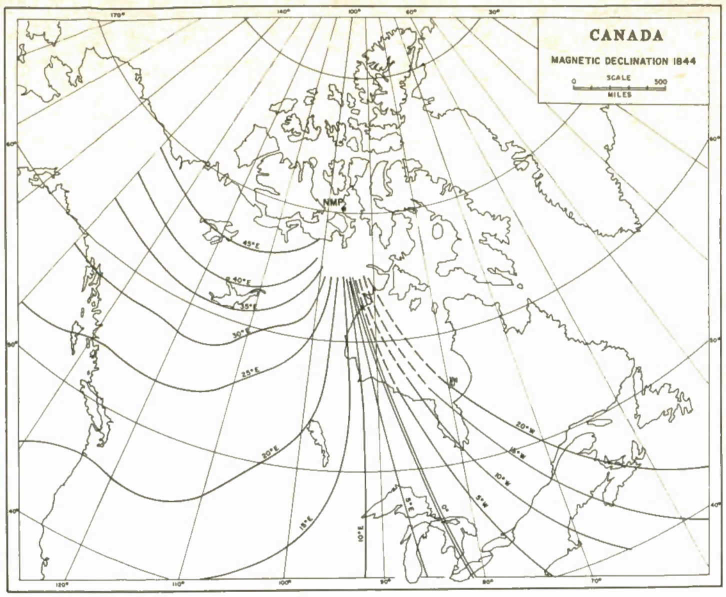
derived from EPB aeromagnetic surveys, from 1953-76. During this period over one million kilometres were flown. In Figure 1, the data distribution for the period 1955-73, the flight track pattern is clearly visible.

All charts have varying amounts of smoothing applied to the data. Except for Lefroy's total intensity, or F-chart, for 1844, all Canadian national magnetic charts up to 1970 appear to have been drawn by linearly interpolating isoline values between averaged values. Lefroy's F chart (Fig. 4) was derived by fitting an analytical expression to the F observations. Since 1970 computer techniques have been used to derive national magnetic charts.

Figure 2 shows modified versions of the magnetic declination charts for 1844, 1932 and 1980. Most charts are produced at five-year periods, and in order to correct for the secular variation of the field they show lines representing annual changes. These values are assumed to be constant over the five-year period. The annual change for the years 1932 and 1980, for instance, can be estimated from the dashed lines on the chart. The D-pattern has obviously drifted westward with time. This is a prominent characteristic of the secular change of the geomagnetic field, best illustrated in Figure 3, which shows the superposition of selected isolines from these charts. Edmund Halley, the English astronomer, first noted in 1693 that certain features of the magnetic field drifted westward at a rate of 0.05° per year. Present estimates of drift vary depending on the features examined. During the period 1844-1980, the agonic line (the 0° declination line) has, on average, drifted 0.024±0.01 degrees westward per year. This is lower than the mean drift of 0.043±0.009 degrees westward found in a similar manner by K. Whitham, using five Canadian declination charts from 1922 to 1955, and described in the Canadian Journal of Earth Physics in 1958. Both drift measurements are considerably lower than 0.09° per year, which is the mean result for world features given by J. M. Harwood and S. R. C. Malin in Nature, 1976.



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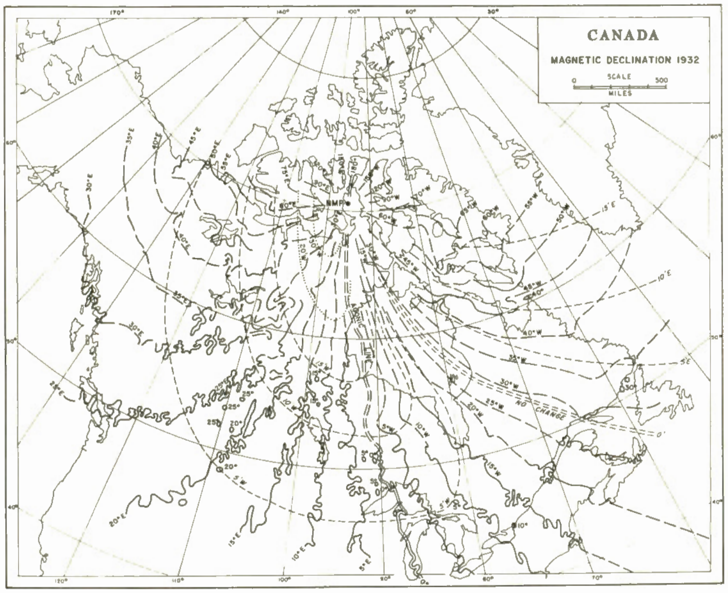

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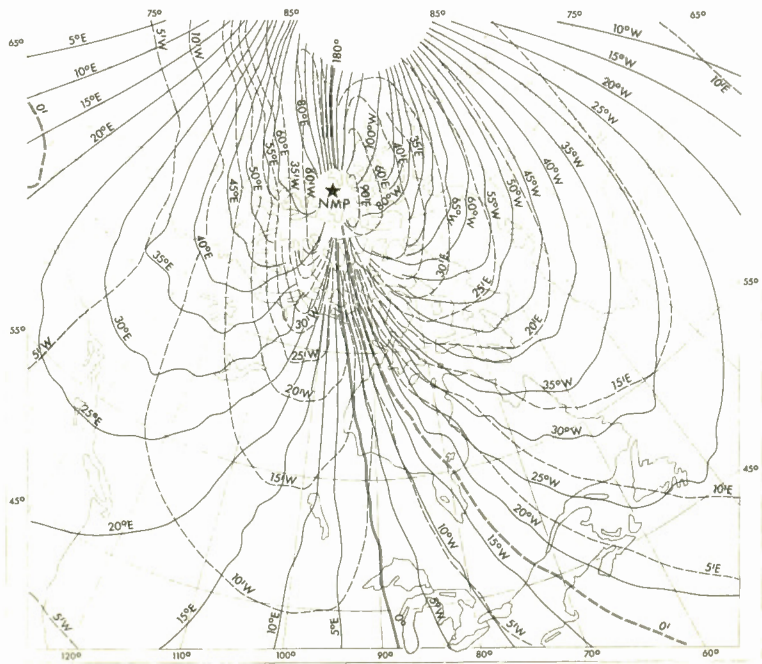

2c

Figure 1 *Distribution of magnetic survey data, 1955-1973*

Répartition des résultats de levés magnétiques, 1955 à 1973

Figure 2 *Examples of Canada's declination charts.*
Lefroy, 1844 (2a). Topographical Survey, 1932 (2b). Earth Physics Branch, 1980 (2c)

Exemples des cartes de déclinaison au Canada. Lefroy, 1844 (2a), Levés topographiques, 1932 (2b). Direction de la physique du Globe, 1980 (2c)

The projected path of the north magnetic pole based on observed positions from 1831 to 1973 is also shown in Figure 3, along with computed pole positions for 1844, 1932 and 1980. The position for 1844 is based on a position computed by P. N. Mayaud, Magnetisme Terrestre, in 1954. From 1832 to 1904 the secular motion of the pole is uncertain. Since 1904, its motion has been predominantly northward, averaging about 10 km per year. (See GEOS Winter 1980).

The magnitude of the Earth's geomagnetic field is measured in nanotesla (nT), a unit of intensity, and Figure 4 shows the total intensity charts for 1844 and 1975. The values of Lefroy's chart, originally expressed in the old British units, were converted to modern units and the chart was re-contoured at 1000 nT intervals. The maximum chart value of F (total intensity) decreased from 65 540 nT in 1844 to 61 560 nT in 1975, a decrease in field strength of six percent. This seems a remarkably large and rapid change for any geophysical property, but, in fact, it is near normal. K. L. McDonald and R. H. Gunst in 1967 reported that since the time of Gauss measurements, in 1835, the strength of the Earth's magnetic field, or its dipole moment, has decreased steadily at approximately the rate of five percent per hundred years.

We still need accurate magnetic charts today. Small coastal vessels and small aircraft still depend on magnetic compasses for navigation. Airport approaches are identified by magnetic bearings and radio navigational facilities are oriented on magnetic north. These values are determined from the latest magnetic charts. The Ministry of Transport re-orients these facilities and carries out flight checks, if magnetic bearings change by more than one degree.

The magnetic coverage of Canada (Fig. 1) is probably more complete than that of any other area of comparable size and, with continuing ground surveys to acquire secular change data, provides an excellent base of measurements for future national magnetic charts.□

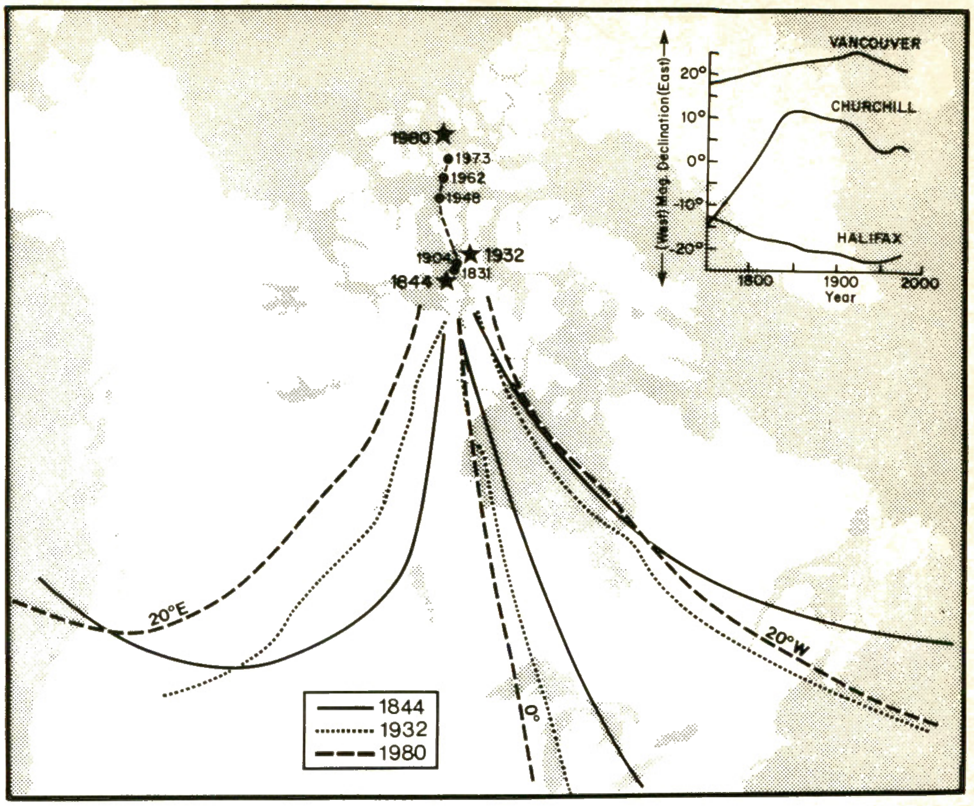

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Figure 3 *The changing pattern of declination from 1844 to 1980. The change in the agonic (0°) line shows the general westward drift of the magnetic field. The amount by which the declination can change is shown for three locations in the insert. A general northward movement of the magnetic pole is also apparent*

Les changements de déclinaison de 1844 à 1980. Le changement de la ligne agonique (0°) illustre le déplacement d'ensemble vers l'ouest du champ magnétique. La case supérieure droite illustre l'importance de la variation de la déclinaison pour trois endroits. On peut voir également le mouvement vers le nord du pôle magnétique

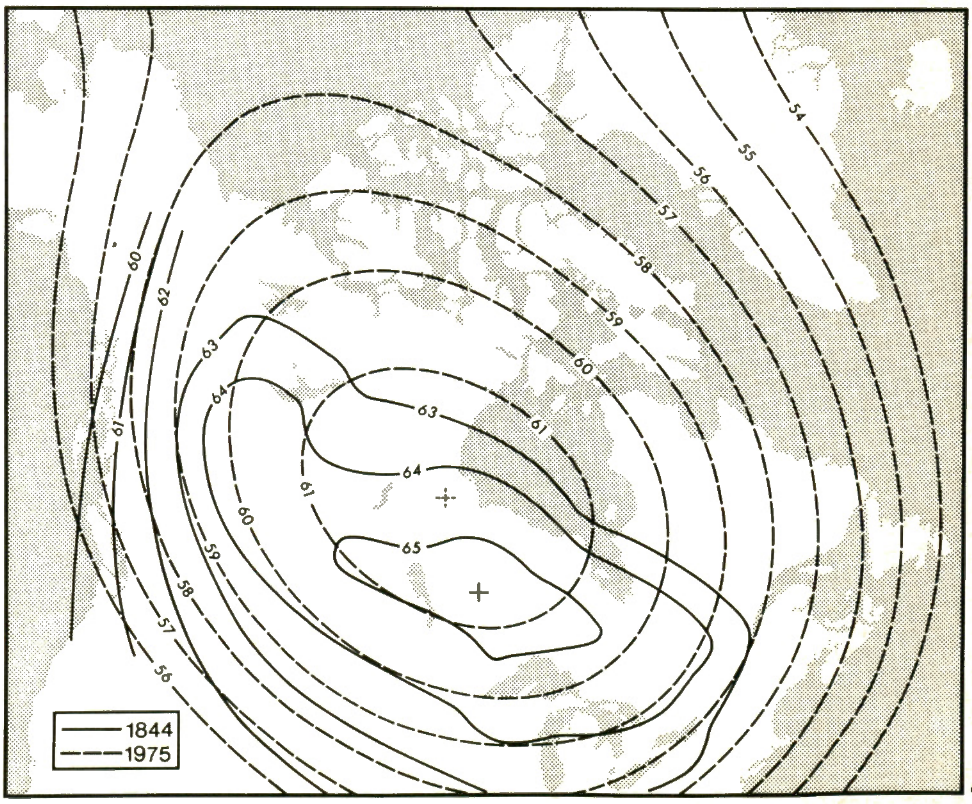

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Figure 4 *Lefroy's total intensity chart, 1844, superimposed on the Earth Physics Branch chart, 1975. Over this period the intensity of the magnetic field has decreased by 6%, from 65 540nT to 61 560nT. (nT equals nanotesla)*

Carte d'intensité totale de Lefroy, 1844, superposée à la carte de la Direction de la physique du Globe, 1975. Pendant cette période, l'intensité du champ magnétique a diminué de 6% pour passer de 65 540nT à 61 560nT. (nT = nanotesla)

Tomates à la raffinerie!

Comment rendre productive l'énergie résiduelle

Par Pedro Rodrigues

Le raffinage du pétrole est, de toutes les activités industrielles, l'une de celles qui consomment la plus grande quantité d'énergie. De plus, cette énergie doit être utilisée sous forme de chaleur de haute ou de moyenne températures, ce qui entraîne le rejet d'une quantité appréciable d'énergie dégradée dont ne s'accommodent pas les procédés de raffinage.

Depuis près de deux ans, la raffinerie de Ville d'Anjou, au Québec, de BP Canada, cultive des tomates et cherche ainsi à démontrer qu'il y a mieux à faire que de jeter dans l'atmosphère l'énergie résiduelle de ses installations. Grâce à la participation financière d'Énergie, Mines et Ressources Canada, BP, en collaboration avec *Connolly & Associates, Reg'd*, conseiller en construction, a construit sur le terrain de sa raffinerie deux serres dont tout le chauffage est extrait du système de refroidissement de cette raffinerie.

Jusqu'ici, l'on n'avait pas cru bon de tirer profit de cette énergie trop dégradée pour servir à un usage industriel mais, par souci d'utiliser plus efficacement des sources énergétiques devenues rares et chères, l'on tente désormais de regrouper plusieurs consommateurs de diverses qualités d'énergie.

Ainsi, la faible chaleur qui se dégage d'une raffinerie peut fort commodément servir au chauffage domestique ou encore, comme tente de le prouver l'expérience d'Anjou, à favoriser des cultures maraîchères. Les deux serres que BP a construites sont longues chacune de 30 m et utilisent ensemble pour leur chauffage environ 1 % de l'eau chaude disponible. Conçues par M. Connolly, elles sont semblables à celles du type Institute Brace de l'Université McGill afin de tirer le meilleur parti possible de l'énergie solaire.

L'eau du chauffage parvient aux serres à la température de 38°C après avoir franchi environ 300 m depuis la raffinerie dans des canalisations souterraines bien isolées. Un système d'aérothermes logé dans le plafond fait passer une partie de la chaleur de l'eau dans l'air ambiant que des ventilateurs refoulent vers le sol. L'eau, qui a perdu une partie de sa chaleur, retourne alors dans le circuit de refroidissement de la raffinerie.

Dans chaque serre poussent environ 600 plants qui donnent chacun près de 10 kg de juteuses tomates. Depuis janvier 1979 jusqu'à la fin de mai 1980, les serres ont fourni trois récoltes de tomates ainsi que de précieuses indications sur ce moyen peu banal d'économiser l'énergie. Des chercheurs de l'Université Concordia ont en effet, tout au long de l'expérience, mesuré l'ensoleillement, la température du sol et de l'air ainsi que l'humidité relative qui régnait à l'intérieur des serres. L'on s'est également intéressé d'une manière toute particulière au rendement du système de chauffage. Afin de faciliter les comparaisons et d'améliorer les résultats, les deux serres sont construites en enfilade et séparées par un mur, ce qui permet de faire varier les conditions dans l'une ou l'autre et d'établir des parallèles fort instructifs.

De plus, on a installé dans la moitié de chaque serre une batterie de grosses lampes à vapeur de mercure dans le but de savoir si le mûrissement plus rapide des tomates représente une économie par rapport à la dépense d'énergie nécessaire au fonctionnement de ces lampes.

Ce que l'on sait avec certitude, toutefois, c'est qu'aucune de ces récoltes n'aura coûté un seul sou de chauffage. "Seulement pour ce qui est du carburant," explique Denis Prince, agronome responsable des serres, "il en coûte habituellement de 25 à 27 dollars par mètre carré pour chauffer des serres comme celles-ci, ce qui signifie que nous économisons environ 15 000 dollars par récolte, soit près de $1,50 le kilo de tomates!"

L'expérience de BP est assurément convaincante et, malgré une mise de fonds appréciable, l'entreprise pourrait rapidement atteindre le seuil de rentabilité. L'expérience semble d'ailleurs si intéressante qu'une autre raffinerie de Montréal s'y est lancée: la société Petrofina récoltera en effet cette année, dans des serres chauffées de manière similaire, environ neuf tonnes de tomates. Il est peu probable toutefois que la société BP poursuive ses activités agricoles mais il n'est pas impossible, selon Pierre Côté, gérant de la raffinerie, qu'elle accepte de céder à l'avenir au moins une partie de son énergie résiduelle à qui voudra bien l'utiliser.

D'autres importants utilisateurs d'énergie se penchent d'ailleurs sur cette possibilité. Ainsi, Hydro-Québec poursuit une étude afin de trouver le moyen d'utiliser le plus efficacement l'énergie résiduelle de la future centrale nucléaire de Gentilly.

Une quantité phénoménale d'énergie serait ainsi disponible. A lui seul, le système de refroidissement de la raffinerie BP utilise en circuit fermé plus de 225 T d'eau par minute. Cette eau sort des installations à une température de 40°C et doit être ramenée à 20°C au moyen d'un ensemble de tours de refroidissement. Ainsi, chaque minute, la raffinerie doit se débarrasser de 4,5 millions environ de kilocalories, ce qui, en théorie, suffirait à chauffer confortablement plus de 50 000 logements bien isolés.

Voilà certes une formidable source d'énergie. Toutefois, il y a encore loin de la théorie à la pratique car cette énergie de forte entropie est difficile à extraire. En effet, le rendement des dispositifs échangeurs de chaleur dépend largement de l'écart de température qui existe entre la source et l'utilisateur. Plus cet écart est faible, plus il est difficile de transférer l'énergie. Comme il n'est ici que d'une vingtaine de degrés, le rendement thermique ne dépasse pas 5 à 6 %.

Il serait avantageux si l'on en croit une étude de l'Institut de recherche de l'Hydro-Québec, d'extraire cette énergie au moyen de thermopompes plutôt que d'utiliser seulement des échangeurs par conduction ainsi qu'on le fait dans l'expérience de BP. Il serait également intéressant de réexaminer dans une optique de conservation la conception des nouvelles raffineries.

Nous devons reconnaître que l'industrie fait de très grands efforts pour réduire ses besoins en énergie et ne semble pas se soucier encore de mettre à profit ses déchets calorifiques.□

BP Canada, with EMR financial backing, has for two years been growing tomatoes at its Anjou Quebec oil refinery. The experiment demonstrates that the residual energy from the refinery can be put to good use, instead of being released into the atmosphere. BP has built two 30-metre greenhouses, making the greatest possible use of solar energy, but otherwise heated entirely by the refinery's cooling system. The author interviewed agronomist-manager Denis Prince and EMR's Barry James for information on the experiment.

This article is also available in English.

M. Rodrigues est géologue et rédacteur scientifique à la pige. Il prépare un livre sur les énergies nouvelles.

JOHN MACOUN, First GSC Botanist

By W.A. Waiser

John Macoun was the first botanist hired permanently by the Geological Survey of Canada. He came to a young Survey suffering from competition for funds and professional rivalry among the staff, some of whom considered a botanist superfluous. At that time botany was barely recognized as a science by most Canadians. No wonder he found his new colleagues apprehensive about his arrival.

W.A. Waiser is an historian writing a biography of John Macoun for his doctoral thesis at the University of Saskatchewan.

Initially employed for summer field work in 1875, Macoun sought a permanent position, but first had to prove the value of his science to the Geological Survey. Among the skeptics was the Survey Director, Dr. A.R.C. Selwyn, but in spite of Selwyn's persistent opposition Macoun was appointed Botanist to the GSC in 1882, and five years later, Assistant Director.

Even then his position was challenged, but John Macoun achieved a lifelong ambition and let nothing interfere with his effort to establish a place for botany in Canadian science.

Born in Maralin, Northern Ireland, 1831, John immigrated to Canada with his family at the age of 19 to escape the potato famine. As a farm hand, his interest in wild plants was aroused. He spent Sunday afternoons with another farmer friend who shared his interest and lent him a

Macoun (on left) in the field with Percy Traverner, museum ornithologist.
M. Macoun (à gauche) sur le terrain en compagnie d'un ornithologue, M. Percy Taverner.

Autobiography, John Macoun, has recently been republished by the Ottawa Field-Naturalists' Club for their centennial year. W.A. Waiser, the author of this article, has indexed and edited the new edition, using footnotes. It is available from:
The Ottawa Field-Naturalists' Club
Box 3264, Postal Station C
Ottawa, Ontario
K1Y 4J5.

book on the botany of England. From then he studied in every spare moment.

Wanting to learn more, Macoun, who had limited elementary school education, made a three-day study of English grammar, walked 43 miles through the snow to see the county inspector, and boldly applied for a teaching position, which he was granted. Subsequently, he spent his summers on field excursions, travelling in pursuit of new plant communities and his reputation as a botanist blossomed. Asked in 1868 to take the chair of Natural History of Albert College in Belleville, Ontario, he eventually became Professor Emeritus there, and was called "Professor" for the rest of his life.

On one of his summer field trips, in 1872, Macoun met Sandford Fleming, heading an expedition to find the best route for the Canadian Pacific Railway. Invited by Fleming to join the party as botanist, Macoun took leave of absence from Albert College without a backward glance.

Macoun shared his knowledge and interest generously, especially with young people. He is the namesake of a young naturalists' club in Ottawa, The Macoun Field Club.

M. Macoun partageait généreusement ses connaissances et ses intérêts, surtout avec les jeunes. Un cercle de jeunes naturalistes d'Ottawa, le Macoun Field Club, porte son nom.

The party's secretary was Rev. G.M. Grant. He described Macoun's field work in his famous journal *'Ocean to Ocean'*:

At whatever point the steamer touched the first man on the shore was the botanist, scrambling over the rocks and diving into the woods, vasculum in hand, stuffing it full of mosses, ferns, liverworts, sedges, flowers and grasses, till recalled by the whistle that the captain always obligingly sounded for him ... This morning the first object that met our eyes on looking out the stateroom window was our botanist on the highest peak of the rugged hills that enclosed the harbour of Gargantua.

From Thunder Bay the expedition travelled to Fort Garry (Winnipeg) and northwest to Edmonton, covering 900 miles in 25 days. At Edmonton Fleming dispatched Macoun and the expedition's outfitter, to follow the Peace River and cross the mountains to the coast. After his return to Belleville, the Professor prepared a report of his findings in which he related the agricultural prospects of Western Canada to the various plant forms and communities he had observed. This was an approach new to the Geological Survey and caused a stir of interest.

Several weeks before Fleming hired John Macoun to join the expedition, MP James Brown had written to the Under Secretary of State for the provinces recommending Macoun's appointment to the Geological Survey. The letter was forwarded to the new Survey Director, Dr. Selwyn, who replied:

... I beg to state that I do not think that such an appointment is desirable in connection with the Geological Survey. The Geological Survey Act, moreover, makes no provision for botanical exploration ... No useful purpose could be served by connecting it with the Geological Survey; the objects and requirements of the two are entirely distinct ...

The Director's attitude changed, however, when he read Macoun's 1872 report. The practical applications of the botanist's work were useful and Selwyn invited Macoun to accompany his expedition through the Upper Peace River country in 1875.

The first part of the expedition with Selwyn essentially retraced his earlier journey through the Peace River District. At every halt the botanist labelled, dried and packed his plants. At Fort St. John he left the expedition and continued his studies in a cottonwood dugout 700 miles down river to Fort Chipewyan. He nearly starved to death because of his foolhardy failure to carry adequate supplies; the supply boats he expected to pass never appeared. He reached home late that fall after travelling 8 000 miles in 8 months.

Feisty self-taught naturalist overcame jealousy and opposition at the young Survey to contribute to the exploration of Canada

Anxious to proceed with the Canadian Pacific Railway project, the new Macdonald administration made Macoun explorer for the Canadian government in the Northwest Territories in the spring of 1879. During that field season and the two following, Macoun criss-crossed the prairies between Cypress Hills and Lake Manitoba. He was entertained by the Territories' Lieut.-Governor David Laird at his Battleford mansion and by Chief Crowfoot at his Blackfoot encampment in the Red Deer Valley.

During these expeditions he combined his knowledge of botany with his experience in the field to endorse the agricultural potential of the Canadian west. His efforts led to his appointment on January 1, 1882 to the Geological and Natural History Survey of Canada. This was the title of the Survey from 1879 to 1889, and it was then responsible for botanical and zoological surveys, as well as natural history, mineralogy and geology.

Making the Survey museum in Ottawa his new base of operations, the Professor concentrated on the botany of Canada's relatively unsurveyed areas. For the next three summers, in the company of one or other of his sons James and William, he travelled to the eastern provinces. On Anticosti Island the blackflies were so bad the pair spent ten days encased in a mixture of stockholm tar and castor oil. Macoun also explored through western Ontario and around Lake Nipigon. At one of the railway camps in this district, Macoun, learning of the disruption caused by whiskey peddlers, pretended he was a magistrate, confiscated all the whiskey in camp and took the peddlers prisoner.

The Professor's eldest son, James, worked closely with his father, and the two co-authored the Catalogue of Canadian Birds. In 1913 James succeeded his father as chief of the Biological Division, GSC. His other son, William, eventually became Dominion Horticulturalist. William's great nephew, John O. Wheeler, is former Deputy Director-General of the Geological Survey.

John Macoun was a determined man, and he could be tyrannical, as he made plain to the GSC Select Committee in 1884:

I will tell you honestly, that I would not allow any subordinate that would be sent with me, the privilege of examining a tract of country without I had my eye on him . . . I have not the greatest of faith of subordinates in carrying out their instructions.

The botanist wanted his work to be excellent. There was intense competition for the meagre funds allotted to the Survey in those days. Dr. Otto Klotz, a surveyor, recorded the mood of the staff during a visit to Ottawa in 1886:

What struck me this time more than ever is the extreme jealousy that exists between the different departments and between officers of the same department — Dr. Bell called Selwyn the director a 'pig headed beggar', the botanists' work useless — Prof. Macoun told me that the geologists' (topographical) surveys were unnecessary, that we (land surveyors) should do all that.

Macoun was apparently successful in his work, for in 1887, again against the wishes of Director Selwyn, he was promoted and made Naturalist to the Geological Survey and Assistant Director as well as Botanist. He received notice about the position on Christmas Eve in a letter which stated that the Hon. Mr. White, Minister of the Interior, wished him to accept the position as a Christmas box!

When finally told of the appointment Dr. Selwyn was very angry and pointed out that a Dr. Whiteaves was a zoologist at GSC, and there was no necessity for a naturalist. He advised Macoun to reject the position on the grounds that it gave the botanist no higher position than he had held before. The Professor retorted:

Dr. Selwyn, I have studied geometry and I have learned that the greater always includes the less and 'Naturalist' included 'Zoologist' so that, from this time forward, Dr. Whiteaves is under me and I am not his servant any longer.

The Professor, now 56, assumed the new position in full stride. A new national museum was proposed. Macoun saw the collections and arrangement of material as his own personal task, and expanded his collecting efforts to include zoological specimens. For the next 25 years he continued his field work, venturing as far north as the Yukon. By the time a stroke finally forced his retirement in 1912, at the age of 81, the biological division had made great progress. Its collections form the basis of today's National Herbarium and National Museum of Natural Sciences, which assumed that responsibility from GSC.

The Professor returned to the simple joys he had once known as an amateur collector, investigating the natural world of Vancouver Island until the death of his son James in January of 1920 shattered him. He wrote to the Dominion Agrostologist, " . . . my botanical interest is dead." Yet he still managed to conduct a natural history column in the local paper until a few days before his death in July of the same year.□

M. John Macoun a été le premier botaniste permanent de la Commission géologique du Canada. Totalement autodidacte, il devient naturaliste et directeur adjoint de la C.G.C., après avoir débuté comme valet de ferme. Il a toujours été en butte à la résistance de personnes qui ne croyaient pas en la valeur de la botanique. Au nombre de ces sceptiques se trouvait même le directeur de la Commission, M. A.R.C. Selwyn.

Cet article est disponible en français

The objective of the Department of Energy, Mines and Resources (EMR) is to enhance the discovery, development and use of the country's mineral and energy resources and broaden our knowledge of Canada's landmass for the benefit of all Canadians. To attain this objective the department devises and fosters national policies based on research and data collection in the earth, mineral and metal sciences, and on social and economic analyses.

Le ministère de l'Energie, des Mines et des Ressources (EMR) a comme objectif la mise en valeur de la découverte, du développement et de l'utilisation des ressources minières et énergétiques canadiennes, ainsi que l'accroissement de nos connaissances des richesses naturelles du Canada, au bénéfice de tous les Canadiens. Pour atteindre cet objectif, le Ministère met sur pied et appuie des politiques nationales de recherches et de compilation des données relatives aux sciences de la Terre, des mines et des métaux, ainsi que des résultats d'analyses sociales et économiques.