GEOS

Vol. 11 No. 3 Summer/Eté 1982

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

GEOS

A quarterly concerned with the earth's resources

Publication trimestrielle sur les ressources de la Terre

Vol. 11 No. 3 Summer/Eté 1982

GEOS is published quarterly by the Department of Energy, Mines and Resources
Minister, The Hon. Marc Lalonde
Minister of State for Mines, The Hon. Judy Erola
Deputy Minister, M.A. Cohen

GEOS est une publication trimestrielle du ministère de l'Energie, des Mines et des Ressources
L'hon. Marc Lalonde, ministre
L'hon. Judy Erola, ministre d'état aux mines
M.A. Cohen, sous-ministre

Editor / Rédactrice en chef
Constance Mungall

Associate Editor / Rédacteur en chef adjoint
Guy Angers

Graphics / Présentation graphique
ACART Graphic Services Inc.

GEOS is distributed without charge on request. If you would like a copy of any article in the other official language please write to: Editor, GEOS, Energy, Mines and Resources, 580 Booth Street, Ottawa, Ontario K1A 0E4

GEOS est distribué gratuitement sur demande. Si vous désirez recevoir le texte d'un article dans l'autre langue officielle, veuillez écrire au: Rédacteur — GEOS, Ministère de l'Énergie, des Mines et des Ressources, 580 rue Booth, Ottawa, Ontario K1A 0E4

ISSN 0374-3268

Contents/Sommaire

COVER: Geological Survey of Canada field party travelling in Nansen Sound along the cliffs of Northern Axel Heiberg Island in 1957, from the collection of Ray Thorsteinsson. See p. 1.

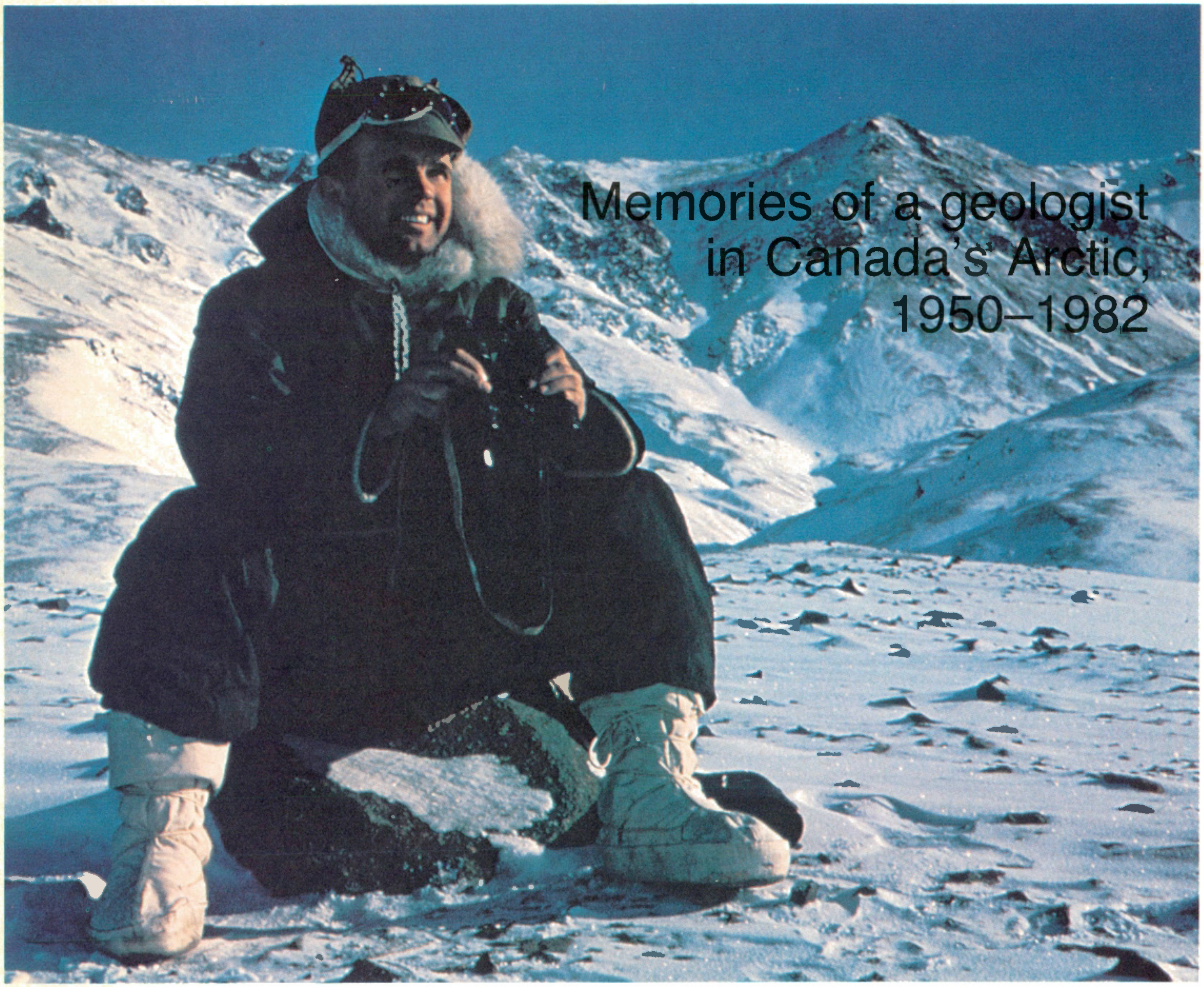
COUVERTURE: Une équipe chargée de travaux sur le terrain avance dans le détroit de Nansen, le long des falaises du nord de l'île Axel Heiberg en 1957; de la collection de Ray Thorsteinsson. Voir p. 1.

GEOS is ten years old! Started in Summer 1972 to foster an awareness of the earth sciences, it originally was mailed to a readership of 5 000, mostly in industry, governments, and universities. Now it goes to 15 000, including many members of the general public who want to know more about the geosciences. Along the way, GEOS has won 30 awards, for design, for specific articles, and for the journal itself. With this issue, GEOS enters its second decade, ready to answer the challenge of evolution on two levels: in reporting on the fast changing sciences as practised and applied at EMR, and to a public which is daily demanding more information, and more sophisticated information, about those sciences.

La revue GEOS existe depuis dix ans. Fondée à l'été 1972 pour susciter de l'intérêt dans les sciences de la terre, la revue ne comptait au départ que 5 000 lecteurs, la plupart rattachés aux secteurs industriel, gouvernemental et universitaire. Les listes d'envois comptent maintenant 15 000 personnes. Plusieurs d'entre elles font partie du grand public; elles veulent en savoir davantage des sciences de la terre. Au cours de ces dix ans, Geos a obtenu dix prix pour sa conception, pour des articles qu'elle a publiés et pour la tenue générale de la revue. Avec la présente édition, Geos entreprend sa deuxième décennie, prête à relever un double défi: rendre compte de l'évolution rapide des sciences dont nous traitons, témoigner de leur application à ÉMR et satisfaire un public qui exige une information toujours plus complète et détaillée à propos des sciences auxquelles nous nous intéressons.

A less stressful form of life . . .

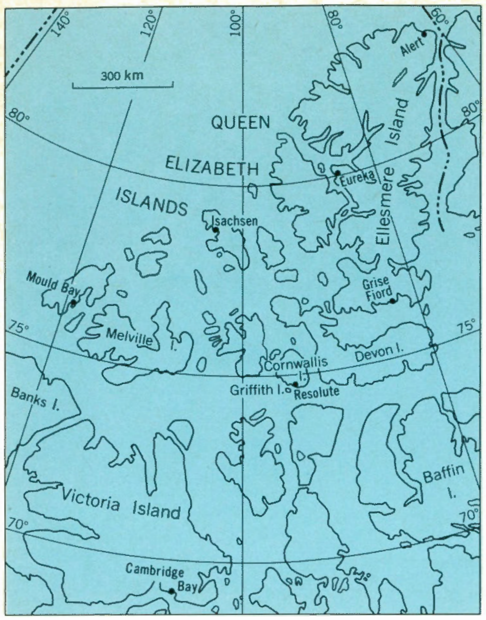
Memories of a geologist in Canada's Arctic, 1950–1982



Ray Thorsteinsson has been traversing the Arctic Archipelago for 32 years, since as a young geologist he joined the first team of the Geological Survey of Canada—the first trained geologists to go to the area. Since then he has mapped more than 200 000 square miles, worked on every island in the archipelago except Baffin and King William Islands, and in 1981 was given the Massey Medal, the highest Canadian award for individual achievement in geography and related fields. Other medals recognizing his contribution have come from the Royal Society of Canada, the United Kingdom Royal Geographical Society, the Geological Association of Canada, and the Canadian Society of Petroleum Geologists.

More important to Thorsteinsson, who at 61 is head of the GSC Arctic Islands Section at EMR's Institute of Sedimentary and Petroleum Geology, is the record of his work from 1950, in nearly 30 reports, for the GSC and scientific journals. The latest, a memoir on Devon Island, is in press now. They include the first official identification of the Arctic as a major oil province. Many were written with other pioneer Arctic geologists: Yves Fortier, R.J.W. Douglas, D.K. Norris, R.L. Christie, J.W. Kerr . . . . His most frequent partner was E.T. Tozer, now at GSC in Ottawa.

Thorsteinsson recalled the changes he witnessed in 28 Arctic summers in taped interviews with GEOS editor Constance Mungall this spring. This is an edited version of his conversation.



RAY THORSTEINSSON:

The joint Canadian-American weather stations built by the Americans, mainly in the late 1940s, were essential to the opening up of the Queen Elizabeth Islands. Resolute and Eureka were set up in 1947, followed by Mould Bay and Isachsen in 1948. Alert was established in 1950, the first year I went to the Arctic. Each of the stations had an airstrip. Before the establishment of these stations there were no permanent settlements in the Queen Elizabeth Islands.

Once the weather stations were established, the Geological Survey began making plans to study this remote part of the archipelago. Resolute, on Cornwallis Island, was the principal weather station in the Queen Elizabeth group, and they decided to commence work on Cornwallis Island. The Survey knew that the island included Paleozoic rocks and therefore that a stratigraphic-paleontologist would be required for the planned field project. When they asked me if I wanted to participate, I accepted. At that time — 1949 — I was attending the University of Kansas, and had completed five summers as a field assistant with the Survey.

The party that set off to Resolute in 1950 consisted of Y.O. Fortier as party chief, Trevor Harwood of the Defence Research Board, and me. Harwood had spent two years — 1935–37 — with the Hudson's Bay Company at Dundas Harbour on neighbouring Devon Island. We were flown by the RCAF from Edmonton to Resolute in a Lancaster Bomber, with our 22-foot freighter canoe in the bomb bay. Unfortunately, the canoe was too large for the bomb bay doors to be fully closed, and Fortier, Harwood and I had a miserably cold ride to Resolute.

We arrived at Resolute on June 1st, and we had to wait for about a month at the weather station before the ice in the channels around Cornwallis Island had melted, and we could set off in our canoe. During this delay we carried out geological studies around the weather station, and we were fascinated to find a thick succession of much deformed Ordovician and Silurian sediments.

In early July the three of us set off in our canoe. We planned to circumnavigate Cornwallis Island, which we did. We carried with us all our food, equipment and fuel for the trip. The fuel was stored in jerry cans. Our canoe was powered by a 5-horsepower motor of which we had only one. This was a chancey affair, because if the motor broke down we might have been stranded and forced to walk overland to Resolute. After that, I always had two motors with me, one as a spare.

We had a two-watt receiver/transmitter with which we hoped to keep in contact with the weather station at Resolute. It proved to be next to useless; we were able to contact Resolute only once. I carried this radio with me during the next six field seasons, and only on one other occasion was I able to contact a weather station. I can't forget all of the wasted effort in carrying this radio around with me.

The circumnavigation of Cornwallis Island took about two months. During this time we travelled about 300 miles, as we were keeping close to the coastline, and travelling in and out of virtually every bay. Our method for gathering geological information was to travel until we came upon good exposures of rocks, where we would stop and camp for two or three days, measure and study the exposure, and then go on. Several times we were prevented from canoeing because high winds or ice conditions kept us from moving on.

The only maps available to us were the old British Admiralty charts, which were not especially accurate. One of these charts showed a small island lying off the northeast coast of Cornwallis Island. As we passed through this area, a careful search showed that the island did not exist!

If aerial photographs had been available, we could have picked the best localities for conducting geological studies in advance of field work, and would have been able to operate much more efficiently. But not hav-

Field party in Cañon Fjord, Ellesmere Island, April 1957

Équipe chargée de travaux sur le terrain, au fjord Cañon, dans l'île Ellesmere, en avril 1957

ing photographs or good topographic maps, we were forced to operate in much the same way as members of Geological Survey, like R.G. McConnell, J.B. Tyrell and G.M. Dawson, had conducted their studies in the last century.

As far as the old explorers were concerned, the most useful observations were made by the Franklin searchers, people like M'Clintock who were field naturalists, and others who were trained in natural history. They had gathered fossils and recognized limestone and dolomite cliffs, for instance. And on the basis of those observations one was able to make a rough geological map of the Arctic Islands.

Back in 1850–51, a British squadron had wintered quite close to Resolute Bay. M'Clintock was on that expedition, and so numerous fossils were collected on Griffith Island, a small island just off the south coast — which told us we were going to find Silurian rocks in particular.

But we were the first trained geologists, and don't forget that geology had advanced tremendously in the 100 years from the days of the early explorers. Unfortunately, some explorers made precious little in the way of geological observations. Stefansson was one. If one reads all his reports, one could not really infer anything of the geology of the islands he discovered and explored.

I was one of the first persons to travel widely in these islands since the early explorers, and so we came across many of their cairns and caches. One could very often determine where one could expect a cairn by reading their accounts, because all these Arctic explorers left published accounts of their explorations, and I usually took the time to sort through them.

At the same time the British Admiralty expedition was wintering close to Griffith Island — Sir John Ross was wintering on the south coast of Cornwallis Island about 30 or 40 miles away to the east of Assistance Bay.

In 1951, on July 17, I found a note that had been left by Sir John Ross describing his wintering, and left there on August 12, 1851, a few days short of 100 years. It was a particular thrill to discover this note — written in beautiful calligraphy.

We continued to use the freighter canoe as a means of transportation throughout much of the fifties, supplementing it with dog sledging. The use of the sledge meant that we could commence field work in April, May and June, long before the straits and channels had opened. A sledging party usually consisted of two dog teams, two Eskimo dog drivers and two geologists. Each team included anywhere from 11 to 14 dogs. The sledges were sturdily built and designed to haul about a ton of men and materials. Our journeys, which were made out of the weather stations, generally lasted for periods of about 30 to 60 days. On one such trip my party travelled about 700

Not oil and gas territory? . . . Unthinkable!

Thorsteinsson: One of the reasons for the Survey launching a continuing program of geological work in the Arctic Islands was the very fact that the geology was virtually unknown.

Mungall: And then fairly early, between 1950 and 1955, you realized that it was potential oil country?

Thorsteinsson: We began to unravel the geology and realized that we were dealing with lands that had the essential characteristics of oil and gas territory: thick marine sequences, time of phanerozoic age, not too deformed, rocks not altered, metamorphosed . . . It was simply unthinkable that this country was not a potential oil and gas province.

Mungall: Were you the first to recognize that?

Thorsteinsson: I think I am correct in saying that the first published account pointing out the petroleum prospects at the archipelago was a paper by Y.O. Fortier, A.H. McNair and me. It was published in the bulletin of the American Association of Petroleum Geologists in 1954.

It wasn't until 1960 that the big leasing play developed in the Arctic islands. I think the first inquiry that I had from people interested in the geology of the Arctic islands was in 1959. They had read the reports of people that had been working up there, and they decided to look into the matter further.

Breaking camp after breakfast in Eureka Sound, 1957

Levée du camp après le déjeuner, dans le détroit d'Eureka, en 1957

miles. On these journeys we never bothered to carry a two-way radio.

Our method of conducting geological investigations on sledging journeys followed much the same pattern as our canoeing parties. We searched for critical outcrops, and when we found them, set up our camp, and stopped over a day or more to study the rocks.

We would stop, put up our shelter — igloos or double-walled tents depending upon the temperature — and make our evening meal, and that would take two hours. We did all the cooking while the Eskimos handled the dogs, cutting up seals and feeding the dogs and tying them on a long chain to keep them from fighting and eating their harness at night. By the time those chores were done, we'd be through with our cooking. Then we'd discuss geology in our quarters.

On the average one would only get six or seven days a year when one could sit outside the tent and cook and bask in the sun. The temperatures are hovering around 40°, 45°F. One would be moving during the day wearing a parka or a good jacket, warm clothing, and one could sit down and make a pot of tea and eat one's lunch, but one was not going to lie around and rest too much.

Spring break generally commences in late June or early July in these islands, and puts an end to the sledging season. Between the end of sledge travel and the beginning of the canoeing season there are two to three weeks when the only practical means of travelling is by foot and carrying a pack. From about the middle of July until the end of August, with the onset of winter, we travelled by canoe.

During breakup we'd come across cracks in the ice that were say six or eight feet wide, and we'd push our 20-foot sleigh across the crack. We had one sleigh go in, but that was by design, not by accident. The Eskimos pushed it in. The crack wasn't too wide, probably four or five feet. Instead of the Eskimo running behind and keeping the sleigh at right angles to the crack, he gave it too hard a push and it just dropped crosswise into the crack instead of going across.

I guess they thought if things got wet we would decide to quit and go home, because it was late in the season, in July. Tim and I were wanting to make one last journey down to some outcrops of special interest to us. They wanted to go home; the dog's feet were getting cut on the ice and they were having trouble keeping shoes on them.

One of the most serious limitations in conducting geological investigations by means of dog teams and canoes is that observations are limited to fjord walls and shorelines. We seldom made protracted journeys with our dog teams because of the danger of damaging the sledge runners on projecting rocks. But this was back in days when any geological information about an area could be very important, and we did proceed a long way toward elucidating the geological history of the Arctic Islands by using these methods of transportation.

The big change in field transportation in these far islands took place in the late fifties with the advent of light fixed-wing aircraft such as the Otter and Piper Super Cub that were equipped with oversized balloon tires that permitted landings on unprepared terrain. This novel means of transportation had been initiated by the U.S. Army operating on the tundra of northern Alaska, but the idea was turned into a commercial enterprise by a remarkable man named W.W. Phipps, of Bradley Air Services Ltd. Later he headed his own company under the name of Atlas Aviation Ltd. The Otter aircraft, which could carry about a ton, was used mainly for transporting equipment and other supplies, but the Piper Super Cub was used in much the same manner as a helicopter. In the hands of such excellent pilots as Phipps himself, and R.M. deBlicquy, these little aircraft could be landed almost anywhere, even on mountain tops, hillsides and creek bottoms. We used the Piper Super Cub aircraft throughout the sixties, but by the early seventies the Cub was overtaken and then replaced entirely by the helicopter.

The late fifties also brought a major change in field communications with excellent receiver/transmitter radios. This has permitted us to maintain radio contact at all times between base camp, traversing parties and aircraft.

One still sees lots of wildlife. In the early part of my work in the Arctic, we were often in areas that hadn't been visited by zoologists, and these observations were important. When the Canadian Wildlife Service began working up there — I think it was in the early sixties — it no longer became important to try and report what life one had seen.

There were no Eskimos when I first got there, and then they brought two bands of people into the far islands, one at Resolute and one at Grise Fjord, and they're still there. On Cornwallis Island, before the Eskimos were brought in there in 1953, polar bear were very common — one could see polar bear virtually every day of the week. After they got there, they began shooting polar bear for their furs and they reduced the population enormously, but never to the extent of exterminating them, which would have been impossible, because these Eskimos covered only a very small part of the Queen Elizabeth Islands.

In the '50s and '60s we relied heavily on dried foods, dried prunes, dried potatoes, dried pea soup, dried everything. And we'd also take up some canned bacon, things like that. But once we began using helicopters and fixed-wing aircraft, we would fly back into Resolute and pick up food orders. And nowadays, with the big helicopter operations and the camps we have, we eat much the same foods that we eat down here, if not better. . . bakery bread, jams, fresh potatoes, celery, lettuce, steaks, and so forth.

There were advantages in using dog teams and canoes to conduct geological studies. Then one was seldom stopped by mechanical failures. Today a helicopter may break down and be out of service for as much as a week waiting for spare parts to be brought in from the south. Moreover, dog teams and canoes encouraged a more relaxing and less complicated way of carrying out field work than aircraft. The advantage of the aircraft is, of course, the fact that much more territory can be studied in the course of a field season, and studied more thoroughly. But this makes for a more intense life style. Information is being gathered at a much more rapid rate. To operate efficiently, a geologist must spend a good portion of each evening assimilating this information in order to plan the next day's work. To be forced to repeat a badly planned traverse by helicopter might easily involve an extra cost of one or two thousand dollars to a field project. In contrast, the total cost of our field projects involving dog teams and canoes for the entire season was about $5000. On the other hand, it could take ten years to study the geology of an area that you could cover in about two years of intensive work with aircraft.

Ray Thorsteinsson est actuellement le chef de la Section des îles de l'Arctique de l'Institut de géologie sédimentaire et pétrolière de Calgary. L'Institut relève de la Commission géologique du Canada (C.G.C.) qui fait partie du ministère de l'Énergie, des Mines et des Ressources. Membre de la première équipe de géologues expérimentés qui a exploré l'archipel de l'Arctique, il y a passé 28 étés après son premier voyage dans ce territoire en 1950. Il a été l'un des auteurs du rapport qui, de tous ceux publiés pour le compte de la C.G.C., a, le premier, reconnu la présence de gisements d'hydrocarbures dans l'Arctique.

Le printemps dernier, il s'est entretenu, à son bureau de Calgary, avec Mme Constance Mungall, rédactrice en chef de la revue *GEOS*, au sujet des changements dont il a été témoin dans l'Arctique.

Cet article est disponible en français

Offshore Eastern Canada:

From Plate Tectonics To Petroleum

By Charlotte Keen

Photo by R. Belanger, BIO

Geophysical models help us understand the evolution of the continental margins and predict petroleum potential. . . .

The continental margins off Eastern Canada are often called passive, but they have not always been so. In fact, they have been the scene of rifting, shearing, thinning, collapse, heating and finally cooling. If geologic time were speeded up, their evolution would look like a Cecil B. DeMille film of the creation of the earth.

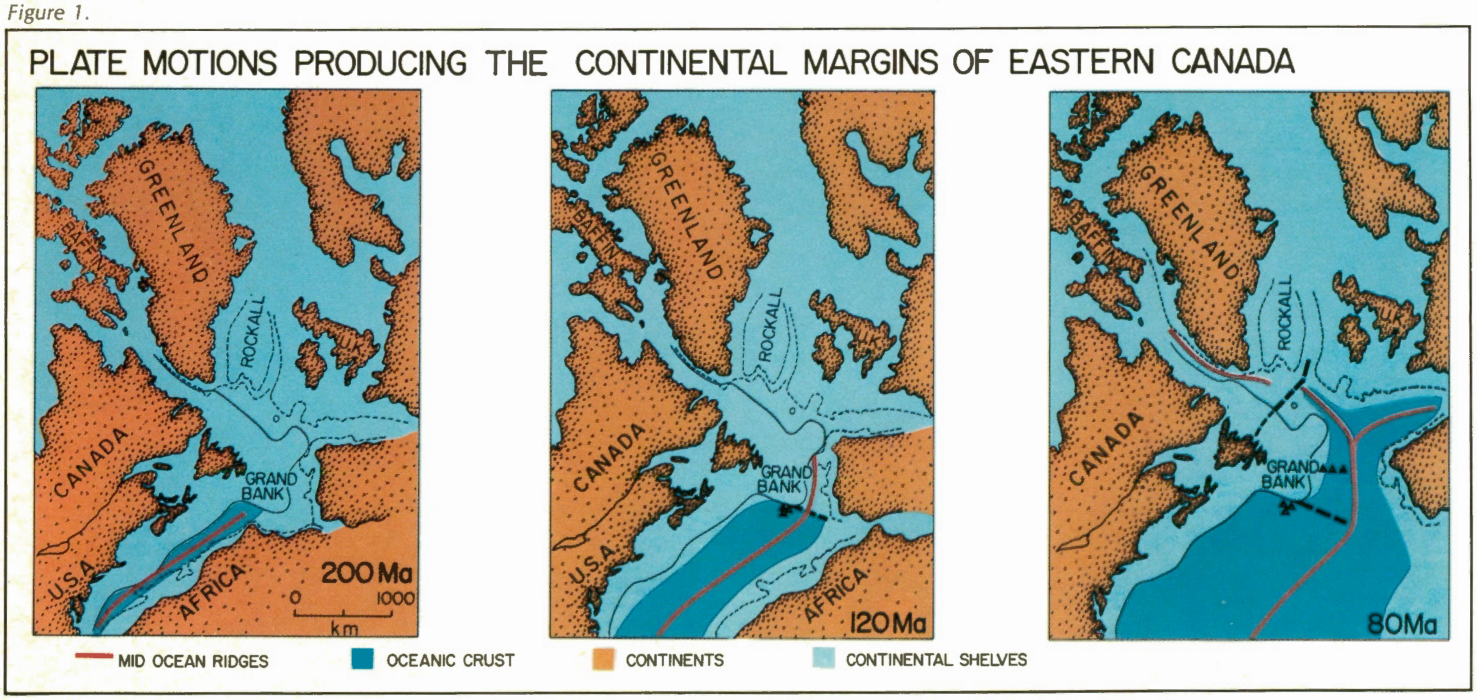
It was these events that produced the rich oil and gas deposits lying offshore of Nova Scotia and Newfoundland. And understanding the events is important, because it can help in the identification of source rocks and in estimating their petroleum potential.

The geological lifespan of the continental margins began about 200 million years ago, when the supercontinent of Pangea fragmented to open the Atlantic Ocean Basin and its northern extensions into the Arctic. This break-up was the beginning of complex rifting events which lasted for about 120 million years and produced the margins of Eastern Canada (Fig. 1). First, about 200 million years (Ma) ago, the Africa-North America plates moved and began to create the continental margins off Nova Scotia and south of the Grand Banks. Then about 120 Ma ago, Iberia separated from the eastern Grand Banks. And finally, 80 Ma ago, the region west of the U.K. rifted away from the northeast Newfoundland shelf and Greenland separated from Labrador and Baffin Island.

These rifting episodes produced progressively younger margins to the north,

Charlotte Keen has been marine geophysicist at EMR's Atlantic Geoscience Centre, the Geological Survey of Canada's arm at the Bedford Institute of Oceanography in Dartmouth, for 12 years, since her post graduate work in marine geophysics at Dalhousie and Cambridge universities. She is active nationally and internationally as chairman of the Canadian Lithosphere Committee, a Fellow of the Royal Society of Canada, member of the Commission on Marine Geology, and a member of the international Deep Sea Drilling Project Passive Margin panel. Her work has been recognized by the Young Scientist Award from the Association of Atlantic Provinces Interuniversity Committee on the Sciences, and the Past President's Medal from the Geological Association of Canada. Her current interests include the geodynamics of sedimentary basins, deep seismic structure of continental margins, and properties of the sub-crustal lithosphere.

Figure 1.



and created rather different structural styles for the various margin segments. Some of these differences appear to depend on the sense of relative motion between the separating continents, on the fabric of the crust being rifted, and on the length of time required to achieve complete continental separation. For example, off Nova Scotia, plate motions were roughly perpendicular to the margin, rifting it. By comparison, south of the Grand Banks, the continents slid past each other, shearing the margin.

To understand margin evolution, we need to know the plate tectonic motions which produced them. However, this is only part of the story; knowing the motions that created the margins does not explain the physical processes active during their creation. We need more clues.

The quantity, quality, and diversity of data available for the margins of Eastern Canada is among the best in the world. Samples from deep exploratory wells indicate stratigraphic and geochemical properties of the sediment. Seismic reflection data delineate the thicknesses and structural characteristics of the sedimentary strata on a regional scale. We also have seismic measurements of the deep crustal structure of the margin, gravity anomaly measurements, and magnetic anomaly observations. Given this unique data set, the challenge is to use it well to determine the processes occurring during rifting and the subsequent margin evolution.

One way is to construct theoretical models which can be described mathematically and predict a number of parameters to compare directly with the observations. If the predictions and observations do not match well, the model must be modified or discarded. This is the kind of model which Chris Beaumont of Dalhousie University and I have been developing. Others in the U.K., France and the U.S.A. have been working on similar studies.

The models which best satisfy the observations are conceptually simple. They assume that the lithosphere extends during rifting (Fig. 2). The extension causes the lithosphere to thin and hot material from the asthenosphere rises beneath the thinned region and produces high temperatures in the lithosphere. The combination of thermal expansion of the lithosphere, and the replacement of the light thinned crustal material by more dense mantle material, changes basement elevation. These changes may take the form of uplift, or of subsidence, depending on the details of the stretching process (Fig. 2a and b). As the separation of the continents is completed, extension stops. The lithosphere cools and thickens towards its equilibrium thermal state. Thermal contraction causes the margin to subside, which creates a depression where sediments accumulate. The weight of sediments produces further subsidence depending on the mechanical strength or rigidity of the lithosphere (Fig. 3). The rigidity changes with time as the margin cools; a young, hot margin is less rigid than an old, cold one.

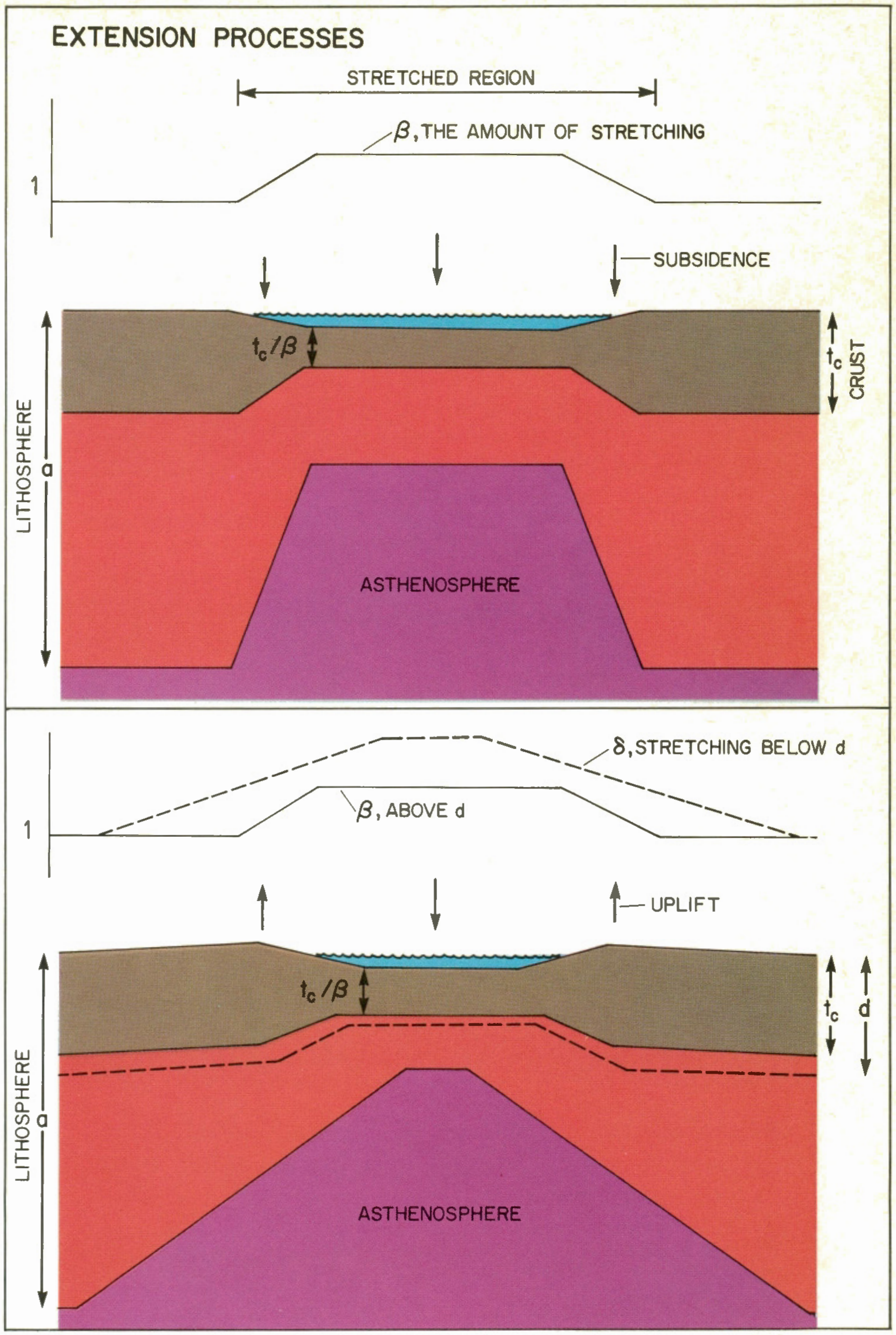


Figure 2. Extension Processes
a. The whole lithosphere is extended and thinned by an amount β. This gives subsidence shown by arrows.

b. Lower lithosphere extended by δ, upper lithosphere by β.
This gives uplift of rift shoulders as shown by arrows

Processus d'allongment.
a. Toute la lithosphère s'allonge et s'amenuise d'un facteur β. Cela produit la subsidence que montrent les flèches.

b. La lithosphère inférieure s'allonge du facteur δ, la lithosphère supérieure, de β. Il en résulte un soulèvement des épaulements du fossé tectonique tel que le montrent les flèches

In making the mathematical model describing the evolution of the margin, we incorporate all of these factors. We need two inputs: the amount of extension during rift-

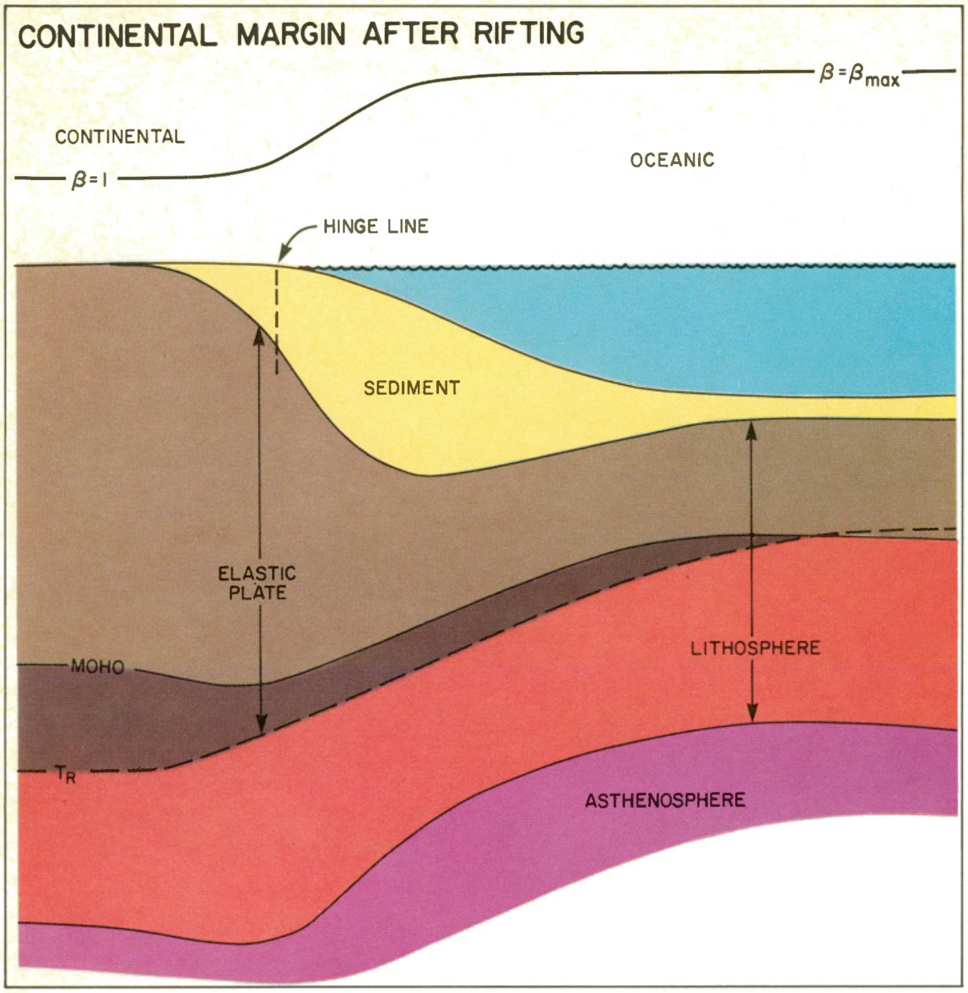


Figure 3.

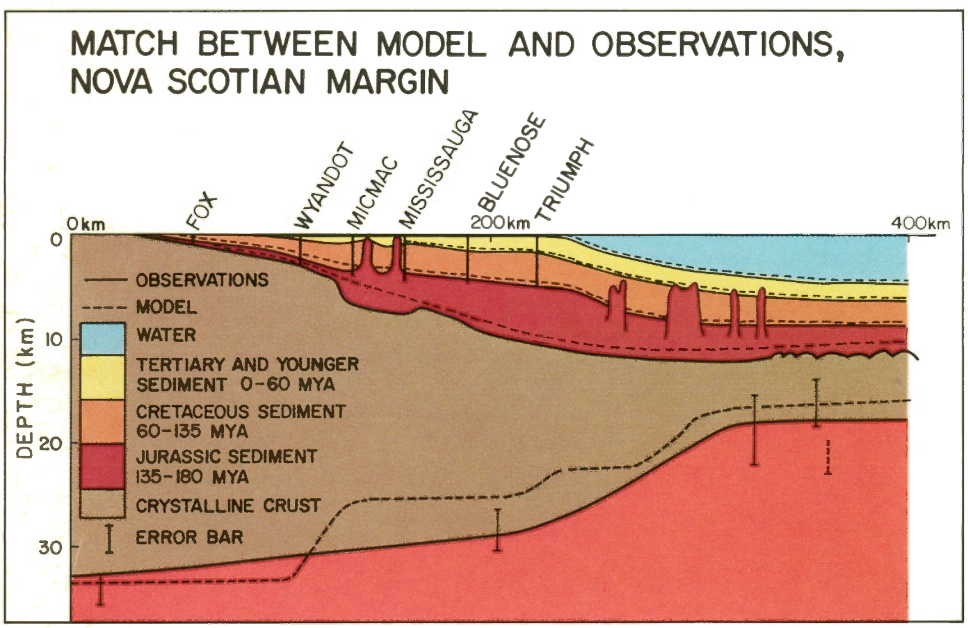


Figure 4.

ing, and the sediment influx versus time. We determine the amount of extension from the thickness of crystalline crustal rocks which were thinned by extension during rifting (Fig. 3) and now underlie the sediments. We measure crustal thicknesses in crustal seismic refraction experiments. In general, extension varies across the margin and increases toward the ocean basin. We determine sediment influx from the ages of the sediments and their thicknesses, shown by biostratigraphic studies of sediments sampled in deep exploratory wells and by seismic reflection measurements. We then compute the cooling of the lithosphere and the subsidence due to cooling and to sediment loading, and trace the evolution of the margin from the time of rifting to the present.

Using these models, we can compute how far the margin has subsided, at what rates, the shape of the marginal sedimentary basin, the gravity anomalies across the margin, and the paleotemperatures in the sediments and basement rocks. We can test the validity of the model by direct observation for all but the last characteristic. These paleotemperatures are very important, because temperature and time determine the thermal maturation of organic matter, and can be used to estimate the petroleum potential of the sediments as source rocks.

Why is this kind of modelling particularly useful in studying margin evolution? First, it allows us to integrate all kinds of data in one model, instead of studying one or two parameters only, apart from others which could influence the final interpretation. Second, the models are predictive in the sense that, if we know some characteristics, a model can describe other properties of the margin's history. Some of these, like paleotemperature, would otherwise be difficult to determine. Third, the models are quantitative. They allow a degree of precision in describing margin evolution unattainable except in a mathematical framework. All these attributes are extremely useful in testing hypothese against observations.

Geological evidence strongly favours extensional models. On margins where the basement rocks are not deeply buried by sediments, listric normal faults have been mapped. The geometry of these faults indicates that extension by factors of 1.5 to 3 has occurred. On the Labrador shelf we can see the upper surface of normal faults in seismic reflection data, and on the Grand Banks the presence of northeast trending grabens such as the Jean d'Arc Subbasin probably results from extensional forces during rifting. Also, the crust beneath the sediments thins toward the ocean basin (Fig. 3, 4) from typical continental thicknesses of 35 km to about 15 km beneath the axis of the marginal sedimentary basins. This thinning by factors of 2 to 3 is difficult to explain except by extension.

Finally, the models are consistent with the development of thick sedimentary basins on the margins and with the stratigraphy of these basins. The timing of the onset of seafloor spreading is roughly consistent with the age of the oldest marine sediments on the Labrador and Nova Scotian margins, as predicted by the model.

The models also indicate that the rate of subsidence decreases with time after rifting. Therefore, the depression available for sediment deposition would be greatest early in the history of the margin. Observations confirm this. On the Nova Scotian margin, a large thickness of Jurassic sediments (180-135 Ma) with progressively thinner layers of younger sediments occupy the basin (Fig. 4).

We have applied the model successfully to the rifted margins of Eastern Canada, as well as to other areas. Figure 4 compares observations and model results for the Nova Scotia margin. Six wells have been projected onto the cross section and were used to determine the stratigraphy. The thickness and age of the deeper sediments on the outer shelf 200 km from shore, and further seaward, was inferred from seismic data. The thinning of the crystalline crust was determined from deep seismic experiments. Salt diapirs are plentiful in this region, (Fig. 4) but for simplicity were not included in the model.

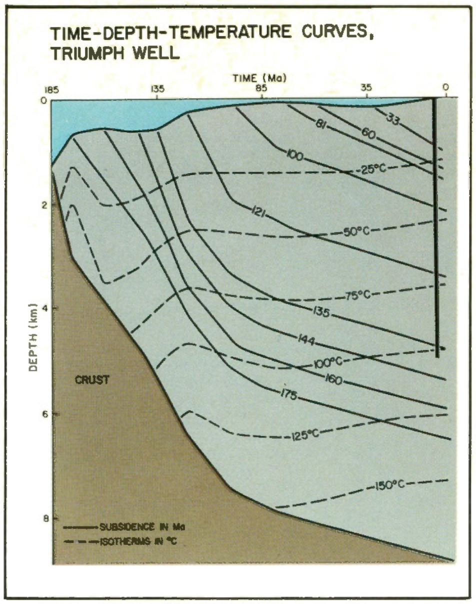


Figure 5.

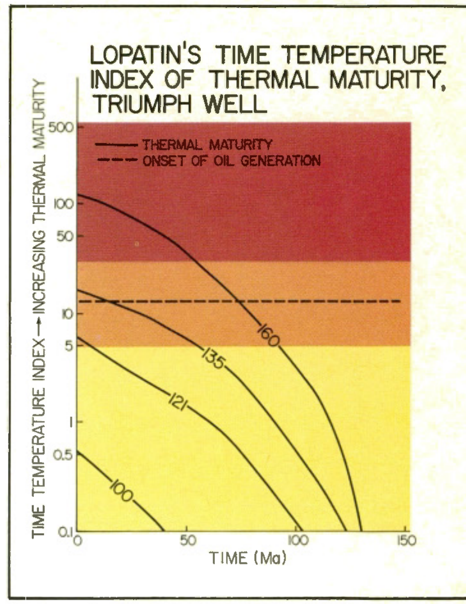


Figure 6.

The model describes a sedimentary basin remarkably similar in shape and stratigraphy to reality. It is important to remember that this was in no way fixed beforehand. In calculating the model, we determined the amount of subsidence from the amount of extension, estimated from measurements of crustal thickness. If the model was inappropriate, the calculated depression created by subsidence would not satisfy observations of sediment thickness and water depth. The good agreement, as well as a good match with observed gravity anomalies, compellingly supports the model. It also clearly demonstrates a fundamental relationship between sedimentary basin and deep crustal structure. This is an important advance in understanding geology in three dimensions.

Paleotemperatures within the sediments, described by the model, are important for practical reasons. Because the calculations trace the cooling history of the lithosphere since the time of rifting, the temperatures at any time and depth can be found. Data from the Triumph well on the outer Nova Scotian shelf near Sable Island illustrates the potential significance of this aspect of the model results (Fig. 5). The Sable Island region is underlain by the Verrill Canyon Formation of Early Cretaceous-Late Jurassic age (125 Ma and older), which has tentatively been identified as the source rock for gas discovered in the region (GEOS, Fall 1981). The subsidence histories for strata of various ages are shown in Figure 5. Superimposed on the subsidence curves are the isotherms, the depths of which are computed as part of the modelling procedure. These two sets of curves give the entire depth-time-temperature for the well.

The thermal maturation of the sediments is a function of the cumulative temperature-time history and can be computed from the modelled paleotemperatures. The thermal maturity of the sediments is a guide to whether they have experienced a thermal history favourable for the generation of petroleum. The Time-Temperature Index of Lopatin (TTI) is one measure of thermal maturity which is easily computed from the predicted temperatures (Fig. 6). Thermal maturity increases with time since deposition, as the sediments experience higher temperatures and longer cooking times. TTI is computed from the length of time the sediments spend in each 10°C temperature range. The approximate value of 15 TTI units corresponds to the onset of oil generation. If sediments reach values of thermal maturity above this line, their thermal history has been favourable for petroleum generation. At the Triumph well therefore, the results suggest that Jurassic sediments (135 Ma and older) will be thermally mature. Early Cretaceous and younger sediments will be immature.

The curves shown in Figure 6 are also useful in determining how long petroleum generation takes and therefore provides estimates of the earliest time that petroleum could migrate from source rock to reservoir. For example, 160 Ma old sediments attained thermal maturity 75 Ma ago and migration could not have begun before that time.

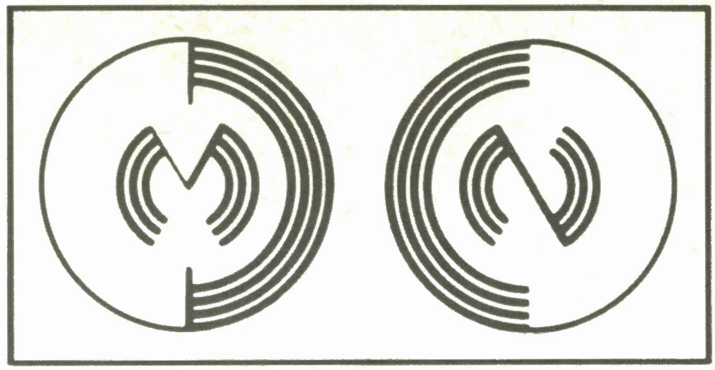
The models thus give us a potentially powerful petroleum exploration tool which has not been fully exploited. However, many deficiencies still exist. We need measurements of thermal conductivity and radiogenic heat production for the sediments in order to compute paleotemperatures accurately. Bottom hole temperatures in the wells must be carefully logged so they can be corrected to equilibrium values. These temperatures are important in estimating present heat flow and in validating the model results. The relationship between geochemical models of petroleum generation and of thermal history needs to be clarified so that the predictive capabilities of both are strengthened.

We look forward to the integration of geochemistry, geology, and geophysics in predictive models for petroleum occurences in future exploration. It's up to the exploration divisions of the petroleum companies to recognize the value of the models and use them.

Les modèles géophysiques peuvent intégrer plusieurs facteurs dans un cadre mathématique. Ils nous aident à comprendre l'évolution des marges continentales, et constituent, pour trouver du pétrole, un outil potentiellement très efficace, dont on n'a pas encore tiré pleinement parti. Les modèles qui suggèrent que la lithosphère s'allonge au cours de la création des fossés d'effondrement sont actuellement vérifiables au moyen d'observations, dans la région de l'île de Sable, sur le plateau continental de la Nouvelle-Écosse.

Cet article est disponible en français.

A new kind of map



By John H. Baines

Digital mapping forces us to reexamine our ideas... stimulating changes in perception of the earth and its population

Visualize inspecting selected hiking or canoe routes through the Canadian wilderness before going near it — not on a map, but on a TV screen, and with a choice of perspectives, including aircraft approaches and takeoff.

Or consider the potential of fast routine up-to-date analyses of scientific, financial or ecological statistics associated with any terrain-related subject, from prospective engineering construction to the natural resources of all of Canada — analyses based not on laborious specific surveys, but computed from comprehensive precise data transmitted from the same general reference system that showed you the hiking route.

These possibilities would once have seemed like science fiction, but today they are imminent. Using spectacular developments in computer technology, including graphics, a basic topographical information processing system is already installed at EMR. It needs only further technical refinements and wider coverage to become this comprehensive.

'Only money, not technology, is holding us back,' says Dr. J.M. Zarzycki, Director of the Topographical Survey Division of EMR's Surveys and Mapping Branch. 'Development started here in the late 1960's,' he continues. 'Then the limitation was technology. That is no longer true.'

Aerial photography can distinguish detail smaller than human beings, and this resolving power is improving rapidly. For up-to-date archives, analysis and display of our changing geographic information, the only methods with the necessary speed and quality transform panoramic images into the strings of pulses of a digital electronic code.

About 40 technicians in the Topographic Survey Division are evolving and operating the national archives and the 'dictionary' for this digital electronic language. This system is known as the National Digital Topographic Data Base, or NDTDB. It will do for users of topographic information what financial data bases do for banks, but with more diversity in the way it can be accessed. A variety of distant customers will eventually be in rapid telecommunication with it and with each other. They will include provincial government agencies, petroleum companies, construction conglomerates, pipeline builders, university researchers,... anyone needing information about the earth's surface or resources.

An engineer building a dam will be able to quickly calculate the land area to be flooded.

A conservation officer will judge the nesting potential of an isolated swamp for migrating fowl.

An epidemiologist will predict incidence of nutritional deficiencies based on soil and water chemicals.

The implications of NDTDB's potential are so radical that the very word 'map' will soon mean something quite different. Already, the group working on the system refers to 'graphic maps,' or less aptly, 'classic maps' when they mean the traditional drafted or printed versions. They predict that we will have to extend our meaning to include the record of electronic pulses that describe a map segment. These electronic codes themselves represent all the information, and more, that a skilled map reader can derive from a printed map. But they are stored on discs or magnetic tapes, instead of on paper, and they may never be printed as a graphic map. The information is more complete and at the same time more precise than could ever be crammed onto a traditional map.

'The impact of digital mapping is forcing the photogrammetrist as well as the cartographer to re-examine the entire concept of collecting, editing, disseminating, displaying and storing terrain information,' said Dr. Zarzycki at an international congress in Montreux, Switzerland last year.

So far, NDTDB can produce maps with different scales, colours and perspectives, automatically drawn on either EMR's or the customer's own digitized equipment. But video displays, which could be nationally distributed, could have similar variety. Animation and compatibility with video reference systems such as Telidon are also in the books. An animated presentation could, as in the scene imagined at the beginning of this article, show you a selection of moving perspectives of a route, from on or above the land surface.

As the coverage of the system increases, more scientific and legal reference data for the customer's own choice of analysis and mathematical modelling will be supplied. Utilities need this geographic referencing to assess prospective hydro, rail or road routes. Exploration companies can correlate precisely surface conditions like minerals and water movement. Agricultural agencies can calculate the erosion of arable land. Provincial and municipal governments will exchange details about legal boundaries.

Visitors from many countries are coming to EMR to investigate the data base, but the wide application of the existing service is still in the future, according to Dr. Zarzycki, leader of the group developing the system. Data from New Brunswick was

With a background in electronics, John Baines is an Ottawa consultant interested in the relationship between linguistics and recent advances in science.

Photogrammetric Digital Data Acquisition System. Television-like terminals display digitized terrain features extracted by the technician from a pair of aerial photographs viewed through binoculars of the B-8 stereoplotter

Système de saisie de données photogrammétriques numériques. Des terminaux à écran affichent des éléments de terrain convertis en numériques, que le technicien a extraits d'une couple de photographies aériennes observées à travers le binoculaire du stéréorestituteur B-8

used as a pilot project in 1979, and data from parts of Ontario and the Arctic islands have been collected in the NDTDB. Moreover, most customers do not yet have their own NDTDB-fed equipment for map drawing or video display. Therefore, since non-graphic reports are alone an inadequate general substitute for panoramic perception, the latest forms of printed maps are still the largest end product requirement from EMR.

Let's follow the creation at EMR of this new kind of digital map, from input to output.

Quantifiable terrain data like lakes, hills, swamps, railway lines and buildings are obtained by airborne stereo-photography, with resolution down to about one metre. The images may also come from a satellite, but in that case resolution is more limited, because electronic imaging systems have not yet matched the resolving power of high precision aerial cameras. Or the original input may be digitized from existing graphics.

A Canadian invention called a Gestalt photo mapper automatically generates a terrain elevation model. Elevation contours are derived from that data by means of a computer program.

In stereo-plotting centres, overlapping aerial photographs are interpreted and measured by a skilled technician. The geographic position of all details is registered on a magnetic disc, which is then checked and edited. Features that cannot be easily seen on photographs, like boundary monuments, navigation markers, oil wells, geodetic survey controls, and parks, are all incorporated from other maps or from documents that give their geographical position.

Operators at interactive graphic control consols at these centres can view the digitized features at any scale, and tie in adjacent map segments. They make changes to the digital data that they would normally make on a pencil manuscript. Geographic data in a photograph may be hidden by a shadow, for example. In that case, the missing information can be transferred from an overlapping adjacent stereo photograph.

Another source of digitized data — Raster scanning of graphic manuscripts — is analogous to a TV camera's sequential line scanning. It is being investigated as an alternative to cumbersome manual digitizing of existing traditional maps.

Storing

It is impossible to foresee all feasible applications of data at the time it is digitized, so the map segments must be classified and stored for easy retrieval. The Topographical Division uses two basic types of storage files, and they are more easily and quickly updated than files of graphic maps. The first is the Position file, known as POP. This file contains a record of all topographical features in the correct location on the earth's surface. Its information comes from aerial photography, large scale plans or from ground surveys.

The second is the Representation file, known as REP, and is created from POP to meet the specifications of the map. A cartographer displaces or deletes features, selects symbols, and orders the automatic drafting of colour separation negatives for printing. Cartographers make the modifications, since not all the skills needed for advancing map requirements can be programmed into electronic data processors — human judgement is still required.

Drafting

The digitally driven automated map drafting machine used by the Topographical Survey Division is the Kongsberg flatbed plotter. It can symbolize map features, and offer a choice of scale, contour generation and colour coding, but it has a limited capacity to print text.

There are several advantages to recording topographic data in digital as well as in graphic form. It increases content and accuracy. No features are lost because they are so close together that they can't be shown on a piece of paper. The accuracy of topographic data compiled on a graphic manuscript is limited by its complilation scale, and the accuracy of data digitized from it is also limited by this factor. This is not the case when information is digitized directly from aerial photographs; then the major limitations are only the scale of the photography and the skill of the operator.

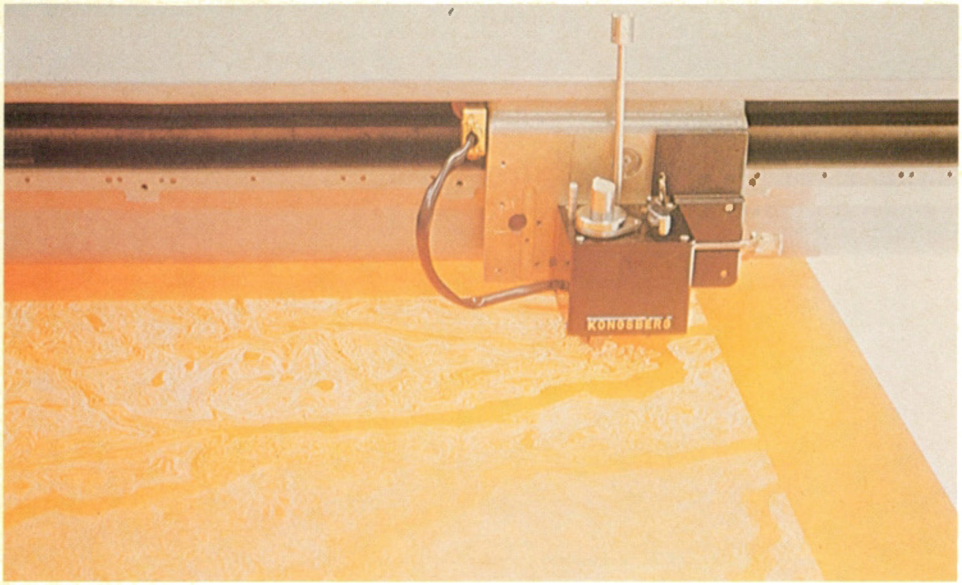
Distribution

The National Digital Topographic Data Base has been designed for telecommunication links with data bases across the country, to be used with phone lines, but at present the tapes must be mailed or delivered by hand.

Commercial equipment is now available for digitizing all these stages of geographic information processing, but at present such a complete mapping system cannot be bought in one package. The development of such a system from commercial components would take about a year, Dr. Zarzycki estimates.

'To take full advantage of the power of digital technology, an agency plugging into NDTDB must focus on the special potentials of the new system, rather than on trying to emulate current manual practices,' he adds.

Pilot production and staff training could take another six months.



Close-up of an automated drafting table scribing a topographical map

Gros plan d'une table de dessin automatique traçant à la pointe une carte topographique

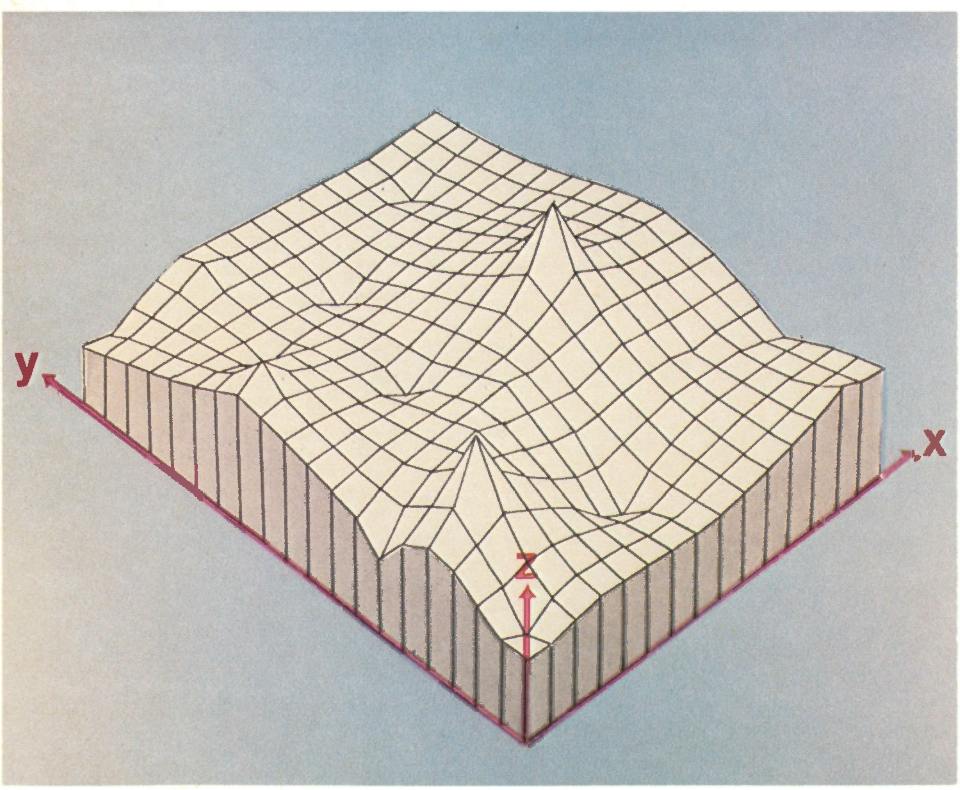
Several demonstration projects are underway now in the Topographical Survey Division to demonstrate NDTDB's potential. One at the Geological Survey of Canada integrates topographic and geological information. The digital data is used to rectify gravity measurements for EMR's Earth Physics Branch, and satellite imagery for Canada Centre for Remote Sensing. The Dept. of Public Works uses it in drafting zoning plans around airports. And it provides the structure for Statistics Canada's area master file of census data.

Standardization

Ideally, a topographical feature: road, house, property boundary or telephone line, will be digitized only once, and then supplied to other users through the system. However, digital mapping technology has evolved so quickly, and so much digital data has been collected by different users, that not much thought has been given to a common standard to facilitate data exchange.

At the request of the Canadian Council of Surveys and Mapping, EMR's Topographic Survey Division has organized technical committees to tackle the problem of standardization. They have prepared a draft of national standards for digital data exchange, which are being distributed now. A secretariat has been estabished to receive feedback and update standards.

The expertise and innovation behind this whole enterprise can be appreciated on several different levels. The improving topographic equipment that incorporates this digital electronic language, and innovative users of the equipment, are at the same time mutually stimulating an accelerating advance in perception of the earth and its population. The equipment, its origins in and its effect on human thought, are all analogs of the fertile conjunction of panoramic perception and linguistic rotes.



Digital terrain model *Image plastique numérique*

La Division des levés topographiques de la Direction des levés et de la cartographie, à EMR, apporte des perfectionnements à un système de traitement de données topographiques qui vient d'être mis en place et élargit son champ d'application. Appelé Base nationale de données topographiques numériques, ce système sera pour les utilisateurs des informations topographiques ce que les bases de données financières sont pour les banques, mais avec un accès à l'information plus diversifié. Il peut produire des graphiques qui sont automatiquement tracés sur papier ou affichés sur écran vidéo. Il peut aussi analyser et sortir l'information sous forme numérique; on s'attend d'ailleurs que cette applications, qui offre l'avantage d'un contenu plus nombreux et plus précis, prendra de plus en plus d'importance.

Cet article est disponible en français

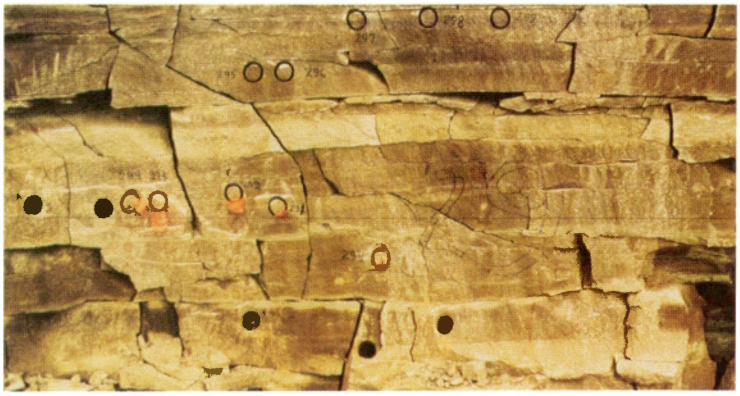
L'ARCTIQUE CANADIEN SOUS UN CLIMAT ÉQUATORIAL?

Par Pierre Lapointe et Peter Dankers

Par une étude paléomagnétique des sédiments du Dévonien on a pu déterminer que, dans le passé, l'Arctique se trouvait sous des latitudes plus clémentes.

Une section stratigraphique type de la formation de Snow Blind Bay sur la côte est de l'île de Cornwallis. On peut y voir l'alternance des conglomérats et des pélites

Typical geologic section from Snow Blind Bay formation on the east coast of Cornwallis Island, showing alternating conglomerate and pelite



Un échantillonnage type dans une section sédimentaire. Chaque horizon propice est foré latéralement et verticalement

Typical sampling in a sedimentary section. Each suitable horizon is drilled laterally and vertically

Suivant le principe d'une boussole, les minéraux magnétiques (magnétite, hématite) s'orientent vers le pôle magnétique qui prévaut lors de la formation de la roche. Ainsi, lors du dépôt d'une roche sédimentaire ou du refroidissement d'une roche ignée, les grains magnétiques s'alignent dans la direction du champ magnétique terrestre de l'époque. L'étude de cet emprisonnement magnétique sert à localiser le pôle magnétique de l'époque, et cette étude porte le nom de paléomagnétisme.

On retrouve dans les îles de l'Arctique canadien une succession imposante de formations sédimentaires qui représentent une section d'au moins 1 000 millions d'années de l'évolution géologique de la terre. L'étude paléomagnétique des séquences de sédiments rouges de la période dévonienne permet de déterminer la latitude sous laquelle ces sédiments se sont déposés. De plus, en étudiant des sections stratigraphiques géographiquement distantes on peut établir si elles sont équivalentes en temps ou non. Étant donné que la région étudiée de l'Arctique canadien est considérée tectoniquement stable, les pôles provenant de cette région peuvent servir de pôles repères pour définir tout déplacement dans des zones qui ont subi des mouvements tectoniques depuis le Dévonien.

Les différentes zones géologiques des îles de l'Arctique sont schématisées et les différentes sections stratigraphiques qui ont été échantillonnées apparaissent dans la figure 1. À chaque localité, une section stratigraphique d'au moins 100 m a été forée, soit environ 200 carottes par section chaque carotte mesure 2,5 cm de diamètre, et environ 12 cm de longueur. L'échantillonage se fait dans les horizons propices tout le long de la section stratigraphique.

Les trois sections étudiées se situent dans l'île de Somerset, dans l'île Prince-de-Galles et dans l'île Cornwallis (Fig. 1). Dans chaque cas, la section stratigraphique représente un intervalle de temps entre le Silurien supérieur et le Dévonien inférieur (405-385 Ma, Fig. 2). La section de l'île Somerset se compose de la formation de Somerset, sur laquelle reposent les membres inférieur et supérieur de la formation de Peel Sound. Cette succession se compose d'une alternance de carbonate, de pélite et de grès déposés dans un environnement alluvionnaire.

La deuxième section dans l'île Prince-de-Galles contient principalement les deux membres de la formation de Peel Sound, et se compose d'une alternance de conglomérat, de grès et de calcaire. La troisième section dans l'île Cornwallis est différente, bien que du même âge (Fig. 2). La formation de Snow Blind Bay est composée d'une alternance de conglomérat et de pélite. Ces trois sections représentent donc un intervalle de temps identique et un environnement de déposition très similaire.

Quelles sont donc les étapes qui nous permettent de définir la latitude sous laquelle ces roches se sont formées?

Lorsque l'on mesure l'aimantation d'une roche à l'aide d'un magnétomètre, on obtient un vecteur composé de l'aimantation de chaque minéral magnétique; cette aimantation s'appelle l'aimantation rémanente naturelle (ARN). La figure 2 permet de visualiser la direction et l'inclinaison du champ magnétique mesurées dans les différents échantillons provenant d'un même site. Il est à noter que l'intensité du vecteur mesuré n'est pas représentée dans ce genre de diagramme. Deux points importants sont à noter; le premier est qu'en montant la colonne stratigraphique (Fig. 2) on s'aperçoit que le groupement des directions d'aimantation est meilleur. Le deuxième est la présence de deux directions distinctes; une dans le cadran sud-est, l'autre dans le cadran nord-ouest. La direction sud-est se retrouve principalement dans la formation de Somerset. La direction nord-ouest se retrouve généralement dans la section du membre supérieur de Peel Sound et de son équivalent dans la formation de Snow Blind Bay (Fig. 2). De plus ces deux directions sont inversées l'une par rapport à l'autre. Ce phénomène est interprété comme étant la signature d'un renversement du champ magnétique. Par conséquent, la formation de Peel Sound ou son équivalent pourrait éventuellement, être utilisée comme horizon repère.

Comment peut-on prouver ou tout au moins vérifier ces conclusions? La deuxième étape d'une étude paléomagnétique, la désaimantation, apportera une réponse à cette question.

Trois types de désaimantation sont possibles; la désaimantation par champ alternatif, celle par traitement thermique et celle par traitement chimique. Quel est le principe de la désaimantation et à quoi nous sert-elle? La désaimantation est l'annulation par étape de l'aimantation rémanente, ce qui a pour but de vérifier la présence ou l'absence d'une autre aimantation et, ce qui est tout aussi important, de définir la stabilité de celle(s) présente(s). La stabilité est une mesure de résistance aux différents traitements appliqués.

Cette stabilité est reliée à la composition chimique des minéraux magnétiques, à la grosseur des cristaux et à leur origine (c'est-à-dire quel type d'aimantation? détritique, thermique, chimique ou visqueuse, etc.). Par exemple, une roche ignée dans laquelle on retrouve une aimantation portée par la magnétite, peut résister à des traitements thermiques jusqu'à 570°C (point de Curie de la magnétite, température au-dessus de laquelle le minéral est magnétiquement vierge) ou à des traitements par champ alternatif jusqu'à 100 millitesla (unité du champ alternatif appliqué). Il est à noter qu'une roche peut contenir plus d'une aimantation. Ainsi plusieurs phénomènes géologiques peuvent affecter la roche et les minéraux magnétiques, de façon telle que le champ magnétique existant lors de ce changement sera enregistré, en plus de l'aimantation originale. La désaimantation permet souvent de définir chacune de ces aimantations. Les trois traitements de désaimantation sont faits par paliers successifs; le traitement thermique de 20° à 700°C par étape de 100°C et par plus petites étapes près des points de Curie; le traitement par champ alternatif de 0 à 300 millitesla, habituellement par étapes de 10 millitesla et le traitement chimique en les immergeant dans l'acide chlorhydrique pour un certain nombre d'heures afin de faire disparaître l'aimantation portée par les grains de couleurs rouge et de déterminer la composante détritique de l'aimantation. Après chaque traitement, le vecteur résultant est mesuré de nouveau et l'analyse vectorielle de l'aimantation résultante est possible.

Il est impossible de démontrer ici, d'une façon convaincante, la validité et la totalité des résultats (près de 1 500 spécimens et près de 10 000 traitements divers). Afin de démontrer la stabilité de l'aimantation des sédiments étudiés, quelques exemples de désaimantation (thermique et par champ alternatif) sont montrés (Fig. 3). Chaque symbole représente le vecteur résultant, mesuré après une étape de désaimantation. En comparant ces deux échantillons, on peut trouver plusieurs caractéristiques précises permettant dans les deux cas de déterminer la nature et l'origine des aimantations. La stabilité des aimantations définies est excellente: en effet les aimantations résistent à des traitements de plus de 600°C et à près de 200 millitesla. On peut voir aussi que la différence

Pierre Lapointe œuvre dans le domaine de la géophysique à la Direction de la physique du globe à ÉMR. Il a effectué des travaux sur le terrain surtout dans les Appalaches et dans l'Arctique. Peter Dankers détient un Doctorat en physique des roches de l'université d'Utrecht. Il travaille au service géologique de Petro-Canada.

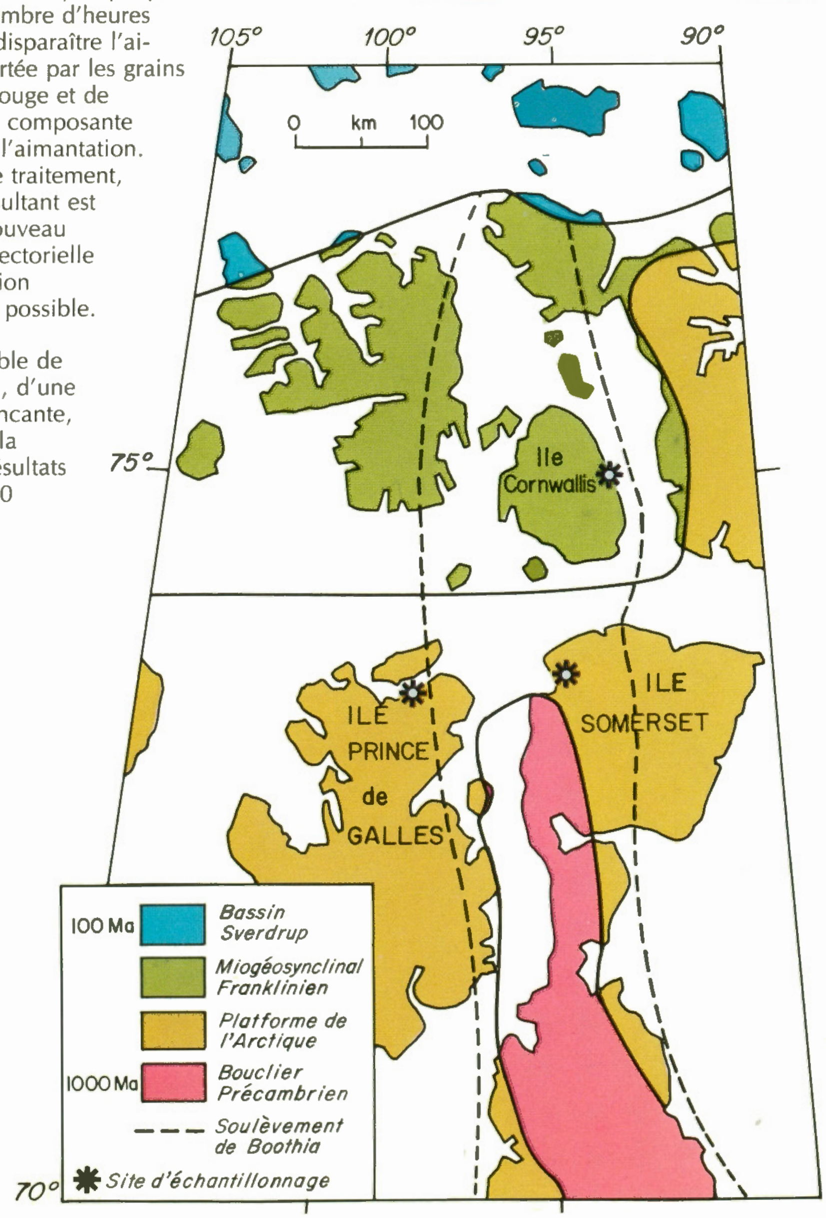


Figure 1.

des directions d'aimantations, soit sud-est et nord-ouest (Fig. 2) se trouve confirmée, étant donnée que chacune d'elles est stable et bien définie, après désaimantation. On peut remarquer aussi la différence dans le niveau d'intensité d'aimantation entre les deux types de roches, soit faible pour la dolomie, et forte pour la pélite. Un autre phénomène fort intéressant apparaît dans la courbe d'intensité versus le traitement thermique, c'est la présence de deux plateaux (Fig. 3), l'un entre 20°-550°C (magnétite) et l'autre de 550°-670°C (hématite). Le fait que ces deux minéraux ont enregistré la même direction d'aimantation implique que l'aimantation a été acquise rapidement lors du dépôt de la roche. La magnétite est reliée à une aimantation d'origine détritique, lors du dépôt, et l'hématite est reliée à une aimantation d'origine chimique sous la forme de la pigmentation rouge de la roche acquise lors de la diagénèse. Toutes ces caractéristiques nous permettent de conclure que ces aimantations sont une représentation fidèle du champ et du pôle magnétique lors de la déposition de ces sédiments. Quoique les deux aimantations présentes soient anti-parallèles, elles conduisent à la détermination d'un pôle magnétique unique pour chacune des formations, puisque l'anti-parallélisme est attribuable à un renversement du champ magnétique.

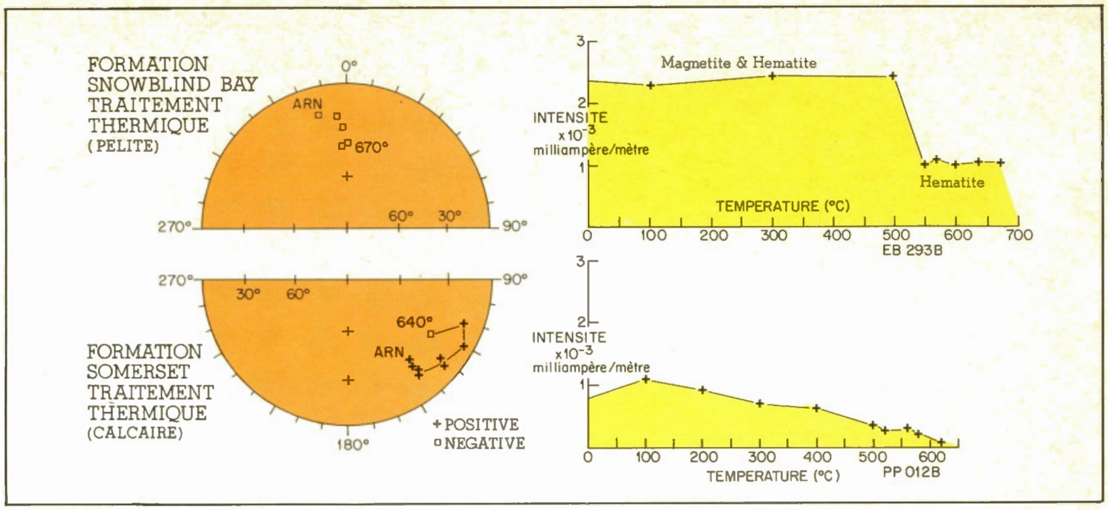


Figure 2 Coupe stratigraphique schématisée des trois sections étudiées. Les hachures diagonales représentent une discordance angulaire et les verticales une discordance d'érosion. De plus on peut associer la variation des aimantations rémanentes naturelles de la section de l'île Somerset

Geologic section of the three sections studied. The diagonal lines represent an angular unconformity; the vertical, an erosional unconformity. The variation in the natural remanent magnetization of the Somerset Island section can be associated

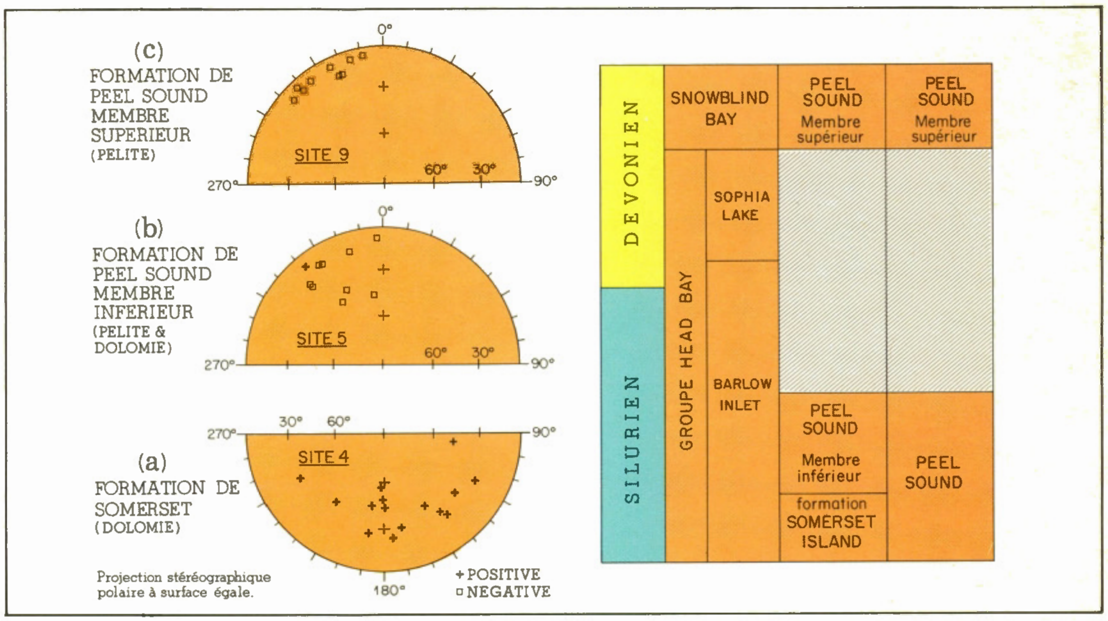


Figure 3

Le paléopôle d'une formation est obtenu en faisant la moyenne de tous les échantillons traités présentant une aimantation stable. La différence entre les pôles de chaque formation n'étant pas statistiquement significative on a donc fait la moyenne des trois pôles.

Ainsi par une relation simple de trigonométrie sphérique (la tangente de la paléolatitude est égale à la tangente de l'inclinaison de l'aimantation divisée par deux), on a pu calculer la paléolatitude de cette région. Cette paléolatitude est la latitude du site lors de la formation de la roche. Il faut ajouter à ce stade que l'hypothèse de base du paléomagnétisme est que les pôles géographique et magnétique coïncident tout au long des différentes époques géologiques. Les paléolatitudes ont été transposées sur une carte géologique où l'on retrouve les différents lithofacies du Dévonien (Fig. 4).

Cette carte nous permet donc d'imaginer le continent nord-américain au Dévonien. L'équateur coupait la partie supérieure des îles Arctiques. La presque totalité du sol canadien se trouvait donc sous un climat beaucoup plus tempéré qu'aujourd'hui! On peut ainsi associer les bassins sédimentaires et leurs formations respectives avec le climat dérivé de cette carte de paléolatitude. De même peut-on associer les différentes flores et faunes et éventuellement en déduire leurs environnements de vie. Dans le cas présent une évaluation sommaire des types de roches et des évidences fossilisées de la faune et de la flore dévoniennes trouvées dans ces sédiments a permis de corroborer un climat équatorial lors de leur formation.

De telles déterminations permettront à l'avenir de mieux connaître l'environnement de formation des différents faciès géologiques de l'Arctique et d'en maximiser l'exploitation.

Paleomagnetism can be used to determine the paleolatitude of an area at the time of formation of a rock type. A wide sampling program of Siluro-Devonian sedimentary sections from the Arctic Archipelago has been applying this technique for the last three years. All the sections show a field reversal, which can be used as a horizon marker for stratigraphic correlations. The results indicate that in Devonian time these rocks were deposited in an equatorial climate.

This article is also available in English.

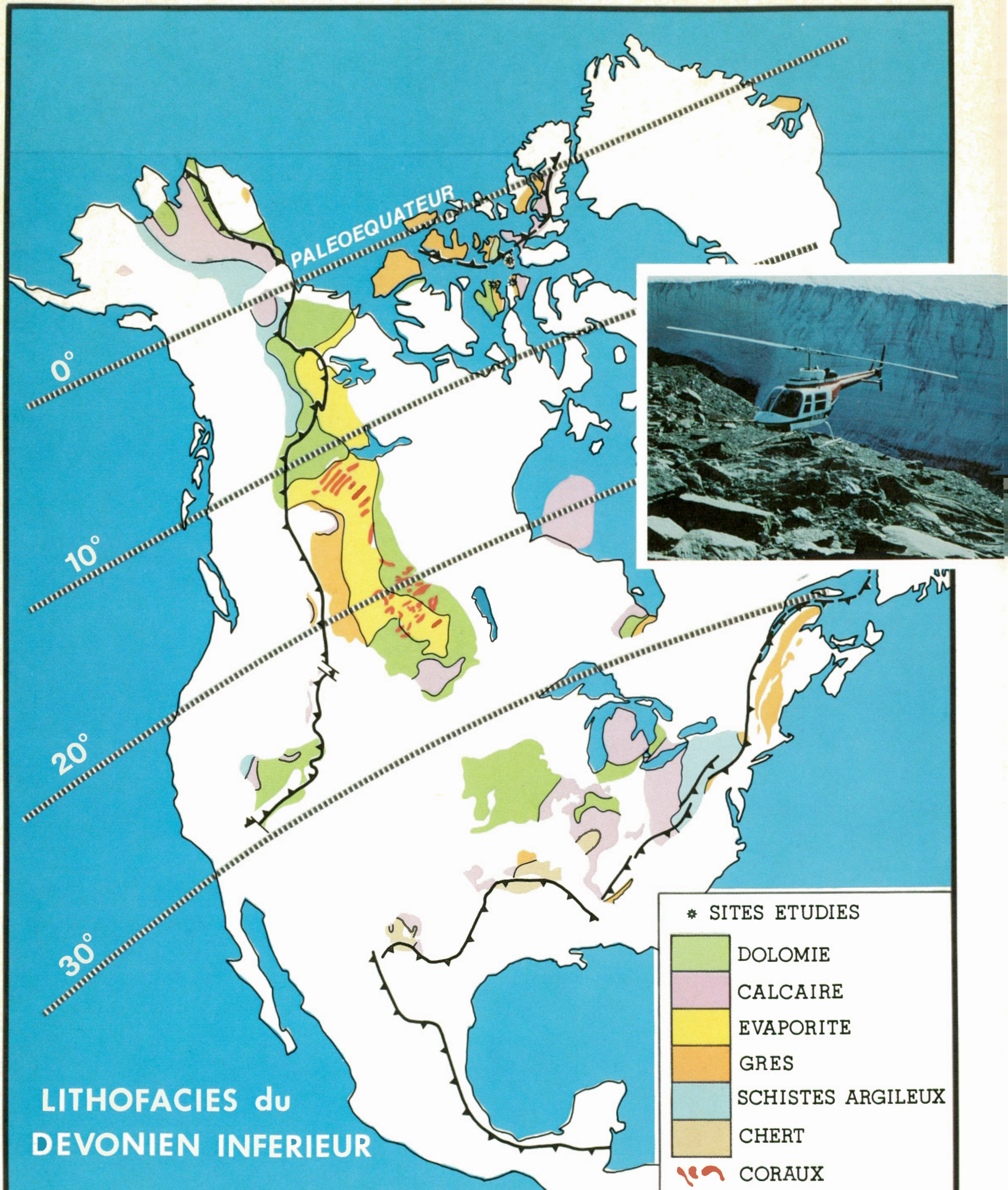


Figure 4

Source des lithofacies: Stratigraphic Atlas of North and Central America (Shell Oil Company, 1975)

How much coal in Canada?

by A.R. Cameron, D.W. Gibson and J.D. Hughes

Studies of coal geology and composition help evaluate the resource. Computer methodologies make the data accessible. Result: better scientific understanding and reduced exploration costs.

Coal, Canada's most abundant fossil energy source, will play a much larger role in future energy scenarios. To define the size of that role, EMR's Geological Survey of Canada (GSC) is compiling a national coal inventory, in collaboration with other government departments and industry. This is not merely a matter of totalling up numbers of coal seams and calculating tonnages. Reliable calculations depend on a detailed study of the geology of coal bearing formations and the quality, or composition, of the coal.

Some of Canada's coal basins already have a well-documented geological and quality data base, but most do not. Far-flung, they range from Newfoundland to Vancouver Island and from the U.S. border to northern Ellesmere Island, but more than 90 percent of the identified resources lie within the three western provinces, Saskatchewan, Alberta and British Columbia. They include structurally complex deposits in the Rocky Mountains and Foothills, relatively flat lying strata of the prairies, and the off-shore fields of Nova Scotia, each with special geological problems for evaluation. Many occurrences shown in Figure 1 are not economically attractive at present, partly because they are far from transportation corridors and markets, and we have concentrated on more accessible major fields.

Sedimentological processes form coal beds, and determine their size and shape, as well as their quality. Many coals were formed in deltas near the sea, others in alluvial plains beside lakes and rivers far away from a coastline. Still others formed in intermontane basins completely removed from major alluvial plains and deltas. Such diverse environments often occur at the same time and in adjacent places, as in the lower part of the Mississippi River. The schematic paleogeographic map of an ancient coal-forming environment in southeastern B.C.'s Crowsnest Pass area (Fig. 2) shows how this could happen. Peat, coal's parent material, accumulates in the swamp-marsh areas.

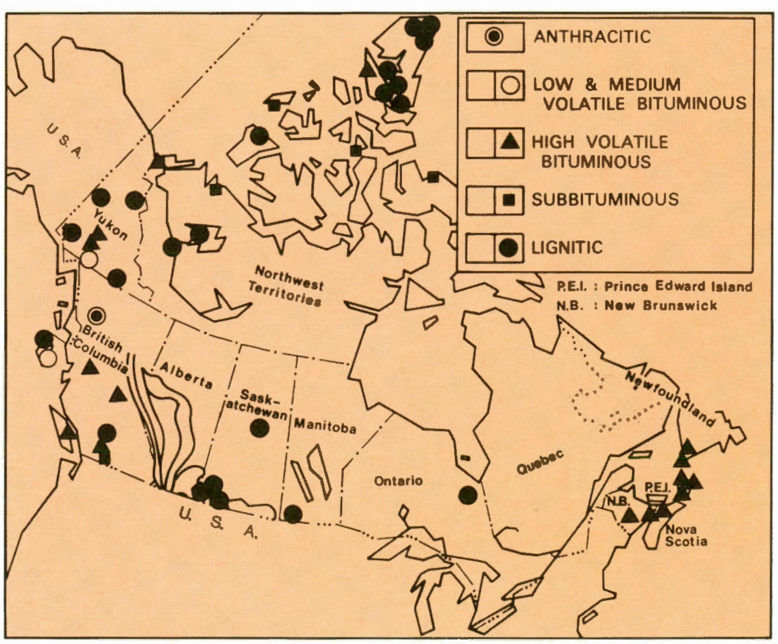


Figure 1: Occurrences of coal in Canada by rank. (from Report ER 79-9)
Venues de charbon au Canada par rang. (du rapport ER 79-9)

Variations in such environments affect the thickness, distribution, and quality of coal. They also affect the type and distribution of the enclosing rocks: strength, water holding capacity and permeability of the roof and floor strata. These in turn influence practical mining problems such as roof control and slope stability.

The geological cross section in Figure 3 shows complexly folded and faulted coal seams in an area of the Rocky Mountain Foothills of Alberta's Crowsnest Pass. Clearly, a thorough assessment of the structural complexity of a coal-bearing area must precede resource calculations and mine planning.

Microscopic examination shows that coal is not a homogeneous substance and is composed of both organic and inorganic matter. Figure 4 illustrates various compositional entities of bituminous coal. Vitrinite and inertinite are mainly derived from wood, but the latter is subjected to more severe conditions of chemical degradation. Liptinite is derived from hydrogen-rich plant constituents such as spore and pollen coats, leaf cuticles and resins. Coal seams differ in composition, depending on original environments of accumulation and subsequent geological history. Mineral matter and trace element content in coal is being examined on one current GSC project.

Figure 5 represents a columnar section containing a number of coal seams. Coals from these seams were studied microscopically for the distribution of vitrinite, which is not random; the seams near the bottom of the section have significantly lower vitrinite contents than those in the upper part. It is interesting to compare Figures 2 and 5, which are both related to the Crowsnest Pass area in southeastern B.C., for they illustrate the inter-relationships of compositional characteristics and depositional environments. The environment in Figure 2 is a prograding alluvial deltaic complex, which produced a wedge of sediment that with time built itself out into the Fernie Sea. As the shoreline advanced seaward, peat, which yields a low vitrinite content, accumulated at or near the shoreline. Coal

Cameron, Gibson and Hughes are members of the Coal Geology Subdivision of EMR's Institute of Sedimentary and Petroleum Geology, in Calgary, part of the Geological Survey of Canada. They are, respectively, heads of the Coal Technology, Geology, and Resource Evaluation sections. This group under Dr. D.K. Norris, and along with some personnel at EMR's Atlantic Geoscience Centre, is responsible for Canada's coal inventory.

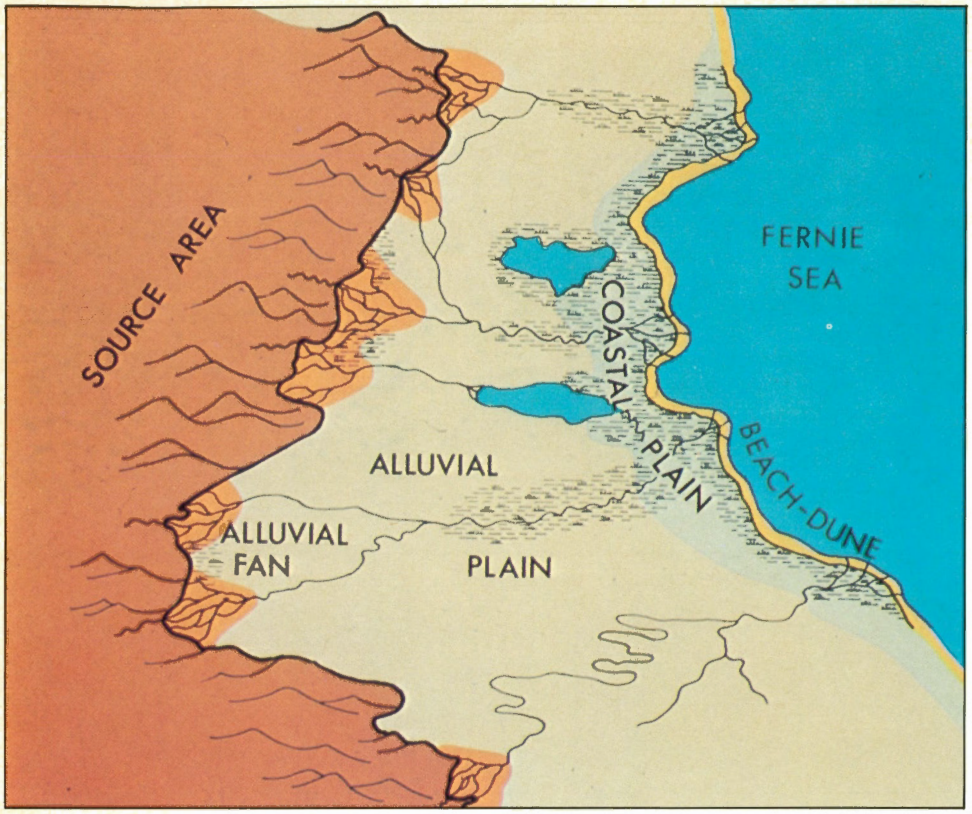


Figure 2

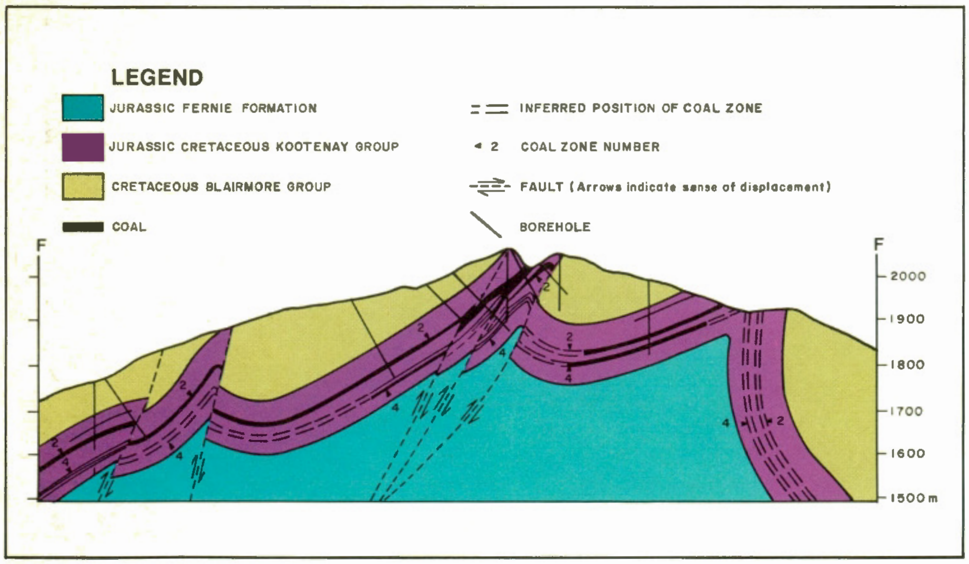


Figure 3

Figure 4

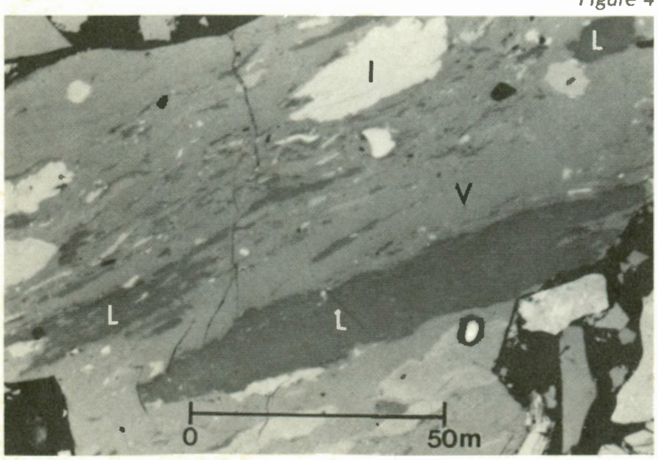
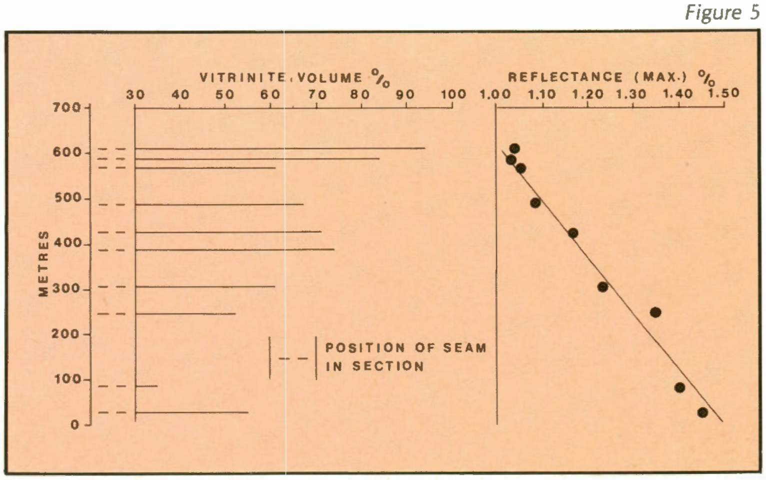


Figure 5



seams with higher vitrinite contents formed later, and probably farther away from shore. The cause and effect relationships are not clear cut, but we can speculate that conditions were more favourable for the development of forested bogs inland from the shoreline, preservation of plant material was better and the resulting coals had higher vitrinite contents.

Rank is another important compositional parameter of coal. It defines the stage of maturity in carbonaceous materials and ranges from immature peat to highly metamorphosed graphite.

Rank can be measured both chemically and microscopically (reflectance). In Figure 5 it is expressed as reflectance. As rank increases, so does reflectance. In a structurally undisturbed section, rank increases with depth as shown in Figure 5, because more deeply buried coals are subject to higher temperatures.

All available geological data must be incorporated into an estimate of the quantity and quality of coal present in Canada. These data include subsurface information from boreholes and underground mine workings, and surface information collected from outcrops and trenches. Most of the

Figure 2: Environments of deposition for coal and associated sediments.

Milieux dans lesquels se déposent le charbon et des sédiments associés.

Figure 3: Geological cross-section of deformed coal seams.

Coupe transversale géologique de veinses déformées de charbon.

Figure 4: Microscopic view of bituminous coal in reflected light, oil immersion.

Vues au microscope de charbon gras et flambant dans la lumière réfléchie (immersion dans l'huile) V = vitrinite; I = inertinite; L = liptinite

Figure 5: Compositional variation in a western Canadian coal-bearing section.

Variation de la composition d'une coupe contenant du charbon de l'Ouest canadien.

basic geological data come from industry or provincial agencies, and are then interpreted and stored in a computer data base. Once in this form, the data can be manipulated and displayed in a variety of ways to illustrate the depositional and structural setting of a coal deposit, as well as the distribution and quantity of the resources.

Experts then classify coal resources according to their variability in depth, the spacing of data points used to define them, the probable extraction method needed to mine them, and end use.

Computer programs are available for the statistical treatment, tabulation and graphic representation of all sorts of related data, including areal variation in coal seam thickness, interseam lithologic trends and patterns of quality variation. These may be represented in the form of contour maps, three dimensional diagrams, cross sections, etc. Figures 6 and 7 are both computer-generated from many data points. Figure 6 shows variations in lithology and coal thickness in a central Alberta coalfield. The relatively uncompactible nature of the thick fluvial channel sandstone unit in the lower part has thickened the interval in which it is contained and resulted in the thinning of the overlying intervals. Figure 7, based on data from over 600 drill holes, is a three-dimensional diagram of thickness variations in the rock interval between two coal seams in the Alberta plains.

Geological and resource studies on coal have both scientific and industrial significance. Scientifically, they help us to understand how coal forms and the causes of quality and seam geometry variation. Industrially, it is practical: the greater the geological resource information available for an area, the simpler and less expensive the exploration. In the longer term, decisions on our nation's future coal policy will depend heavily on the reliability of our coal resource estimates.

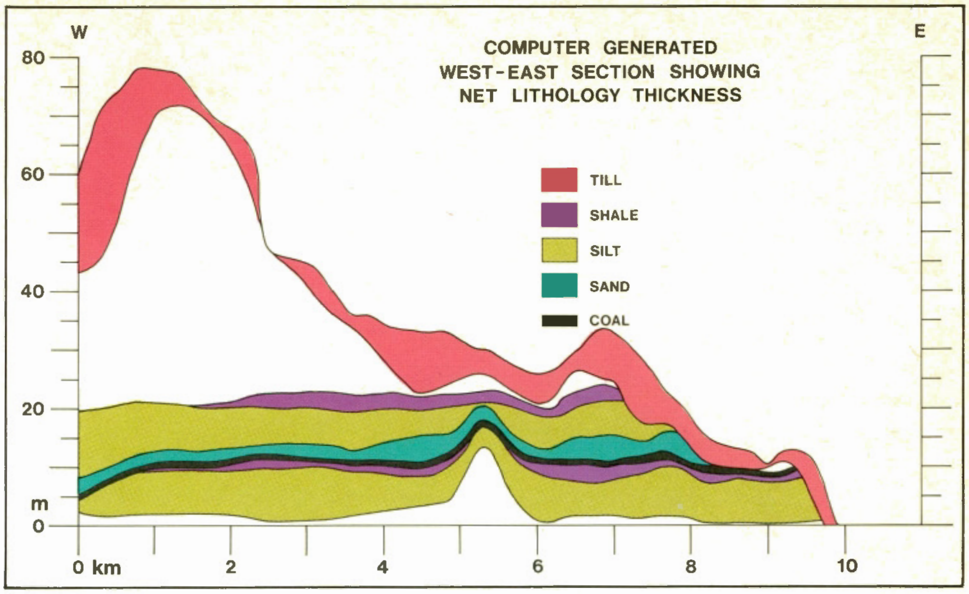


Figure 6

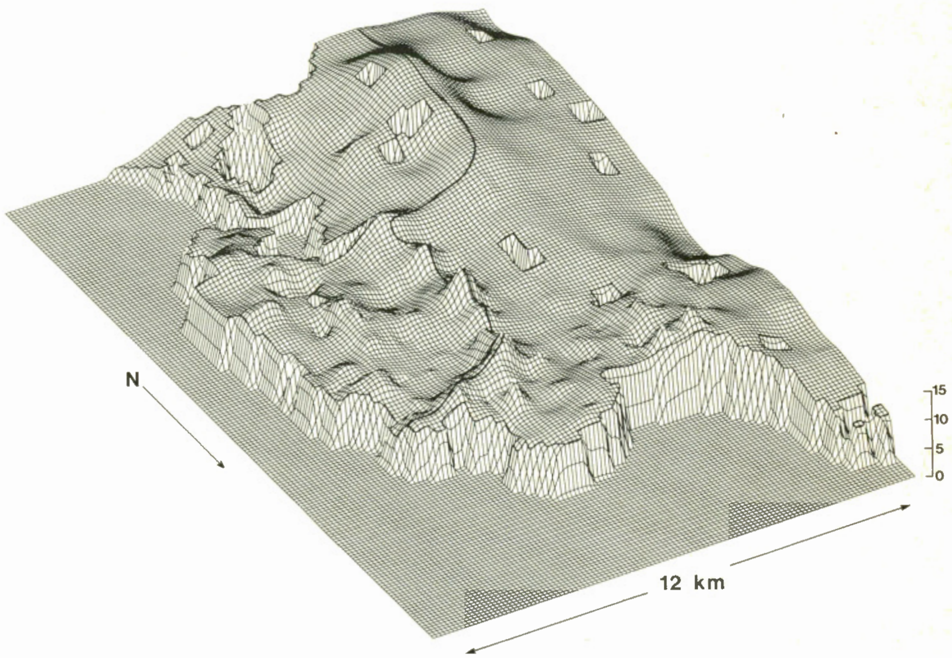


Figure 7: Thickness variation in the clastic interval between two coal seams
Variation de l'épaisseur dans l'intervalle clastique entre deux veines de charbon

La Commission géologique du Canada, qui relève d'EMR, prépare actuellement un inventaire national des ressources houillères fondé sur des études de la géologie et de la composition du charbon. Elle met au point des méthodes informatisées pour traiter la masse de données disponibles sur les charbons du Canada et pour les rendre plus accessibles et les faire mieux comprendre. Les travaux sont exécutés à l'Institut de géologie sédimentaire et pétrolière de Calgary, avec la collaboration du Centre géoscientifique de l'Atlantique de Dartmouth (N.-É.).

Cet article est disponible en français

Estimates of Coal Resources in Canada — 1978

	Measured	Indicated	Inferred
Lignitic	3 562	2 772	10 875
Subbituminous	30 000		102 000
Bituminous			
High volatile	1 555	559	8 457
Low and Medium volatile	15 282	9 898	63 036
	50 399	13 229	184 368
Grand total: 247 996			

From: EMR Report ER 79-9, Coal Resources and Reserves of Canada

Limite des forêts dans le nord du Québec et du Labrador

La limite actuelle des forêts dans le Nord du Québec et du Labrador est en équilibre avec les conditions climatiques. Le couvert forestier qui accompagne cette limite des forêts a subi d'importants changements depuis la fin du siècle dernier.

Subfossile de mélèze datant de 1 500 ans BP, près de la limite des forêts de la région de la Rivière aux Feuilles. Le milieu où le climat s'est refroidi entretemps est occupé par la toundra

1500-year-old larch subfossil, near the forest limit in the Rivière aux Feuilles region. The centre where the climate cooled down is now tundra

Par Serge Payette

Le vaste déploiement que s'offre la grande forêt boréale aux latitudes canadiennes n'a pas d'équivalent chez les autres biomes d'Amérique du Nord. Cette distribution transcontinentale qui résulte d'une histoire quaternaire complexe n'a cependant pas conduit à un régionalisme poussé de la forêt, car du Mackenzie à Terre-Neuve ce sont les mêmes espèces arborescentes, à quelques exceptions près, qui se partagent un espace relativement varié au point de vue climatique et édaphique. À l'est des Rocheuses, la flore canadienne est peu diversifiée et plusieurs espèces à large distribution sont génétiquement appauvries. Cette situation prévaut encore davantage aux confins nordiques de la forêt boréale, où les conditions écologiques sont particulièrement contraignantes pour la croissance des espèces ligneuses et laissent peu de place et de temps à la diversification des processus évolutifs.

Pour des raisons climatiques, la forêt boréale s'ouvre, s'étiole et enfin disparaît à mesure que l'on progresse vers les hautes latitudes; son remplacement par la toundra arctique n'est pas aussi rapide qu'on le croit

Monsieur Serge Payette est directeur du Centre d'études nordiques à l'Université Laval, à Québec. Il possède une vaste formation académique; il a obtenu entre autres une maîtrise ès science (écologie végétale) et un doctorat d'État (sciences: économie végétale). Professeur agrégé de l'Université Laval, il travaille dans le Nord québécois chaque année depuis 14 ans. Il effectue des travaux de recherche multidisciplinaires touchant à la botanique, à la pédologie, à la géomorphologie et à la climatologie.

La limite des forêts dans la région de la Rivière aux Feuilles. Les forêts de mélèze sont confinées dans le bas des vallées, protégées des vents et bien alimentées en eau

Forest limit in the Rivière aux Feuilles region. Larch forests are confined in valley bottoms, protected from wind and well supplied with water

généralement et s'opère le long d'une bande latitudinale de largeur variable selon les régions; cette bande de terrain faisant la transition entre la forêt boréale et la toundra arctique s'appelle la toundra forestière, expression peu judicieuse mais le plus souvent employée, soulignant à tort dans certaines situations que l'on est en présence d'une juxtaposition de milieux de toundra arctique et de forêt boréale. Le contact géographique et écologique de la toundra forestière et de la toundra arctique correspond à la limite des forêts et, bien sûr, à la limite des arbres.

Il existe encore une certaine confusion quant à la définition que l'on donne de la limite des forêts. Les écologistes du Québec et d'Europe (surtout de Finlande) entendent comme limite des forêts la ligne joignant les petits massifs arborescents ou bosquets (composés d'individus des espèces arborescentes qui présentent à la fois la forme et la taille des arbres; un arbre doit avoir une hauteur minimale de 5 mètres) situés dans les sites les plus septentrionaux; ces bosquets renferment généralement quelques dizaines à quelques centaines d'arbres et leur coexistence favorise le maintien d'une flore «forestière». Par ailleurs, les chercheurs anglophones, surtout américains, définissent la limite des forêts comme la ligne où les forêts occupent 50 % de la surface du sol; cette ligne correspond en réalité au passage de la forêt boréale proprement dite à la section méridionale de la toundra forestière. Ces différences de définition ont évidemment des conséquences importantes sur l'interprétation écologique que l'on donne au statut actuel des forêts nordiques et à ses déplacements éventuels suscités par les changements climatiques au cours de l'Holocène (période post-glaciaire correspondant aux derniers 10 000 ans AA: années exprimées en âge radiocarbone, l'année de référence étant 1950). La limite des arbres est la ligne joignant les sites où les arbres atteignent leur distribution la plus septentrionale; cette ligne se situe généralement à proximité de la limite des forêts, parfois à quelques kilomètres au nord de cette dernière.

La carte de la limite septentrionale des forêts dans la péninsule du Québec-Labrador montre que les forêts atteignent le 56°20'N du côté de la baie d'Hudson, dépassent le 58°N dans la péninsule d'Ungava, montent le plus au nord, soit vers le 59°10'N, du côté est de la baie d'Ungava et se situent vers le 57°55'N dans la baie de Napaktok le long de la côte du Labrador. La limite des forêts est généralement plus haute en latitude en milieu continental qu'en milieu maritime; cette situation est reliée à l'influence réfrigérante des mers bordières, notamment le long de la baie d'Hudson où le phénomène est particulièrement bien exprimé.

Quatre espèces arborescentes se retrouvent à la limite des forêts au Québec-Labrador. Dans les secteurs maritimes de la baie d'Hudson, de la baie d'Ungava et de la côte du Labrador, l'épinette blanche (*Picea glauca* (Moench)Voss) est l'espèce qui se rencontre dans les forêts les plus septentrionales; le peuplier baumier (*Populus balsamifera* L.) apparaît sporadiquement dans ces régions sous forme de petits groupements arborescents ou arbustifs. Dans les secteurs continentaux, l'épinette noire (*Picea mariana* (Mill.) BSP.) et le mélèze laricin (*Larix laricina* (DuRoi) K.Koch) dominent en exclusivité les massifs les plus nordiques. À l'est du 74^{e} méridien ouest, le mélèze laricin est généralement plus abondant à la limite des forêts que l'épinette noire; les mélèzaies occupent les sites les plus nordiques, les plus froids et les plus exposés, par rapport aux pessières arborescentes à épinette noire. À cet égard, les paysages de la limite des forêts le long de la Rivière aux Feuilles, d'une section importante de la partie méridionale de la baie d'Ungava et du cours supérieur du fleuve Koroc présentent des massifs de mélèze laricin faisant penser aux paysages sibériens, à l'est de l'Oural. Là où l'épinette noire forme les dernières forêts, surtout le long du versant oriental de la baie d'Hudson, à l'intérieur des terres, le paysage végétal est particulier avec ses teintes sombres, qui résultent de la grande abondance de l'espèce dans ces milieux.

Ce n'est pas sans dommage que les espèces arborescentes se maintiennent dans ces milieux froids, au seuil de leur limite de tolérance physique et physiologique. En fonction des contraintes liées à la forte exposition aux vents, à la déflation nivale et aux basses températures hivernales, ces espèces adoptent des formes de croissance variées, allant de la forme arborescente plus ou moins normale à la forme prostrée, réduisant notamment les épinettes à la taille de petits arbustes comme les éricacées et les saules. Il existe ainsi tout un gradient de formes de croissance exprimant les diverses conditions écologiques qui prévalent à la limite des forêts et à la limite des arbres. C'est dans la toundra forestière principalement que ces formes de croissance commencent à apparaître et annoncent la proximité de la toundra arctique. Il est intéressant de noter qu'au delà de la limite des arbres, dans la toundra arctique, on retrouve de grandes formations arbustives composées essentiellement d'une espèce arborescente, l'épinette noire. Ces formations sont communément appelées krummholz, terme allemand se référant au bois tortueux de ces arbustes. Leur présence de part et d'autre de la limite des forêts paraît problématique. On se demande, par exemple, qu'elle est l'origine des krummholz d'épinette noire dans la toundra arctique? On admet généralement que les épinettes de ces formations se reproduisent presqu'exclusivement par voie végétative, par mar-

L'épinette blanche représente la limite des arbres le long de la baie d'Hudson et de la baie d'Ungava. Cette épinette blanche est âgée d'environ 50 ans et est apparue à la suite du réchauffement climatique du XX^{e} siècle

White pine marks the tree limit along Hudson Bay and Ungava Bay. This one is about 50 years old and follows the rewarming of the climate in the 20th century cottage. Ces formations pourraient être les reliques d'anciennes forêts qui poussaient sur ces sites lors de périodes climatiques plus clémentes que l'actuelle. Ces formations proviendraient ainsi d'individus qui se seraient installés dans ces milieux par graines. Les données disponibles permettent de penser qu'une telle hypothèse est vraisemblable, même si les preuves formelles n'ont pas encore été apportées.

En y regardant de plus près, on constate que la limite des forêts et la limite des arbres sont bordées au nord par une importante ceinture de krummholz d'épinette noire appartenant au biome de la toundra arctique. Nous avons reporté sur la carte de la limite des forêts l'extension des krummholz de la toundra arctique, de la baie d'Hudson à la mer du Labrador. La largeur de cette ceinture varie dans l'ensemble de la péninsule; par exemple, elle occupe 0°45′ de largeur dans la région de la baie d'Hudson, alors qu'elle n'est que de 0°15′ dans les régions de la baie d'Ungava et de la côte du Labrador. Si ces formations devaient donc correspondre à d'anciennes forêts d'épinette noire, la limite des forêts aurait fluctué de moins d'un degré de latitude au cours de l'Holocène; cette valeur reste tout de même minimale, car on ne tient pas compte d'anciennes formations plus au nord et maintenant disparues.

Les recherches en cours au Québec nordique et au Labrador suggèrent que la limite actuelle des forêts est en équilibre avec les conditions climatiques. Le long de la baie d'Hudson, on note que la limite des forêts, et surtout le couvert forestier qui l'accompagne, ont subi des changements d'importance depuis la fin du XIX^{e} siècle. Il semble, en effet, que l'épinette blanche de cette région a entrepris une expansion significative depuis cette époque, en réponse au réchauffement climatique qui s'est fait sentir à partir de 1870–1880. Il est possible que ce changement des conditions du climat ait eu une influence directe sur l'augmentation considérable du couvert forestier le long de la côte, entre le village de Kuujjuarapik (anc. Poste-de-la-Baleine) et le golfe de Richmond où se situe la limite moderne des forêts; ce réchauffement du climat aurait alors eu des effets sur un grand territoire, large d'environ un degré de latitude. Par ailleurs, à l'intérieur des terres, la limite des forêts ne semble pas avoir été fortement affectée par ces conditions, si l'on en juge par les âges des derniers arbres et des forêts les plus septentrionales. On retrouve cependant dans ces milieux une grande abondance de plantules et de gaulis (individus d'espèces arborescentes issus de graines) apparus entre 1920 et 1960. Cette situation reflète cependant une densification du couvert arborescent au cours de cette période.

L'étude de la limite des forêts et de la limite des arbres présente un grand intérêt scientifique. En plus de connaître le degré de tolérance et d'adaptation des espèces arborescentes à leur limite ultime de distribution, la limite des forêts et la limite des arbres peuvent servir d'indicateurs paléoclimatiques lorsqu'il s'agit de reconstituer les fluctuations du climat et des biomes au cours de l'Holocène. Les travaux en cours au Nord québécois montrent, qu'à cet effet, les forêts occupaient une position légèrement plus septentrionale dans le passé, il y a environ 3 000 ans. Les déplacements de la limite des forêts n'ont pas été très importants au Nord québécois au cours de l'Holocène. Dans les Territoires du Nord-Ouest (Keewatin), d'autres chercheurs auraient trouvé les preuves de déplacements spectaculaires de la limite des forêts, de l'ordre de 300 à 400 kilomètres. Il semble rester beaucoup de travail de terrain à faire avant que ces estimations soient fondées. Dans ce contexte, on observe dans l'ensemble du territoire canadien, incluant la péninsule du Québec-Labrador, que les feux de forêts et de toundras ont joué (et jouent encore) un rôle très important dans les fluctuations de la limite des forêts, en faisant disparaître en peu de temps, en période froide, le couvert forestier. Sachant que ces milieux se situent bien au delà de la limite des forêts commerciales où la régénération forestière est assurée sur une base annuelle, le passage des feux sous climat froid peut limiter ou inhiber la régénération des espèces arborescentes.

La limite des forêts est sûrement un des problèmes écologiques les plus importants au Québec-Labrador septentrional.
Comprendre les mécanismes à l'origine de la dynamique particulière de cette limite peut contribuer à une meilleure connaissance de la structure et du fonctionnement des principaux écosystèmes nordiques.
Dans cette perspective, le comportement du couvert forestier des régions nordiques peut servir d'indicateur écologique au moment où ces territoires limitrophes sont appelés à être développés et fréquentés de plus en plus.

Les deux personnes tiennent dans leurs mains une épinette noire âgée d'au moins 150 ans; elle provient de la toundra arbustive du long de la baie d'Hudson. Ces épinettes croissent dans un milieu très exposé et peu enneigé et forment un Krummholz

Black pine about 150 years old, from the tundra along Hudson Bay. These shrubs cut across a very exposed and snow-free centre, and form a region of stunted trees

Utilité pour EMR

Le texte de M. Payette démontre la sensibilité des limites de la forêt et de la toundra face aux changements de climat intervenus dans le passé. Au cours des périodes connues de migrations de l'épinette vers le nord prévalaient des conditions climatiques favorables en certaines parties nordiques du Canada. Par la suite, des conditions moins favorables se sont présentées et elles ont entraîné une extension de la toundra vers le sud. Les données sur les déplacements de latitude des limites de la forêt et de la toundra et, en conséquence, les positions nord-sud du front arctique au cours de la fin du Quarternaire sont de la plus grande utilité pour les recherches actuelles d'ÉMR. Celles-ci portent sur les phénomènes de modèles de terrain, la solifluction, le till, la géochimie des sédiments de lacs et de marais, de même que la mensuration des paramètres de la calotte glaciaire.

The forest limit in Northern Quebec and Labrador is in a fragile equilibrium with the present climate; some parts of it extended northward during the 20th century. During the Holocene period, the forest limit had minor shifts. For example around 3000 BP, the climate was warmer, and the presence of stunted trees beyond the present limit, in the shrub tundra, may indicate former forests during this warm period. Natural fires occurred during the Holocene, and their influence on the forest cover is particularly significant. During cold periods, tree regeneration is generally inhibited, and following fires, forests are replaced by tundra communities. The forest line is a natural phenomenon very well suited to ecological and paeoclimatological studies.

This article also available in English.

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.