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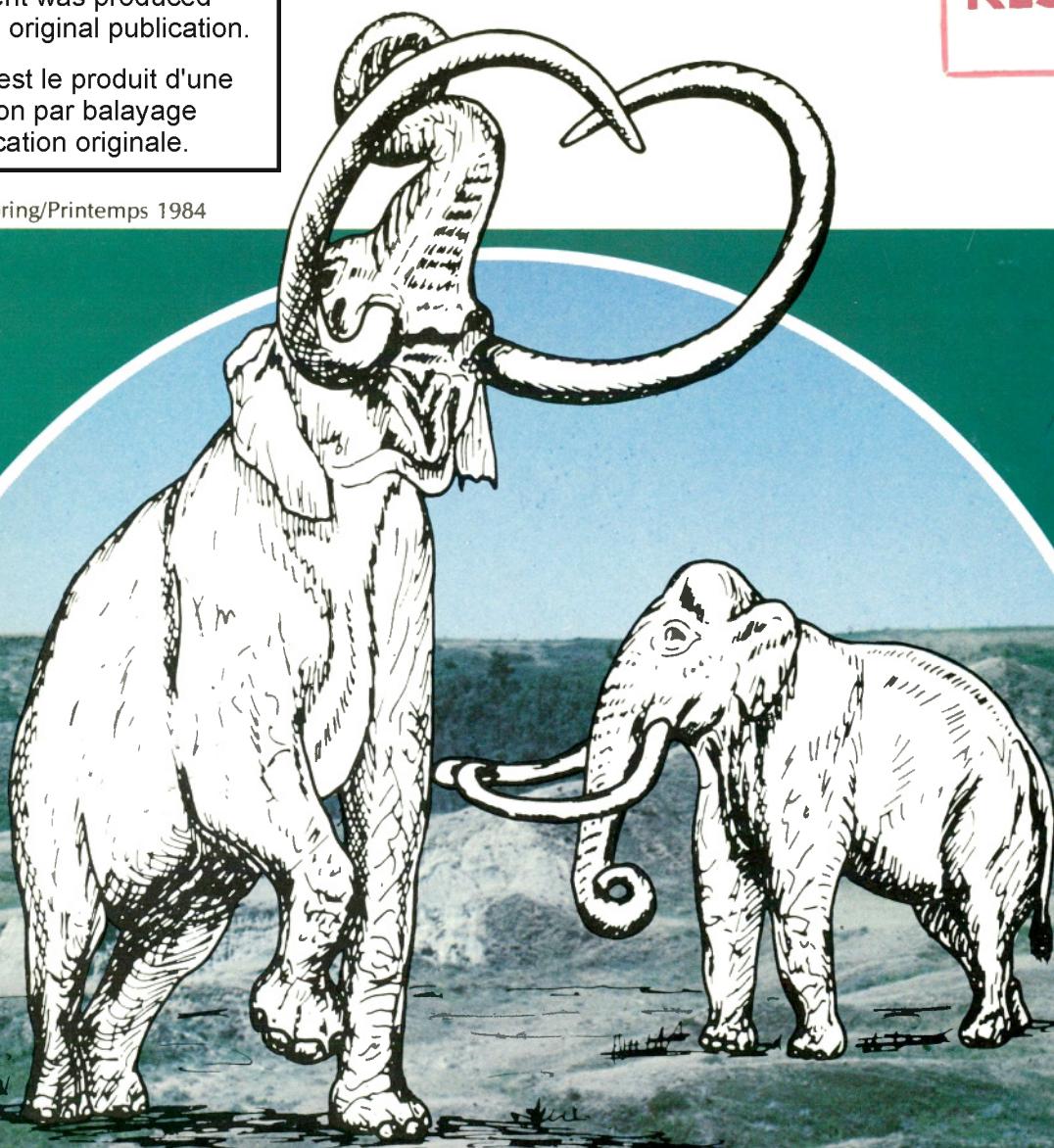
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COVER: Fossils prove huge mammoths once lumbered across western Canada's great plains. Dr. Archie Stalker's article, part of the fold-out in this issue, tells of the extraordinary animals which flourished on the Canadian Prairies between glaciations.

COUVERTURE: Les fossiles prouvent que d'immenses mammouths se sont déplacés lentement, autrefois, à travers les grandes plaines de l'Ouest canadien. L'article d'Archie Stalker, accompagné d'un dépliant dans ce numéro, décrit les créatures extraordinaires qui ont prospéré dans les Prairies canadiennes entre les glaciations.



Shatter cones: epilogue to a dynamic story

By Cynthia Thompson

"Houston . . . , we seem to have found shocked rock formations here on the moon that are very similar to those we examined during our training in Sudbury"

This cryptic statement was transmitted to the U.S. National Aeronautics and Space Administration (NASA) headquarters during the first moonwalk. In the early 1970s, Sudbury had made news headlines as the training grounds for Apollo 16 and 17 crews. The stories made even harder the city's attempts to live down its reputation as a bleak and barren terrain, the closest thing on earth to a moonscape. The fact is, astronauts did not go to Sudbury to get their legs accustomed to clambering over masses of moonrocks. Rather, they were looking for geological evidence of an ancient meteorite impact. So they were out scouring the outcrops, often with noses inches above the rock.

Only a few years earlier, the geological community had generally accepted the theory that the Sudbury Basin and its tremendous mineral wealth were created through volcanic activity. Fissures in the earth's crust brought nickel-rich magma to the surface, and explosive activity created Sudbury breccia, which consists of fragments of rock set in a pulverized material.

Then in 1964, U.S. marine geologist Robert S. Dietz made a trip to Sudbury and identified striated fracture cones that challenged that theory. A shatter cone is a conical fragment of rock with striations radiating from an apex. It may be from a few centimetres to more than a metre in size. It is formed by high shock pressure. Dietz went to Sudbury to look for shatter cones to support his theory that the Sudbury Basin is a meteorite impact site. And he found them.

Like Dietz and hundreds of geologists since, the astronauts went to Sudbury to see shatter cones and impact breccia so common in the region. Shatter cones tell the story of a meteorite exploding against the earth's crust, and cracking it like an egg shell, 1.8 billion years ago. The meteorite must have been from one-half to 10 km wide. Shock waves radiating out from the impact site almost instantaneously melted, brecciated, crumpled and warped the sur-

Science North, \$25 million science centre opening in Sudbury June 19, 1984

Science North, centre scientifique de 25 millions de dollars, ouvrant à Sudbury le 19 juin 1984

rounding country rock into mile-high ridges. Split seconds later, the pressure of impact subsided. The ridges rapidly flattened and slid back towards the initial excavation. Then they rose in the centre as masses of melted, broken and fractured rock continued to be spewed into the stratosphere. A crater that may have been up to 70 km across was excavated. At the point of impact, rocks literally vaporized at temperatures that exceeded 2000°C. Deep below, nickel-rich magma began to well to the surface via cracks that had split the crust down to the mantle.

This tremendous event created thousands of shatter cones now found outside the rim of the Sudbury Basin as it exists today. After nearly two billion years of weathering and the erosion of several kilometres of the earth's crust, Sudbury shatter cones still testify to the creation of the Basin structure. To this date, the only known

Cynthia Thompson is media relations assistant at Science North in Sudbury.

Geology of Sudbury Basin
Géologie du bassin de Sudbury

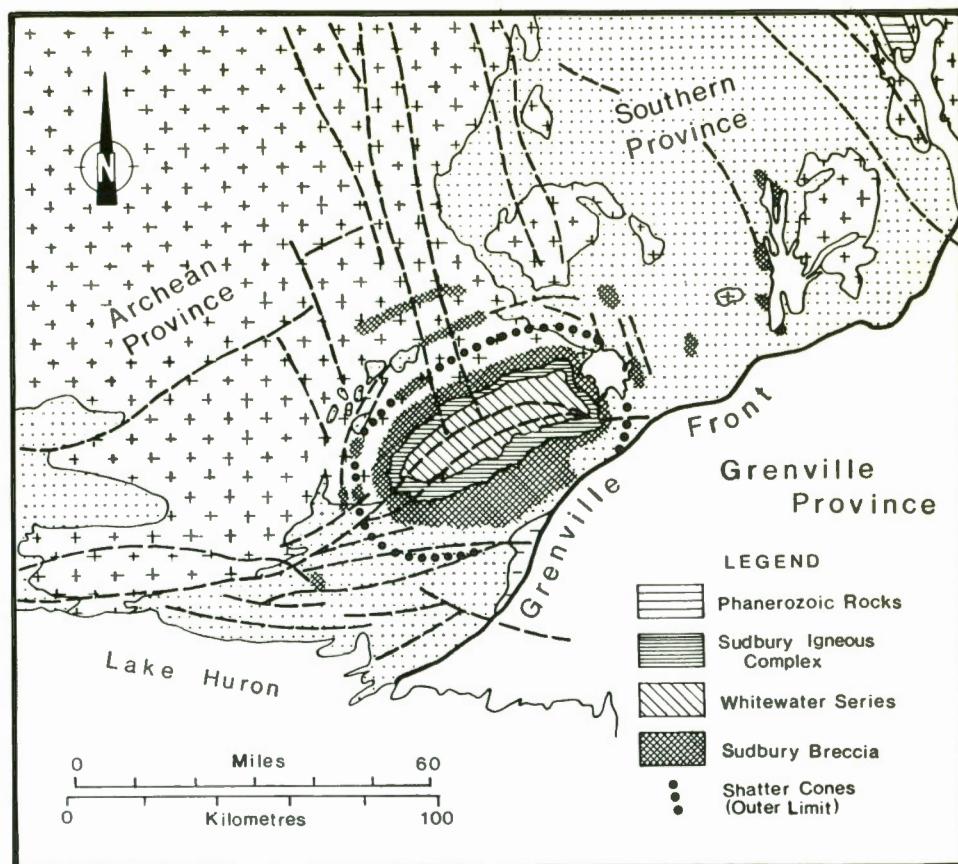
natural method of creating shatter cones is the impact of a meteorite.

Some geologists suggest that violent volcanic activity could conceivably send shock waves through rock and create the same stress feature. However, as Dr. Walter Peredery, Inco Limited research geologist, points out, that has not been proven in the field. "Shatter cones are not normally recorded in volcanic environments, and in cases where shatter-cone-like features are recorded, they are very suspect." Shatter cone formation requires shock wave strength of an order of magnitude higher than that produced in the most violent volcanic explosions. They can be formed by nuclear explosions.

Other shatter-cone-like features have often been confused with shatter cones in rocks, which partly accounts for reported "shatter cones" sightings around volcanoes. One such example is called a slickenside, a surface, usually striated, produced by movement along a fault or subsidiary fracture. Unlike the shatter cone, it has parallel grooving on its surface. The striated surface of a shatter cone radiates from an apex in a horse-tail pattern. Generally the apical angle of a single shatter cone surface is less than 90°. Another important distinction is that shatter cones have curved faces, unlike slickensides, which are flatter.

Although the mere occurrence of shatter cones outside the Sudbury Basin provides us with evidence in support of the impact theory, there are questions concerning the orientation of shatter cone apices and their location outside the rim of the crater structure. In theory, the apices of shatter cones point toward the centre of the crater, indicating the shock waves originated from above. This is observed at several other smaller meteorite impact sites. In Sudbury, the present orientations do not appear to be toward the centre. However, if the rocks are placed in their pre-impact position, most shatter cones in Sudbury do follow the rule. Shatter cones are probably produced just as the initial shock pressure pulse subsides after the impact of the meteorite, a fraction of a second before the upheaval of rock within the structure occurs. This upheaval disorients the shatter cones. Post-impact mountain building activity, the same process that squeezed the basin into an elliptical shape, has also disoriented shatter cones in Sudbury.

In smaller or more recent impact structures, shatter cones are located within the rim of the crater structure and below the crater floor. Why then do Sudbury shatter cones occur outside the rim of the basin? With



Science North above and below ground

Canada's newest science centre, Science North, will open in Sudbury June 19, 1984. A glittering landmark, it has been constructed on top of and imbedded in a rocky outcrop at the edge of the ancient meteorite impact site.

The exhibit program includes themes on geology, atmosphere and weather, biology, physics and mechanics. Visitors will be encouraged to become active participants rather than spectators.

The unique design of the two snowflake-shaped buildings represents the northern climate and the glacial era that ground and sculptured the northern landscape. As interesting as the above-ground construction is the massive excavation below ground. Visitors will stroll through an underground tunnel which connects the smaller entrance building to the main exhibit building. Along the way, shatter cones can be seen in the 2.5-billion-year-old rock.

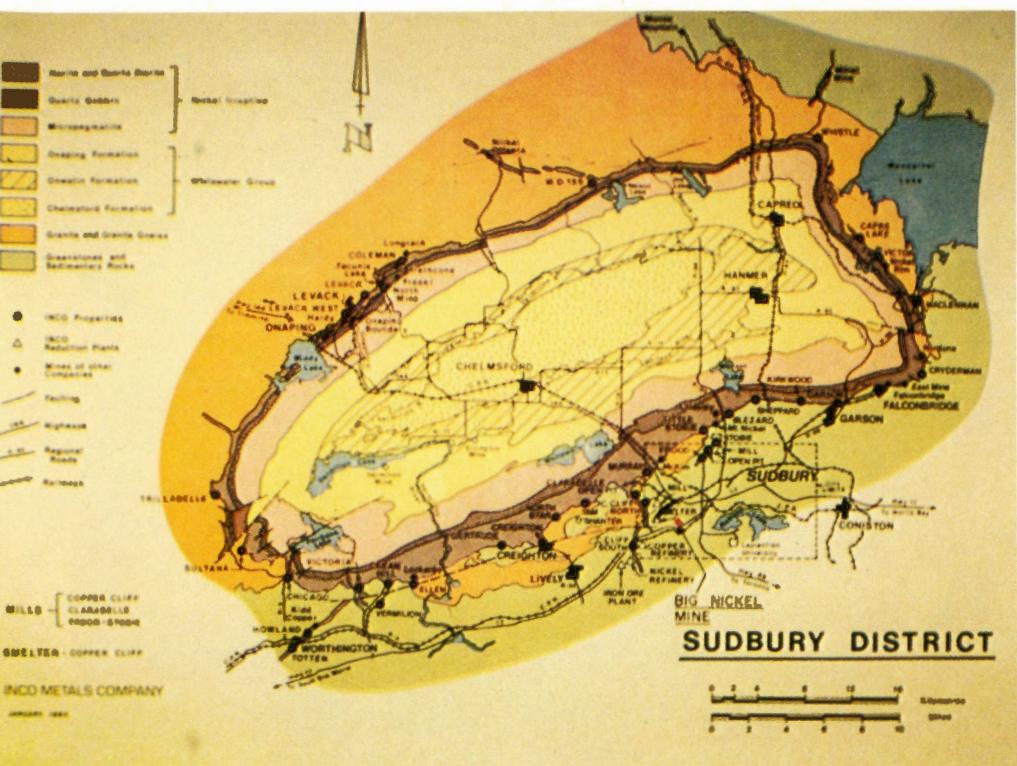
At the end of the tunnel, visitors continue into the cavern where rock

walls soar 9.15 m high. The floor is one third the size of a football field. While the snowflake-shaped buildings represent the glaciers and the North, the cavern represents the Sudbury Basin. The space will be used to show a 3-D film on northern Ontario's natural history, flora and fauna.

Leaving the cavern and an environment enclosed in rock, visitors enter a light, airy space enclosed by glass and looking out over Lake Ramsey as they follow a winding ramp up to the exhibit floors. The Creighton Fault is visible in the exposed rock floor below.

The shattered rock along the billion-year-old fault, long inactive but once a massive San Andreas-like fracture, lay in the path of the ice sheets of 20 thousand years ago. The irresistible power of the ice gouged and splintered the rock and left a four-metre-deep groove along the dislocation, which once shook Sudbury with earthquakes.

Science North cost \$25 million to build. Of that, \$5.35 million came from the Government of Canada, much of it through EMR. EMR also donated an operating seismic unit to the geosphere exhibit.



Shatter cones

Cônes de friction
Photo EMR

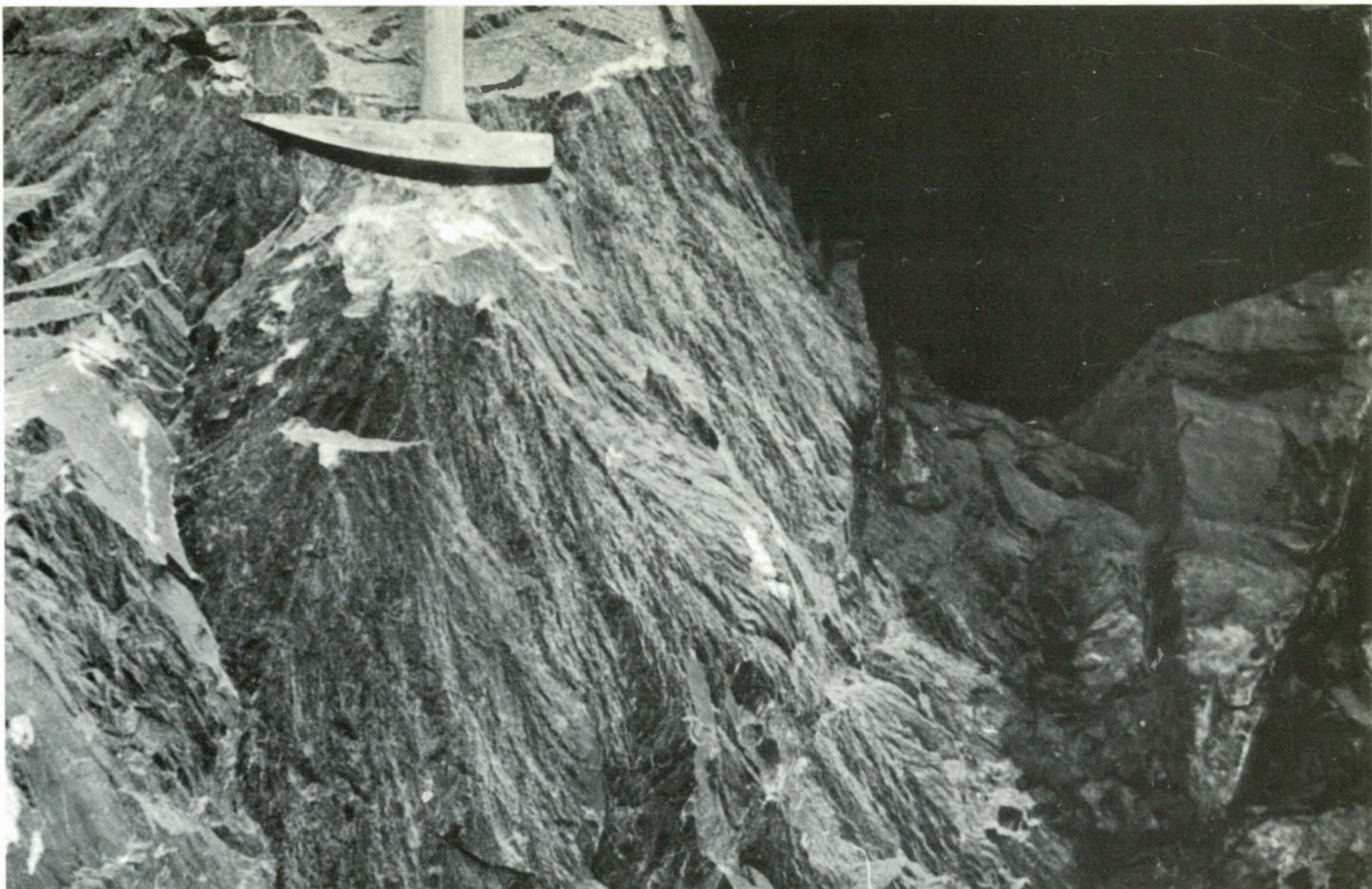
Geology of Sudbury area showing outer limit of shatter cones around the Sudbury Basin

Géologie de la région de Sudbury montrant la limite extérieure des cônes de friction autour du bassin de Sudbury
Source: Walter Peredery, Inco

the erosion of several kilometres of the earth's crust over the two-billion-year history of the structure, the original Sudbury Crater Basin is a shadow of what it once was. Inco's Dr. Peredery estimates that the original roughly circular crater was about 70 km across. The final crater after its subsequent collapse was more than double the original diameter. A distorted 60 km by 27 km structure remains. Because of the concave bowl-like structure of the impact crater, extensive erosion makes the bowl more shallow while reducing the circumference. (To understand this process, visualize a melon cut in two, with thin sections being sliced from the cut surface.) Within the circumference of the original crater, shatter cones occur well within the rim.

Dissenting opinions keep debate over the meteorite impact theory as explosive as the creation of the Basin itself. Some geologists feel that such a complicated and multidimensional structure needs further consideration. Dr. Michael Fleet, of the University of Western Ontario geology department, has proposed that Sudbury shatter cones are actually stress formations created in the sediments on the south side of the Sudbury Basin during the Penokean Orogeny, or mountain building process. As sediments were deposited at the edge of an ancient Precambrian shoreline 2.5 to 2.3 billion years ago, massive sheets of sediments were deformed to produce mountains around 1.9 billion years ago. Dr. Fleet believes that when stress created through this process was relaxed, cones were produced. He suggests that conical structures at Sudbury "postdate emplacement of the nickel intrusion," but if this were the case it would be possible to find shatter cones formed in the intruded rocks. This does not appear to be true.

Other evidence around the Basin is not consistent with this theory. First, if shatter cones were created by the Penokean Orogeny, they should also be found in other sediments towards Sault Ste. Marie that underwent the same process. But shatter cones occur only around the Sudbury Basin. Second, shatter cones occur in granitic rocks north of the Basin which were affected only slightly by mountain building. Also inconsistent with Dr. Fleet's theory are the occurrences of shatter cones in rock clasts within the Onaping formation of the Basin which predate the mountain building process.



Until shatter cones can be identified at locations where meteorite impact has definitely not occurred, proving that they were created through other natural tectonic processes, they will remain the single most visible piece of evidence in support of the theory of meteorite impact at Sudbury.

*Shatter cone
Cône de friction
Photo Inco*

Large, well formed shatter cones beside Kelly Lake Road, Sudbury. The apex was chipped away by souvenir hunters

Grands cônes de friction bien formés, près de la route de Kelly Lake, Sudbury. Le sommet a été enlevé par des chasseurs de souvenirs

Depuis la découverte du bassin de Sudbury, il y a un siècle, ce cratère allongé a intrigué et dérouté les géologues du monde entier. L'origine d'aussi importantes richesses minérales a été discutée et débattue pendant des années. Les scientifiques en ont conclu que l'activité volcanique avait précipité à la surface les minéraux riches en nickel et que les bouleversements explosifs périodiques avaient ainsi créé la brèche de Sudbury et perturbé les formations rocheuses locales. Puis, Robert S. Dietz a découvert des formes coniques striées dans les roches à l'extérieur de la remontée du bassin. La découverte des cônes de friction a relancé la question de la géologie du bassin de Sudbury mais, cette fois, sous un tout autre aspect. Actuellement, tout le débat tourne autour de l'hypothèse d'un météorite qui aurait pu bombarder l'écorce terrestre il y a environ deux milliards d'années.

Cet article est disponible en français.

Lithoprobe⁵

by Ian Darragh

The three-dimensional look at the Earth's crust will have economic spinoffs



A multi-million dollar project called Lithoprobe is being launched this summer to investigate the Earth's interior. The results over the next five years should create a new picture of how Canada's land mass was shaped by plate tectonics, and give us our best look yet at the inside of the Earth.

Earth scientists from Canadian universities and Energy, Mines and Resources will use a combination of methods — from newly refined seismic techniques employing sound waves to deep drilling — to unscramble a host of geological puzzles across Canada that cannot be explained by surface observation. Lithoprobe will provide a three-dimensional look at these enigmatic rock structures.

The focus of the project is the continental lithosphere, the zone extending some 70 to 100 kilometres below the continents. It consists of the crust and part of the upper mantle, and floats on the asthenosphere, a more plastic zone.

The leader of this interdisciplinary study is Prof. George Garland, a University of Toronto geophysicist. He replaced Dr. J.O. Wheeler of EMR's Geological Survey in Vancouver in March 1984.

At this point Lithoprobe is essentially pure research: What is actually down there? But it will have economic spinoffs in the years

ahead. We will learn more about how orebodies were formed in the Shield and how oil and gas were entrapped in sedimentary basins. New approaches to petroleum exploration may emerge.

The most direct way to explore the lithosphere is to drill holes into it, as if performing exploratory surgery on the planet. Drilling has the advantage of providing core samples for analysis by geochemists, but the findings can only be extrapolated to a very small area, very expensively.

Soviet scientists have reportedly drilled a hole 12 kilometres into the continental lithosphere. Very little of their data has been published, except for one report that they were still encountering open fractures at a depth of 10 kilometres. This is a strange and unexpected finding, considering the great pressure on the rocks at that depth.

Oil exploration companies have drilled thousands of holes in Canada's sedimentary basins in the Prairies, the Arctic and the East Coast offshore. But there have been few holes drilled beyond a depth of one or two kilometres into the Shield or the western Cordillera. And that is where many of the geological puzzles remain, and where the payoff is likely to be greatest.

Drilling in the Shield or the Cordillera is expensive — a three-kilometre hole can

Vibroseis seismic technique. Ten-ton trucks hit the earth simultaneously, creating sound waves that produce images of the earth structures up to 50 km below

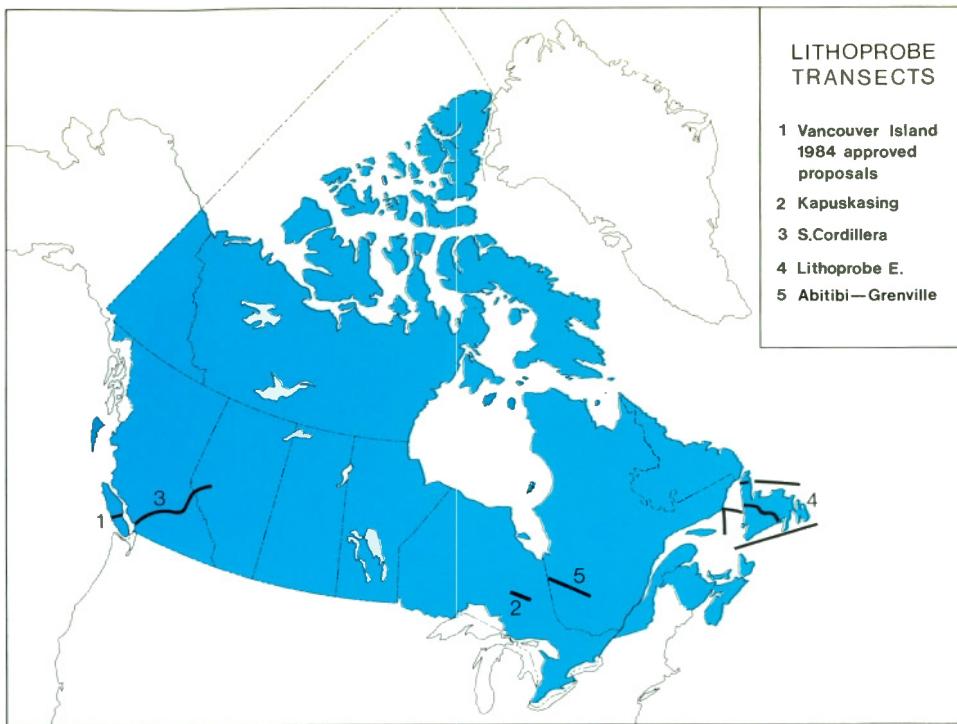
Technique sismique Vibroseis. Des camions de 10 tonnes frappent simultanément le sol, créant des ondes sonores qui reproduisent, en images, les structures de la Terre jusqu'à une profondeur de 50 km

easily cost \$1 million or more to drill and core — so the sites of holes have to be chosen with great care for maximum results.

Lithoprobe will probably engage in deep drilling in the fifth and final year of the program. In the first years, however, a subtler and cheaper method will be employed to investigate the crust. Seismologists use sound waves created by vibration and explosion to produce images of structures in the Earth's crust, just as an obstetrician uses ultrasound to make an image and check the growth and position of a baby in its mother's womb.

Lithoprobe will begin exploring the Earth's inner space in June on Vancouver Island. A bizarre sight on the logging roads near

Ian Darragh is managing editor of Canadian Geographic magazine.



Bamfield on the island's west coast will then be four 10-ton trucks bouncing up and down on the road "like huge dancing elephants". That is the way Dr. Michael J. Berry describes the seismic technique of Vibroseis. He is Earth Physics' chief seismologist and one of the co-ordinators of Lithoprobe.

The dance of the trucks is carefully choreographed. They are lifted by hydraulic mechanisms, which are synchronized so that all four vehicles will rise and fall on the road at the same time, sending sound waves travelling down through the lithosphere. The reflection of these sound waves is recorded by sensitive microphones, called geophones, which are placed in a 10-kilometre long line.

The speed of sound waves travelling through the crust is governed by the changing density and elastic properties of the rock at each depth. The recordings made by the geophones are digitized and manipulated to produce a seismic profile of the lithosphere. This chart gives a wealth of information about formations and faults, providing a look at the continental plate in the third dimension.

Vancouver Island has been chosen for phase one of Lithoprobe, as a rare opportunity to test the model of plate tectonics developed at EMR's Pacific Geoscience Centre using refraction seismology, gravity and magnetic studies. According to this model the oceanic Juan de Fuca and Explorer plates are being pushed underneath Vancouver Island at a rate of between two to four centimetres per year. Vibroseis will give us profiles of geological

formations down to 50 kilometres. These will allow the Lithoprobe team, led by geophysicist Ron M. Clowes of the University of British Columbia, to construct more accurate models of this dynamic process.

Dr. Clowes and his team from Earth Physics and the Universities of Calgary and Alberta will complete a Vibroseis transect of Vancouver Island from Bamfield inland to Port Alberni, and then on to the east coast of the island near Dunsmuir on Georgia Strait.

If the current models are correct the Lithoprobe team's seismic profiles should clearly show the existence of oceanic plates plunging under Vancouver Island. Lithoprobe on Vancouver Island may provide exciting new insight into how the collision of plates is shaping the western edge of the North American continent.

The second Lithoprobe site is in northern Ontario. A group led by Prof. Gordon F. West, a University of Toronto geophysicist, hopes to solve one of the mysteries of the Canadian Shield. Known as the Kapuskasing structural zone, it is a band of high-grade metamorphic rock, formed at high pressure and temperatures in excess of 600°C. It cuts through the Shield for about 450 kilometres from Chapleau, Ont., northeast to James Bay.

Because the rocks are dense and rich in iron oxides, the Kapuskasing uplift shows up as a clearly defined ridge on gravity and magnetic maps of the Shield. Geophysicists call this the Kapuskasing gravity high.

Since the 1960s, geologists speculated about how this structure was formed. Initially, it was interpreted as a thinning of the crust, but it has also been called an

Lithoprobe sites across Canada 1984 – 1989 Sites Lithoprobe à travers le Canada 1984 – 1989

ancient rift valley, filled in by sediments and lava flows. Another suggestion is that it is a block thrust up by faulting.

Recently two Geological Survey geologists, Dr. John A. Percival and Dr. Ken D. Card, have suggested that the Kapuskasing zone is an ancient piece of the lower crust which has been pushed up to the surface along a 30-degree thrust fault. Lithoprobe will be using two seismic techniques to check this exciting theory.

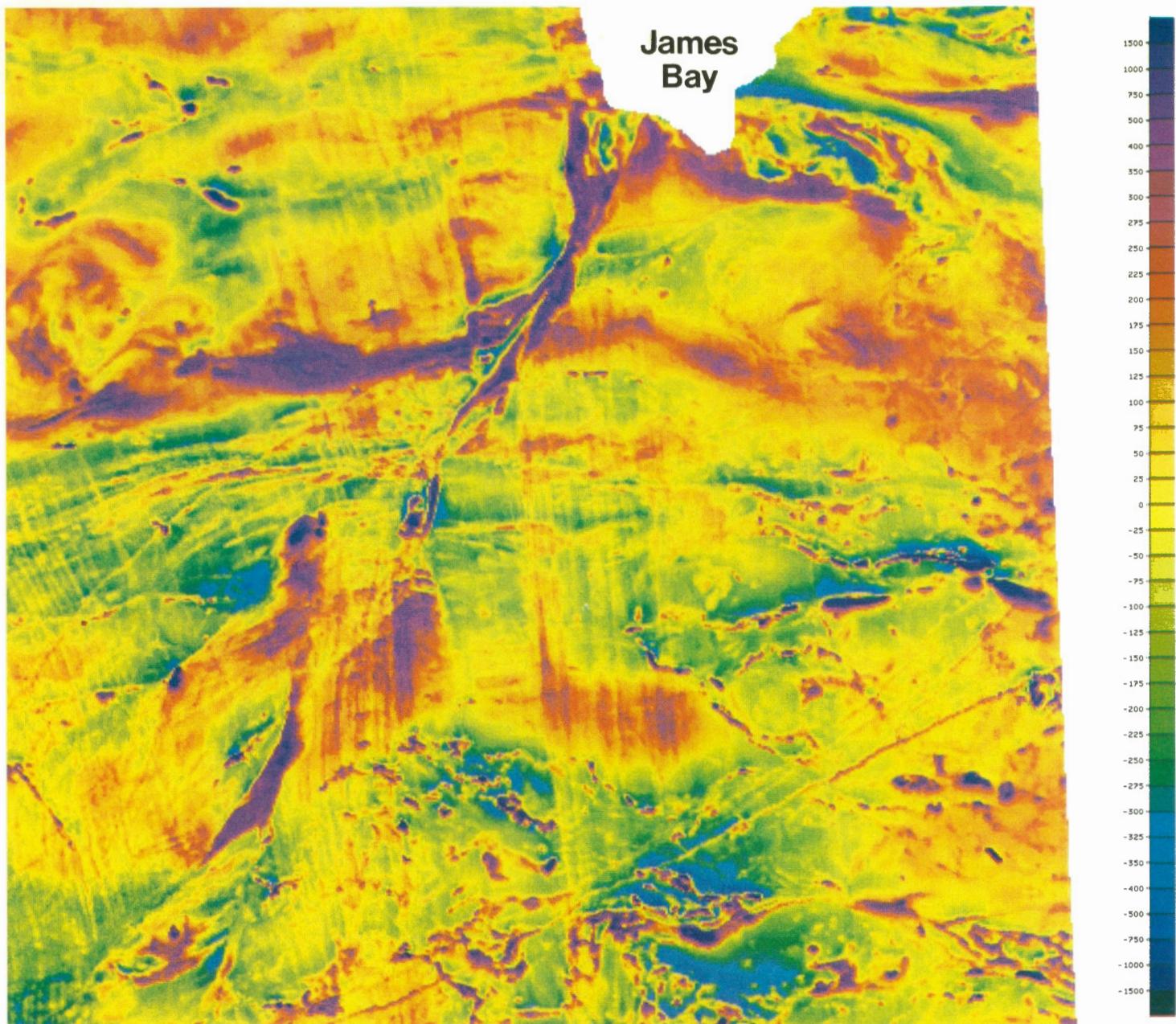
"We have a better sample of rocks from the moon than we do of rocks from the lower crust of the Earth," says Dr. Card. If the seismic work confirms that the Kapuskasing structural zone is indeed a piece of the lower Archean crust, geologists will have a rare opportunity to study an artifact of plate tectonics at least 2.8 billion years old. More work remains to date the Kapuskasing rocks more precisely. They could turn out to be even older.

This uplift in the Shield could become a laboratory for testing the physical and chemical properties of lower crustal rocks, including their radioactivity. By studying the radioactive minerals in the Kapuskasing rocks, we may learn more about heat flow from within the lower crust, says Dr. Card.

In order to test the Percival and Card model, the Lithoprobe team will try to trace the Kapuskasing structure to depths of 20 to 30 kilometres. Their model suggests that a hole drilled east of where the Kapuskasing rocks surface would reveal those same rocks at a depth of between 20 to 30 kilometres. Are they right?

Dr. West and his group from the University of Toronto together with seismologists from Earth Physics and the Universities of Alberta, Calgary, Western Ontario, British Columbia, Memorial and McGill will be carrying out extensive refraction studies along the length of the zone between Kapuskasing and Chapleau. This involves the detonation of explosives, and the recording of the echoes of the sound waves. A pilot reflection study, similar to the one across Vancouver Island, will be carried out across the Kapuskasing zone near the town of Foleyet.

After Vancouver Island and the Kapuskasing uplift, Lithoprobe will investigate other regions. An attempt will be made to unravel the complex geology of Newfoundland and the surrounding continental shelf. A transect of the southern Cordillera, from Alberta across the Rockies, may continue across the interior and coastal ranges to link up with the study of Vancouver Island, and the mineral-rich Abitibi Belt will



Magnetic anomaly map. The Kapuskasing uplift runs southwest from James Bay towards Wawa on Lake Superior

Carte d'anomalies magnétiques. L'élévation de Kapuskasing s'étend au sud-ouest de la baie James jusqu'à Wawa sur le lac Supérieur

be probed from Val d'Or, Que., to Timmins, Ont. Other possibilities include the Grenville Front, the boundary between the Grenville and Superior geological provinces, the Sudbury Basin structure, and a transect across the western Churchill Province and along the Dempster Highway from Dawson to Ft. McPherson in the Yukon.

There are high hopes in the earth sciences community that this concentrated effort will yield basic new knowledge about plate tectonics, the formation of our continent and the nature of lower crustal rocks.

Un programme scientifique de première importance appelé Lithoprobe rassemblera les scientifiques de la Terre d'EMR et des universités canadiennes pour une étude d'une durée de 5 ans, afin de résoudre de nombreuses énigmes géologiques, insolubles par observations de la surface. Des sondes seront introduites jusqu'à 50 km de profondeur en utilisant des techniques de forage profond et de séismique, dont une nouvelle méthode appelée « vibroseis ».

Lithoprobe débutera dans l'île Vancouver en testant des modèles de plaques tectoniques déjà complètement recensés par sismique réfraction et par des études

magnétiques. Le deuxième site se trouve au nord de l'Ontario, dans la zone tectonique de Kapuskasing, soupçonnée être une ancienne partie de croûte poussée à la surface. Des études seront ensuite menées dans d'autres régions, soit sur le plateau continental au large de Terre-Neuve, dans la Cordillère méridionale, dans la zone d'Abitibi et sur le front de Grenville. Au plan des débouchés économiques, il sera possible d'être informé sur la formation des gisements minéraux, dans le Bouclier canadien, et de savoir comment le pétrole et le gaz ont pu être conservés dans les bassins sédimentaires.

Cet article est disponible en français

Dernier espoir pour nos saumons: la télédétection

Biologistes et géomorphologues travaillent à la protection de nos saumons atlantiques

par Jean-Marie Dubois et Daniel Clavet

Il y a très longtemps, le saumon atlantique remontait jusqu'aux Grands Lacs, au centre du Canada. Voilà un siècle, on en comptait de belles pêches dans le Richelieu et, même au début des années 1900, il se laissait encore taquiner dans la Saint-François. Depuis, seule la région en aval du Saguenay en est la gardienne. Mais cette dernière réserve peut être menacée de disparition si des politiques efficaces d'aménagement ne sont pas entreprises. Il reste encore au Québec 116 rivières à saumons, mais pour combien de temps?

L'accélération de l'industrialisation et, par voie de conséquence, de l'urbanisation et

du déboisement des terres ont rapidement modifié la répartition géographique des populations de saumons. C'est ainsi que plusieurs pays d'Europe ont sacrifié leurs dernières réserves de saumons dans leur course au mieux-être. Quant à nous, il nous est encore possible de les préserver et même d'en augmenter le nombre. Nous avons mis au point une méthode d'inventaire hydromorphologique des rivières à saumons, qui s'est imposée d'elle-même

d'après les considérations suivantes. En effet, face aux dangers qui menacent quotidiennement l'habitat du saumon, il est devenu de plus en plus évident que le travail du biologiste ne suffit pas à lui seul, à assurer la survie de cette espèce. Étudier la stricte biologie du saumon est une première étape, mais il faut aussi étudier son habitat. C'est pourquoi le travail du biologiste doit s'associer à celui du géomorphologue.



Plaine alluviale de la rivière Matamek
Alluvial plain of Matamek River

Chute en gradins (rivière Matamek)
Tiered falls on Matamek River



Les auteurs effectuant des travaux sur la haute rivière Matamek. Daniel Clavet et Jean-Marie Dubois (à droite)

Authors during studies on the high Matamek River: Daniel Clavet and Jean-Marie Dubois (right)

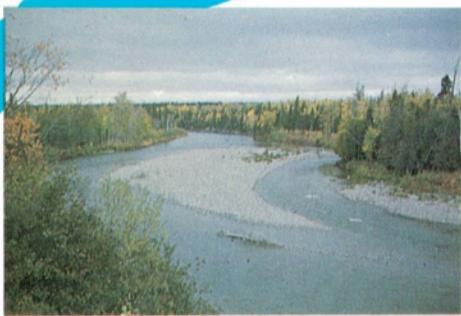
M. Jean-Marie Dubois est professeur titulaire au Département de géographie et directeur de l'Institut d'aménagement de l'Université de Sherbrooke. Il est spécialisé en géomorphologie, en cartographie des dépôts meubles et en télédétection.

M. Daniel Clavet est consultant en géomorphologie, en études biophysiques et environnementales, et en télédétection. Il travaille présentement au Laboratoire de télédétection ainsi qu'à l'Institut d'aménagement de l'Université de Sherbrooke.

Leur travail en collaboration avec la Station de recherche de Matamek est classé sous la contribution n° 81.



Grâce à l'appui du Woods Hole Oceanographic Institute, du ministère du Loisir, de la Chasse et de la Pêche du Québec et du Bureau de la recherche de l'Université de Sherbrooke, il nous a été matériellement possible de développer notre méthode d'inventaire hydromorphologique. La contribution du Woods Hole Oceanographic Institute s'est faite par le truchement de la station de recherche de Matamek. Cette méthode, qui est basée sur l'interprétation de photographies aériennes panchromatiques en noir et blanc, à des échelles variant du 1/10 000 au 1/15 840, prises par les services de



Seuil de gravier sur la rivière Saint-Jean en Gaspésie, idéal pour une frayère

Gravel bed on Saint John River, Gaspé, ideal for salmon spawning

levés aériens d'Énergie et Ressources Québec, et que nous avons pu utiliser, permet de:

- donner aux inventaires d'habitat une dimension spatiale à des coûts réduits grâce à ces levés aériens et à un minimum de travaux de contrôle au sol;
- déduire des sites potentiels d'habitat en vue d'établir la capacité d'accueil des rivières;
- évaluer les interrelations entre les différents environnements géomorphologiques et le type d'habitat qu'ils supportent.

Les travaux ont été exécutés sur les rivières des deux principales régions physiographiques du Québec (figure 1): la rivière Saint-Jean en Gaspésie, dans les Appalaches, et la rivière Matamek sur la côte nord du Saint-Laurent, dans le Bouclier canadien. À titre de comparaison, nous avons aussi effectué des inventaires pour les salmonidés en général dans la rivière au Saumon dans les Cantons de l'Est et la rivière Papashwasati à la baie James. Les biologistes possédaient des données de terrain pour chacune de ces rivières.

Une bonne rivière à saumons doit présenter des fosses à intervalles réguliers; les fosses



Saumons sur une frayère
Salmon on a spawning bed



servent d'endroits de repos ou de milieu de propulsion. Sur son parcours, le saumon ne doit pas rencontrer d'obstacles infranchissables (barrage, digue de castor, amas de débris, chute). De façon générale, une chute de 4 m est la limite acceptable, mais, il peut franchir une chute beaucoup plus haute si elle se présente sous forme de gradins.

Idéalement, les frayères devraient être encadrées de fosses de repos pour les géniteurs et devraient être sisées sur des seuils de graviers, de galets et de quelques blocs. Les blocs servent d'appui à la femelle lors du frai et d'abri aux saumoneaux contre les prédateurs, et la force du courant. Les frayères doivent être recouvertes de 15 à 120 cm d'eau en temps de frai. Si la profondeur de l'eau est moindre, les œufs peuvent être en danger.

La sédimentologie et la dynamique des berges des rivières sont deux éléments importants pour notre étude. À partir de la sédimentologie des berges, il est possible dans certains cas de prédire la sédimentologie du lit des rivières. À partir de la dynamique, il est aussi possible de prédire le colmatage par les silts de certains sites de frayères potentielles sis en aval de zones d'érosion dans ce type de dépôt.

Lorsqu'on possède une couverture de photographies aériennes adéquate — c'est-à-dire prise lorsque le niveau d'eau permet d'apprécier l'emplacement et l'état d'émergence des bancs de graviers qui servent de frayères — les deux problèmes majeurs d'identification qui se posent sont l'identification des fosses et celle de la texture des matériaux du lit (figure 2).

L'emplacement des fosses est facile à identifier dans la plupart des régions. Cependant, au-delà de 1,5 à 2 m de profondeur, elles ne peuvent être évaluées avec certitude. En Gaspésie, le phénomène est inverse, puisque la grande transparence de l'eau ne permet de localiser avec certitude que les fosses de plus de 2 m de profondeur.

L'identification de la texture des matériaux, surtout des graviers, est primordiale dans

ce genre d'étude. On peut déduire la texture des berges à partir des ensembles géomorphologiques, à partir de l'allure de la topographie et des talus, ainsi que des formes d'érosion caractéristiques de chacune de ces textures. Dans le lit des cours d'eau, la texture n'est identifiable que dans les secteurs de rapides et de seuils,

avec l'aide d'un binoculaire 3X. Dans la majorité des régions, les secteurs rocheux ainsi que les principales catégories de textures dans les dépôts meubles sont facilement identifiables, mais il faut souvent pouvoir compter sur la nature des berges.

En Gaspésie, l'homogénéité des couleurs des roches et, par le fait même des matériaux meubles produits, rend la granulométrie des sédiments grossiers difficilement appréciable parce que l'on n'y trouve pas, contrairement aux autres régions, d'éléments foncés donnant un bon contraste parmi des éléments généralement pâles. De la même façon, il est difficile de distinguer le roc émergé de ces sédiments du fait qu'il est fortement altéré en surface et qu'il produit des matériaux meubles d'une même couleur homogène. Le roc immergé, cependant, se distingue très bien en raison de son réseau orthogonal de fractures.

À partir de ces caractéristiques hydromorphologiques, nous avons pu évaluer l'aptitude des différentes régions physiographiques et de leurs environnements géomorphologiques à recevoir les habitats des salmonidés. L'environnement fluvial, deltaïque fluvial, le littoral lacustre et marin et le substrat rocheux ne présentent, dans aucune région, un potentiel d'accueil égal pour l'habitat du saumon.

Prise individuellement, chaque région regroupe une ou plusieurs combinaisons d'environnements offrant des conditions propices à l'existence de fosses et de frayères: le milieu deltaïque proglaciaire en Gaspésie; les milieux glaciaire, lacustre et fluvioglaciaire dans les Cantons de l'Est; le milieu de traînée glaciaire et alluviale ainsi que fluvioglaciaire à la baie James; et le milieu fluvioglaciaire sur la côte nord. Nous avons pu ainsi déduire que l'environnement fluvioglaciaire présente le meilleur potentiel d'accueil en raison de la texture de ses matériaux, essentiellement des graviers et des nombreuses fosses situées principalement dans les méandres des cours d'eau.

Cette méthode d'inventaire du milieu aquatique permet d'identifier et d'évaluer les habitats avec un niveau d'efficacité éprouvé: 86 % des fosses et frayères sont détectées,

Figure 2 Rivière Saint-Jean, Gaspésie, photo aérienne prise au 1/15 000 par Énergie et Ressources Québec, avec interprétation des auteurs

St. John River, Gaspé, aerial photo at 1:15 000, by Energy and Resources Quebec with interpretation by authors

en moyenne, sur la côte nord, en Gaspésie, à la baie James et dans les Cantons de l'Est.

L'utilisation de photographies multi-spectrales a été expérimentée sur un segment de la rivière du Nord dans les Cantons de l'Est afin d'optimiser les résultats. Nous avons utilisé différentes bandes du spectre (panchromatique noir et blanc, vert et rouge, infrarouge noir et blanc et infrarouge couleur) au printemps, à l'été et à l'automne. Nous avons comparé les photographies obtenues d'après la bande spectrale qui offre la meilleure visibilité, c'est-à-dire qui nous permet d'identifier facilement la sédimentologie du lit des rivières, la nature et la dynamique des berges et la végétation.

Nous avons ainsi pu conclure que la photographie aérienne panchromatique noir et blanc de printemps donne pour l'ensemble des facteurs une vision optimale compte tenu de son coût peu élevé et de la disponibilité des couvertures. Notre choix se porte, en deuxième lieu, sur l'infrarouge couleur d'été.

Cette méthode a subi plusieurs autres essais au Québec, et elle commence à être utilisée sur une grande échelle. En effet, le ministère du Loisir, de la Chasse et de la Pêche du Québec ainsi qu'Hydro-Québec utilisent ce type d'approche afin de déterminer la productivité des rivières à saumons à des fins d'inventaires, de gestion et d'études de répercussions sur l'environnement. En plus de servir à détecter les habitats des salmonidés, elle peut aussi contribuer à évaluer l'utilité et l'emplacement d'habitats artificiels accessibles aux poissons, tels les passes migratoires et même les fosses et les frayères artificielles.

The authors have initiated an evaluation of salmon rivers based on the interpretation of black and white panchromatic aerial photographs taken by the aerial survey of Quebec Energy and Resources. A study of the hydromorphological characteristics of the St. John River in Gaspé, and the Matamek River on the North Coast of the St. Lawrence River, revealed that the fluvio-glacial environment best suits the salmonids.

This method, besides efficiently identifying and evaluating the natural salmon habitats, may also help evaluate the use and location of artificial habitats.

This article is also available in English.

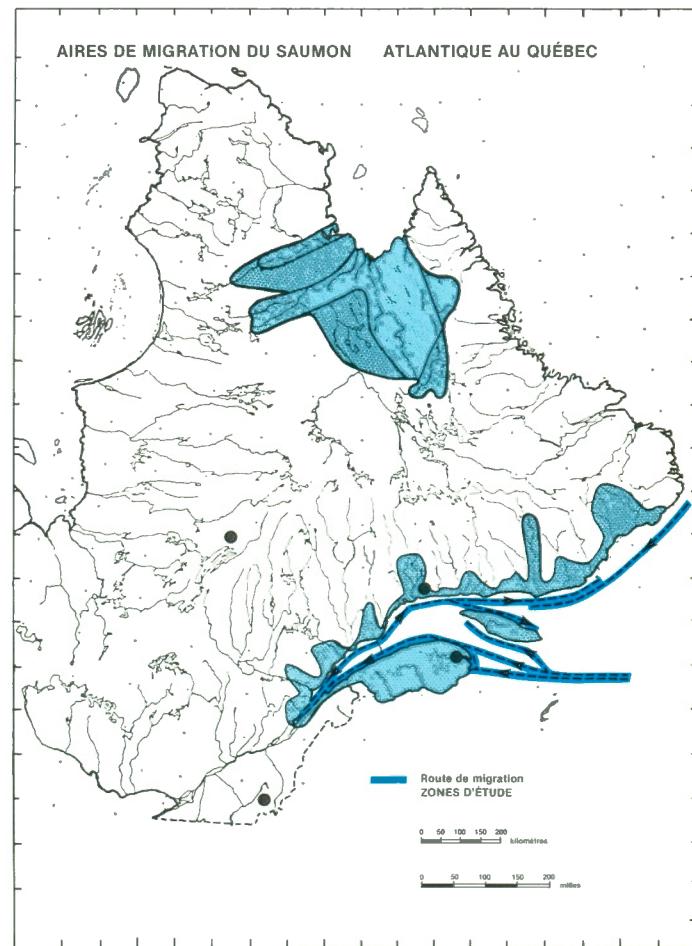
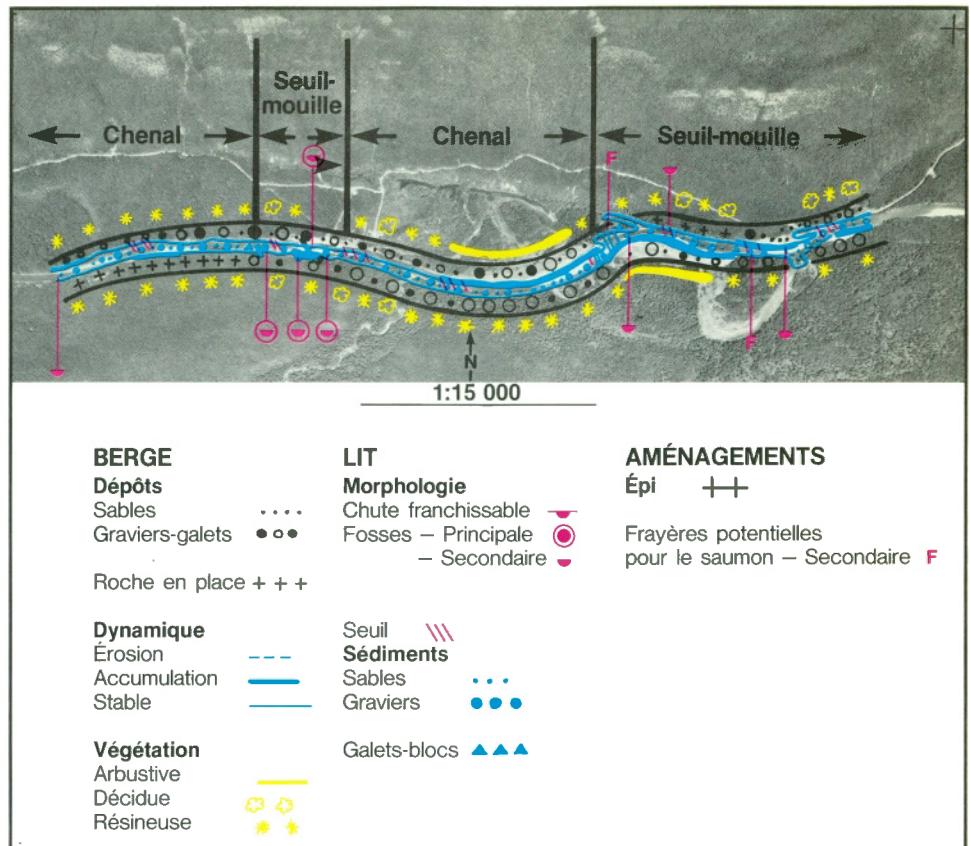


Figure 1 Aires de migration du saumon Atlantique au Québec
Migration areas of Atlantic salmon in Quebec

Ice age bones - a clue

Exotic animals as diverse as Africa's once roamed Canada's great plains

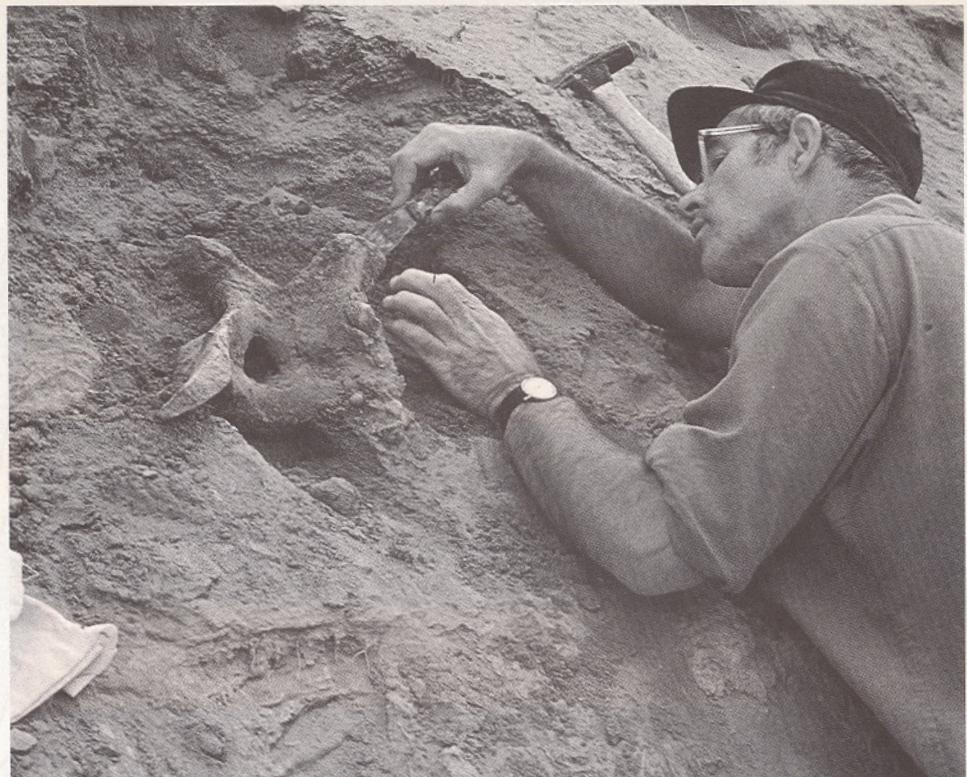
By Archie Stalker

Dr. Archie Stalker is a research geologist in the Terrain Sciences Division of the Geological Survey of Canada. He first did fieldwork with the Survey in 1945 when he was a graduate student. He received his Ph.D. from the Geology Department of McGill University in 1950 and immediately began his career with the GSC in the Pleistocene and Groundwater Section. Dr. Stalker has spent 38 summers in the field studying the stratigraphy and paleontology of the great plains of Canada. The University of Lethbridge is awarding him a D.Sc. for this work in May 1984. Since 1965 he has worked in association with University of Toronto professor Dr. C.S. Churcher, who was born in Kenya and has studied African fauna extensively.

Catastrophes haunted the Ice Age in Canada. Time and time again massive ice sheets scoured the landscape, disrupting drainage, filling river valleys, sweeping away soil, and destroying fauna and flora. In the wake of each slowly retreating ice sheet, plants and animals returned, but always with changes, some minor, some vast.

Until recently we knew few details of those changes. Vertebrate fossils of Quaternary age were considered rare in Canada. Placer gold operations in the Yukon Territory had yielded a significant number of bones and teeth. Extended studies of the Toronto Scarborough beds, which outcrop along the shores of Lake Ontario, had recovered other fossils. But Canadian finds, if at times spectacular, were few, chiefly parts of large animals such as mammoths and mastodons, and mostly from the last part of the Quaternary. In general they added little to our knowledge of the Ice Age.

About 1960, the discovery of many fossil bone sites on the southwest Canadian Prairies changed that. The finds reveal a succession of well adapted faunas as rich and diverse as any now found in Africa, including camels, lions, zebra and elephants. The fossil beds show how the populations changed as some species slowly evolved into succeeding ones and others



*Dr. Archie Stalker uncovers an elephant vertebra
M. Archie Stalker découvre une vertèbre
d'éléphant*

became extinct. They also indicate when new species arrived either from Asia across the Bering land bridge that formed as the ocean lowered during glaciation, or from South America across the Isthmus of Panama.

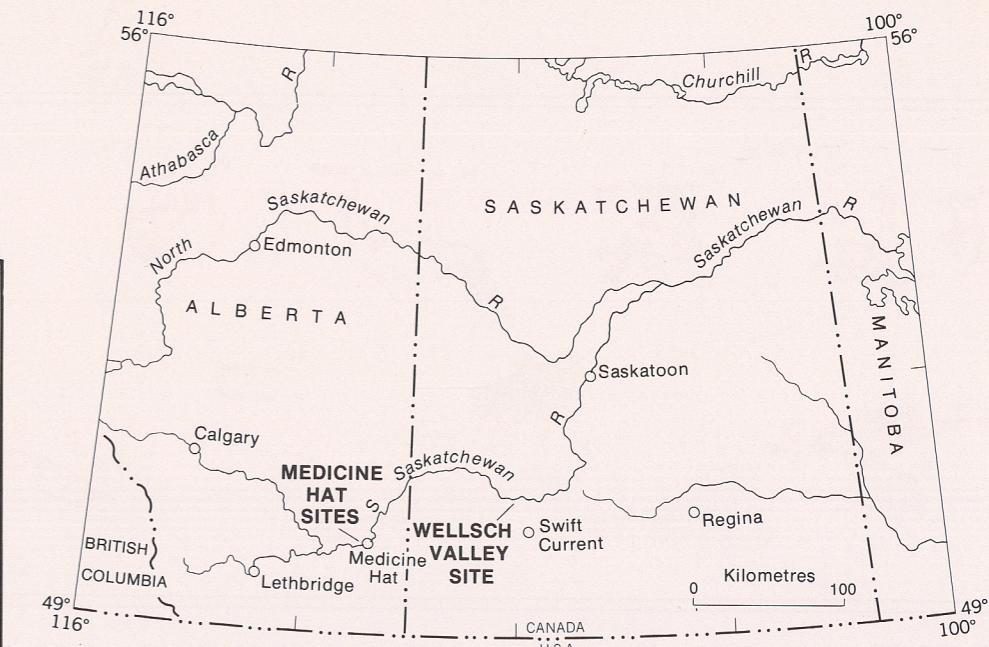
The foldout (Fig. 1), which illustrates the rich and diverse vertebrate faunas that flourished on the Canadian Prairies between glaciations, is taken from a chart first published by the Geological Survey of Canada in 1982. It portrays faunal development through the Ice Age, which lasted from about 1.8 million years ago until the 'great extinction' that followed the last continental glaciation. This covers the greater part of what is known to geologists as the Quaternary Period.

Most of the chart is based on exposures found along the South Saskatchewan River from 10 km above to 20 km below the city of Medicine Hat, Alberta. Here the river cuts across both its preglacial valley and several of its interglacial ones. Early glaciers blocked these valleys, which subsequently filled with debris brought by later glaciers, lakes, streams and wind. The ex-

posures present sections 30 m to 100 m high through a broad range of Quaternary deposits. The Wellsch Valley site, along a short tributary to the South Saskatchewan about 60 km north of Swift Current, provided the information for the oldest fauna on the chart.

The Medicine Hat sites are outstanding for the number of fossil beds found in individual sections. Several exposures contain five bone beds of different ages. In other parts of the continent sections with even three fossil levels of Quaternary age are extremely rare. We do not know why these concentrations of bones exist. Perhaps gentle river banks along with good fords across the rivers enticed migrating grazing animals into the valleys, and abundant shrubs and trees along the river provided ample food for browsers. Moreover, when these animals, breaking through winter ice, caught in floods, or prey to predators or disease, died in the valley, their bones had a good chance of preservation. They were buried in river deposits or in the muck of swampy parts of the floodplain. But the dominant factor in the preservation was a generally semiarid climate that retarded decomposition both before and after burial.

The six till sheets shown in white on the composite section were left by large continental glaciers covering the plains.



They do not contain fossils, but intervene between fossil deposits left by river, lake and wind. In the fossil beds the type of material present partly determines the number and types of bones recovered. Coarse river deposits like gravel typically yield bones of large animals, since small animals were generally crushed during deposition or swept farther downstream by the strong currents which laid down the gravel. Fine material left by gentle streams and lakes may contain the remains of large and small animals. But other factors also influence strongly the number of bones recovered from a site: the amount of study given it, for instance, and the ease of collecting. The South Saskatchewan River continually exposes new deposits at Medicine Hat, for example, and makes it easy to pick out the many bones recovered from the basal beds near river level.

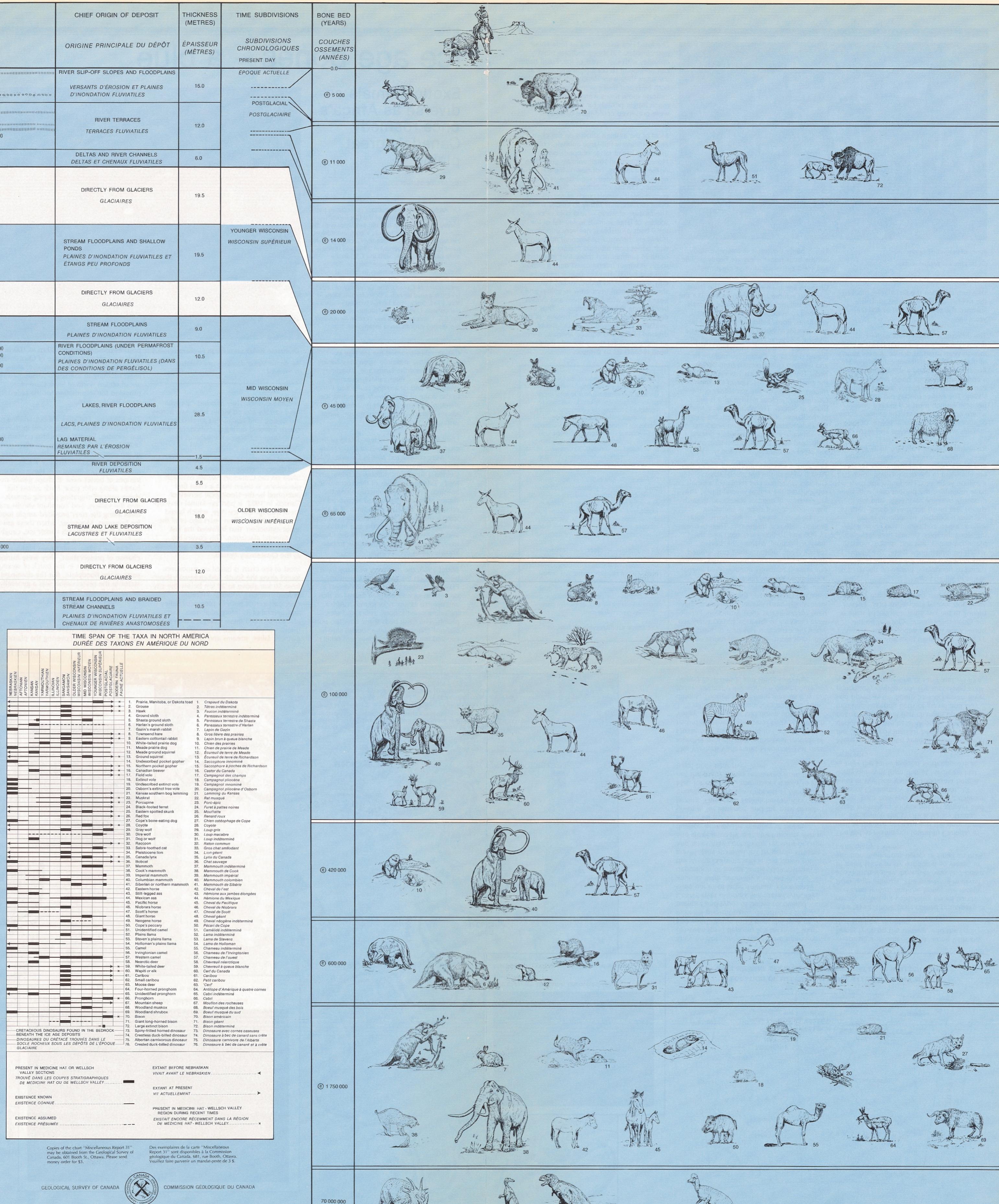
The Wellsch Valley and Medicine Hat sites together provide one of the best records of Quaternary events found in Canada. This record starts with the basal beds at Wellsch Valley, which were laid down about 1.75 million years ago under badland conditions. Though the climate was, as it is today, normally dry, sudden downpours caused flash floods and sheetwash that

swept silt and other debris, along with any bones lying on the surface, into the beds that are now exposed.

As a result, those beds consist principally of poorly sorted silt containing gravel bands and sand lenses, and the bones are mostly from large animals. The overlying material at Wellsch Valley, however, was laid down in quiet lakes or by wind and so yields, in addition, numerous bones of small animals, particularly rodents.

The oldest mammoth found in Canada, as well as the first peccary and the only shrub ox, are among the Wellsch Valley fauna. Small animals include a pocket gopher and a vole, both new species. Of the 72 different types of Quaternary animals shown, 17 were in Wellsch Valley. The fauna here is vastly different from that at Medicine Hat — only the same ground sloth appears at both sites.

More than a million years elapsed before the oldest Medicine Hat beds were deposited. Those basal deposits consist of coarse river gravel that changes upward into interfingering beds of gravel and clay laid down as the South Saskatchewan River periodically overflowed. The succession ends with a thick sequence of sand and silt in a





Bones of prehistoric horses
Os de chevaux préhistoriques

lake formed when the first glacier blocked the river. This whole process probably spanned the period 600 000 to 400 000 years ago.

The difference between the earliest deposits at the two sites, laid down a million years apart, is drastic. A new variety of mammoth and different camels appear. Rodents are rare, and a stilt-legged ass and a comparatively large horse replaced the Pacific and eastern horses seen at Wellsch Valley. The earlier species did not all become extinct; most still existed elsewhere on the continent. The animals either disappeared from the local scene, or their remains were not preserved and recovered.

Remnants of stumps and trunks of large trees, smaller branches, vestiges of leaves and seeds, pollen, and then peaty bands are abundant in the deposits laid down half a million years ago. The landscape must have resembled the present one, with trees drooping over the river edge, and trees, shrubs and brush occupying damp parts of the river floodplain. In addition to the willow, aspen and cottonwood now growing along the river, the old flora included Manitoba maple, ash and spruce, types which no longer grow there. The South Saskatchewan River, periodically inundating its floodplain, preserved the plant remains in silt and clay.

The next animals on the chart are 300 000 years and several glaciations later. They belong to the last great interglacial stage of the Quaternary Period. Once again the bones were in river deposits. We identify 31 types, more than from any other unit.

This is partly the result of intensive study, but the beds nonetheless are highly prolific and yield extremely diverse creatures.

Changes are again remarkable. The fauna began to assume its modern aspect, but the section still includes many exotic animals we tend to associate with Africa: camels, elephants, lions, zebra. Two completely new species of horse appear: the niobrara and the Neogene with its only Canadian occurrence here. Only the white-tailed prairie dog, large Columbian mammoth and western camel remain from earlier beds. The stilt-legged ass has evolved into the small Mexican ass, one of the most prominent equines for the remainder of the Quaternary; a close relative of it is still found in Siberia. The plains llama, a relative of the llamas of South America, has joined the camels and the first bison — a long-horned variety — appears, while ground sloths and lions are still prominent. Most of the other varieties still exist today.

Less drastic changes developed during the 70 000 years of the last glacial stage. Glaciers advanced and retreated; animals repopulated the region several times. The largest array of animals was found towards the middle of that stage — including coyote, bison, skunk, rabbit, horse, camel, ground sloth and mammoth. Then between 15 000 and 10 000 years ago came the 'great extinction'. Mammoths, horses, camels, lions, sabre-toothed cats, ground sloths and dire wolves disappeared, leaving our present relatively impoverished animal population. We are not sure what role man, a ravaging hunter of creatures that were probably already the victims of increasingly harsh climatic conditions, may have played in this great extinction. People were certainly in this area 12 000 years ago when the extinction was near its height and may have been on the scene much earlier.

The fossil bed sections tell us little about past climates. Till sheets indicate frigid episodes with vast layers of ice. Fossil beds can only point to conditions prevailing at the times they were deposited; the fact that both beds and fossils were preserved may indicate those times were abnormal. The much longer periods for which no deposits were preserved could have been very different.

Most of the animals shown on the chart, and particularly the large animals, could tolerate a broad range of conditions. However, certain small animals give clues — the prairie dog, not now living this far north, indicates Medicine Hat was once warmer. On the other hand, the absence of certain small animals, such as snakes and other reptiles, may testify to colder winters. The mixture of warm — and cold — climate species of large animals in several of the fossil beds probably is not very important. It is likely the result of seasonal migrations, with bones from animals that travelled north in summer and those that migrated south in winter intermingled during deposition and burial. Treeless prairie undoubtedly dominated, as it does today, but shrubs and small trees grew in gullies and near sloughs, with larger trees and thicker brush along the river floodplain. Thus the needs of both grazers and browsers, of the predators that preyed on them, and of dryland prairie and aquatic animals, were all met during the many periods the prolific fossil records let us glimpse.

Les dépôts peu constants du Quaternaire, répartis en sections habituellement de 30 à 100 m de hauteur le long de la vallée de la rivière South Saskatchewan, constituent la base de cette carte (fig. 1). Les sections mentionnent des phénomènes de l'époque glaciaire et les dépôts fossiles qui y sont exposés révèlent une série de faunes mammifères bien adaptées; faunes aussi riches et diverses que n'importe quelle faune mammifère que l'on trouverait actuellement en Afrique.

L'accès facile à la rivière, de bons gués pour les espèces migratoires et une nourriture abondante pour brouter ont peut-être attiré les animaux dans la vallée et expliquent la grande concentration d'ossements à Medicine Hat. De rapides enfoncements dans l'alluvion des rivières expliquent pourquoi ils ont été conservés.

La plupart des animaux, particulièrement ceux de grande taille, pouvaient supporter une grande variété de conditions climatiques, ce qui ne nous donne pas beaucoup de renseignements sur les climats passés. Par contre, la présence de quelques animaux de petite taille indique que les conditions climatiques étaient plus chaudes que maintenant.

Cet article est disponible en français.

CESAR cores: geological time capsules

Cores of sediment from the seafloor are geological time capsules. They can help us reconstruct the geological evolution and the climatic history of an area. They can be pointers in the search for resources and in the prediction of atmospheric changes.

CESAR, EMR's 1983 Canadian Expedition to Study the Alpha Ridge, produced 16 piston cores and 14 gravity cores from a 240 km² area of the Alpha Ridge and its flanking basins. These probes of the Arctic Ocean floor were made from a research station on the ice 400 km from the North Pole (Fig. 1). Studies made in that 60-day foray are still being analyzed and interrelated.

The information carried in the cores is helping to delineate the history of the Arctic Ocean, crucial for global paleoclimatic modeling and for predicting the changes that may herald the next ice age in Canada. The detailed history of climatic

By Ruth Jackson and Peta Mudie

We can now say that most CESAR cores record a three-million-year history of sea ice growth in the Arctic Ocean. And one core contains a perfectly preserved record of plankton from a warm Cretaceous sea

change in the CESAR cores is being unravelled by scientists at EMR'S Atlantic Geoscience Centre (AGC) and Dalhousie and Toronto universities, as well as in United States laboratories. They are studying the oxygen isotope chemistry of calcareous zooplankton and the composition of phytoplankton, pollen and spores that record the temperature, salinity and productivity of water at the core sites during the past four to five million years.

Figure 2, scanning electron micrographs taken by F.E. Cole, AGC, shows some of these calcareous fossils that now live under the Arctic ice, along with a few siliceous organisms such as diatoms and glass sponges.

Figure 1 Bathymetry of the Arctic Ocean showing location of the CESAR experiment

Bathymétrie de l'océan Arctique montrant l'emplacement de l'expérience CESAR

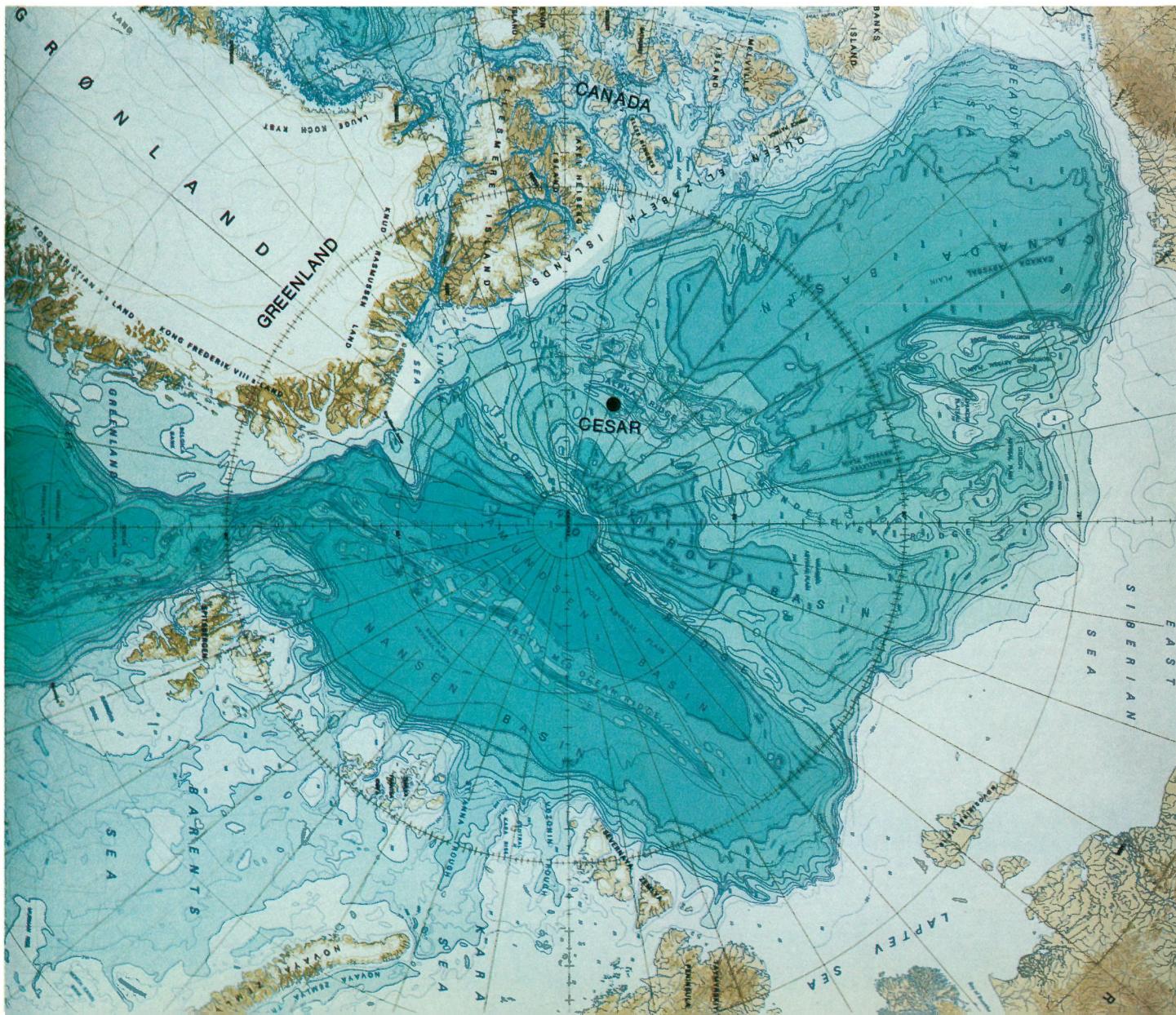




Figure 3

Piston cores from sites on the Alpha Ridge. (a) Basin, CESAR Core 1. (b) Ridge, CESAR Core 6

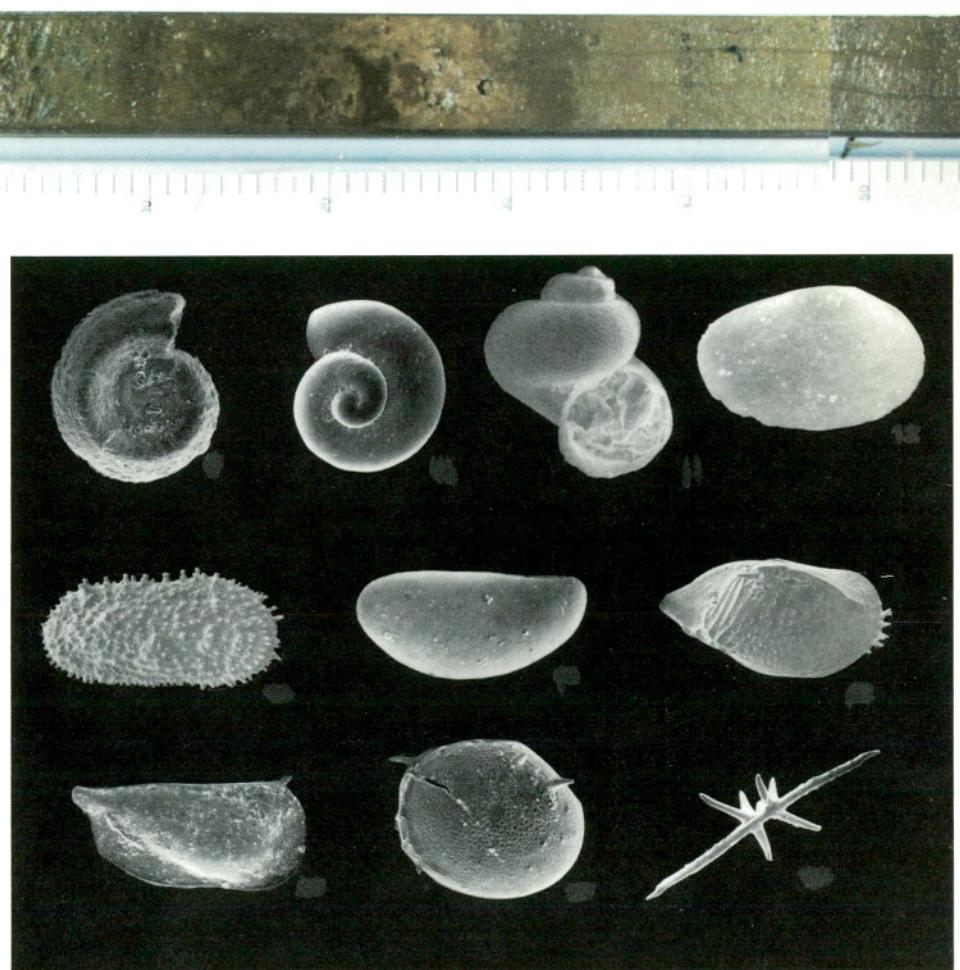
Carottiers à piston des sites de la dorsale Alpha. (a) Bassin, carotte de sondage 1, CESAR (b) Dorsale, carotte de sondage 6, CESAR

So far, the cores have yielded the following information:

- (1) Abundant, perfectly preserved diatoms in CESAR Core 6 show that the Alpha Ridge area of the Arctic Ocean was a plankton-rich, productive warm sea until about 65 million years ago.
- (2) Catastrophic events subsequently occurred. These are associated with traces of volcanic ash in the claystone units of Core 6, and may be related to volcanic clasts dredged from the side of the Alpha Ridge during CESAR.
- (3) The Alpha Ridge area has been a cold, low-productivity marine environment for at least the past four million years.

The most important scientific question now centres on what happened in the Arctic between the warm Cretaceous period and the late Tertiary glacial period. Did tectonic events create the Alpha Ridge at the end of the Cretaceous period, 70 million years (Ma) ago? Did they change not only the Arctic Ocean but also the global seas by forcing a southward flow of low-salinity water into the Pacific and Atlantic oceans? This would explain the extinction of many marine organisms at the Cretaceous-Tertiary boundary, as recorded in most deep-sea sediment cores. Alternatively, was the Alpha Ridge already there in Cretaceous times and did a huge thickness of ice build up over it in the Tertiary when the Antarctic ice sheet started to form? Study of the cores will help us answer these questions.

The number of CESAR cores is small compared with the number recovered from T-3, known as Fletcher's Ice Island, and during the Canadian LOREX 1979 (Lomonosov Ridge Experiment). American geologists took 580 cores from T-3 as it drifted through the Arctic Ocean from



1963 to 1973. They were an average length of 3.5 m. LOREX produced 42 short cores, each about 2 m. The CESAR piston cores had an average length of 4.7 m, and some were longer than 5.5 m. This greater length means two things:

- The cores are more likely to contain bedrock material that could reveal the age and origin of the Alpha Ridge.
- They should contain more sediment of Cretaceous to Pleistocene age. This would cover the time when the climate of the Canadian Arctic Islands region changed drastically. About 100 Ma ago it had a warm, temperate landscape

Figure 2 Scanning electron micrographs show the most common fossils now found in seabed sediments on the Alpha Ridge. Almost all these fossils are the remains of animals with calcareous shells (0.5–1.00 mm)

Les microscopes électroniques à balayage montrent les fossiles les plus courants dont l'espèce existe encore et qui sont enfouis dans les sédiments du fond marin sur la dorsale Alpha. Tous ces fossiles sont pratiquement les restes d'animaux à coquilles calcaires (0,5–1,0 mm)

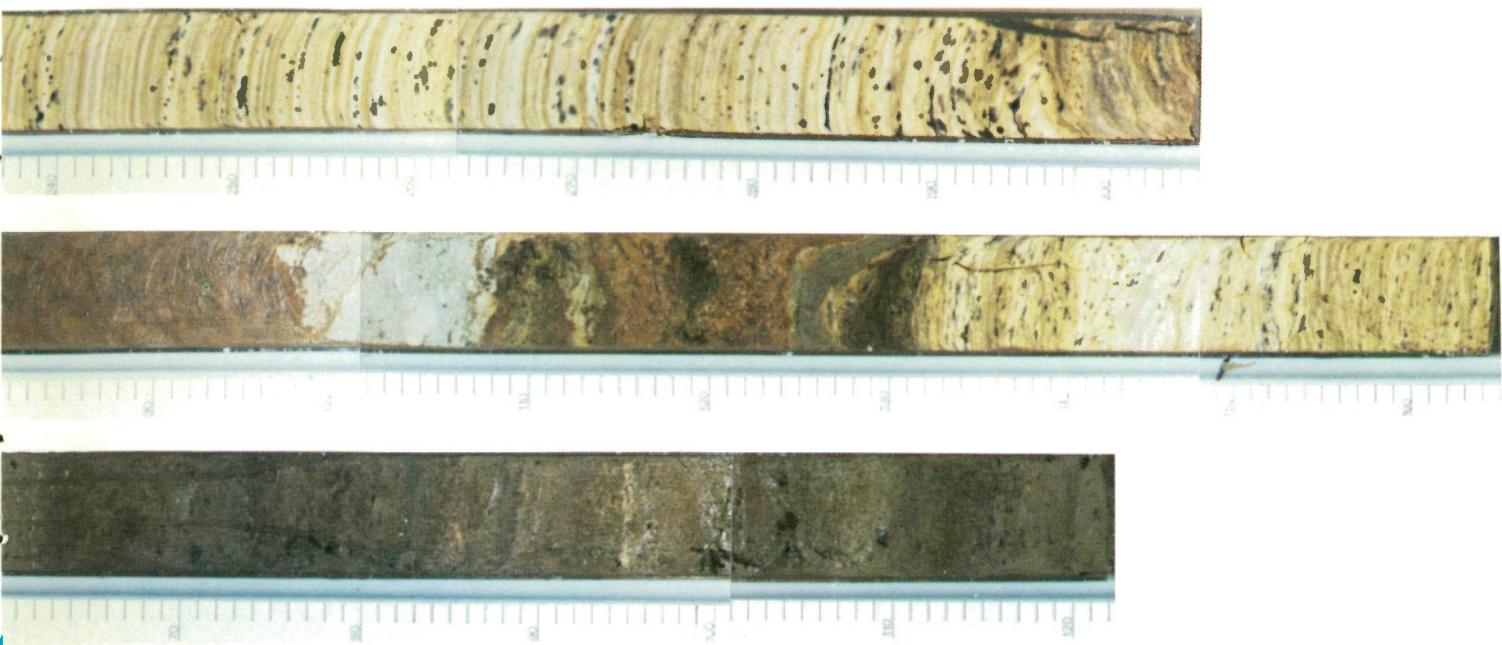


Figure 5. Light microscope photographs of microfossils forming the Cretaceous laminated sediments in CESAR Core 6

Photographies au microscope optique de microfossiles formant les sédiments feuilletés du Crétacé dans la carotte de sondage 6, CESAR. (a) 0,08–0,01 mm, (b) 0,1 mm

covered by redwood-fern forests and shallow seas inhabited by marine dinosaurs and sea crocodiles. Average annual temperature was about 14°C. That gave way to the present tundra-ice landscape inhabited by polar bears and seals, with average annual temperature less than -16°C.

The T-3 and LOREX cores are too short to provide answers to many questions about Arctic evolution, but several of the CESAR cores contain long sequences of brown mud that we hope can be linked to the top of Core 6 and provide the missing clues to our understanding of Arctic Ocean and climatic evolution during the past 65 million years.

The procedure for obtaining these cores is a story in itself. Because large aircraft could land on the thick sea ice at the CESAR site, we could use the heavy and bulky equipment necessary for piston coring. A 1500 kg-winch, 600 kg × core heads and steel A-frames were landed by C-130 Hercules, a significant advantage over smaller ice stations like LOREX and FRAM.

The ice at CESAR was 1.8 m thick. A hole 1.5 m by 1 m had to be cut through it for piston coring, to ensure that the fully rigged corer could pass freely. First, 2.4 tonnes of ice had to be removed. The hole had to be covered immediately, to prevent refreezing, which occurs rapidly at -40°C. Engineer Dave Heffler and technician Fred Jodrey of the AGC constructed a building to cover the hydrohole. Both structure and coring equipment, which they designed and built, had to be capable of safely handling the forces exerted when a 10-m length of core pipe was pulled out of the bottom sediment.

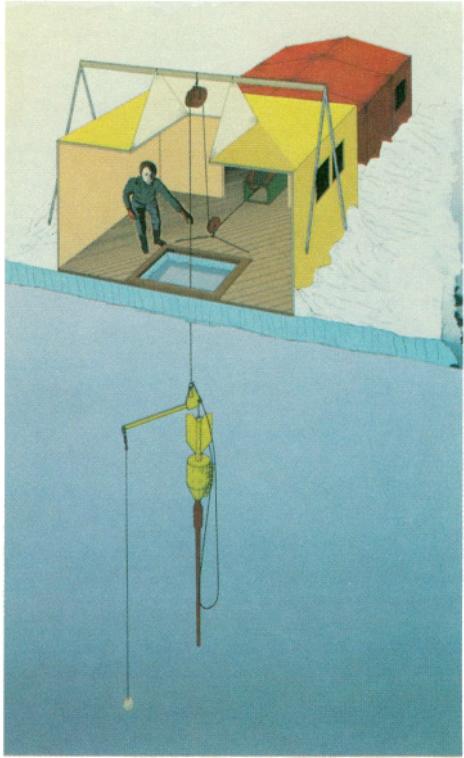
Engineer Jay Arda of Lamont-Doherty Geological Observatory and AGC chief technician Mike Gorveatt, later replaced by PhD student Tom Morris of the University of Wisconsin, handled the time-consuming and labour-intensive job of rigging and derigging the corer. They raised 16 cores, which had to be kept from freezing during storage and shipment home. The Canadian

Armed Forces provided warm and careful handling of the cores from the ice station to Trenton, Ontario, and the cores eventually reached the AGC laboratory in excellent condition.

Meanwhile, back at AGC, excitement grew as reports filtered in from CESAR that such long and potentially revealing cores were on their way.

In order to date and analyze the sediment, special preparations were necessary for the opening and initial inspection of the CESAR cores. Contamination by dust, metal tools and aerial exposure could obscure the geochemical and microfossil histories of the Arctic sediments. So for several days before the opening of the core boxes, the lab floors and walls were swabbed down. Cutting tools were sterilized in preparation for core splitting. The work crew, dressed in surgically clean white lab coats, was headed by technicians Kim Rideout of Geomarine Associates and Flona Cole, AGC Environmental Marine Geology. Finally, these two workers donned large ear muffs to drown the noise of the saw cutting through the thick plastic liner encasing the core sediments.

They cut open about 80 m of core liner with the surgical precision needed to preserve the sediment bedding structures in the cores. They then neatly split each core into two long halves, photographed them, wrapped them in plastic and sealed them in permanently labelled plastic tubes for shelf storage in the AGC refrigerator. Normally, this operation takes about three hours per core, but Kim and Flona managed to complete four cores a day in spite of repeated interruptions by curious visitors.



Coring facilities and equipment at CESAR ice station. Graphic Ken Hale, AGC

Installations et équipements de carottage à la station CESAR. Graphique Ken Hale, CGA

What have we learned so far from the CESAR time capsules? The first core we opened, CESAR Core 1, was from a deep basin (2150 m) northwest of Alpha Ridge. It contained a 4-m-long sequence of brown clayey muds with variable amounts of ice-raftered sand and gravel, alternating with yellowish brown silty beds (Fig. 3a), at the base of which was about a metre of yellowish brown clayey mud heavily mottled with dark brown ferromanganese streaks and speckles.

The sediments in this core were undisturbed and could be matched almost layer by layer with the T-3 cores described by marine geologist David Clark of the University of Wisconsin and his colleagues in the U.S.

Initial laboratory studies of the paleomagnetic chronology, sediment composition and microfossils in two of the cores confirm these similarities and we can now say that CESAR Core 1 records a three-million-year history of sea ice growth in the Arctic Ocean.

The next core we opened, CESAR Core 6, was obtained from a ledge near the top of the Alpha Ridge, where seismic reflection profiles show that bedrock lies near the surface. As shown in Figure 3b, most of this core presented a completely different appearance from Core 1. The top 100 cm is an iron-rich, brown silty mud

with occasional lighter brown mottles and streaks, and with rare diatom and sponge fragments. Abruptly below this unit is about 10 cm of grey sandy claystone containing hornblende, garnet and orthopyroxene minerals and some colourless volcanic shards. This grey unit unconformably overlies about 20 cm of reddish brown claystone, heavily mottled with brown or yellowish, iron-stained sandy mud. The brown claystone consists mainly of highly weathered clay minerals, iron-stained feldspar and quartz, with some amphiboles and pyroxenes, and brown volcanic shards suggesting the inclusion of some volcanic magma. We found no identifiable fossils in either the grey or brown claystones.

Underlying the claystone is 1.75 m of finely laminated yellow and brownish yellow sediment, which has the appearance and consistency of layered cheesecake. We examined tiny scrapings of these layers under a microscope. We saw that each layer of the sediment is made up of billions of diatoms, silicoflagellates and primitive single-cell organisms called archaeomonads (Fig. 5a). Figure 5b shows one of the rare organic-walled fossils obtained after chemical treatment to remove the siliceous materials. X-rays of this biogenic siliceous ooze also revealed the presence of fish bones, providing evidence that small fish probably thrived on the microorganisms in this plankton-rich pre-Ice Age Arctic Ocean.

Most surprising, however, was the fact that the pre-Ice Age siliceous microfossils were almost perfectly preserved — although their shells are composed of delicate glass-like material, few specimens show any evidence of either physical damage or chemical alteration, despite their long burial on the Alpha Ridge. This means that the fossils have never been deeply buried or greatly heated. That is, at least some parts of the Alpha Ridge have escaped deformation by tectonic processes.

Detailed studies are under way to determine the age and origin of this unique marine sediment deposit, which has no close counterpart elsewhere in the global sediment record. According to U.S. Geological Survey diatom specialist John Barron, the diatoms are most similar to those found in marine deposits of the northern Ural Mountains in Siberia, which have been designated somewhat uncertainly as late Campanian in age, about 75 Ma ago. However, the paleomagnetic chronology of CESAR Core 6 obtained by marine geologist Ali Aksu at Dalhousie University does not fit this time period. We know there was no magnetic polarity reversal between 120 and 85 Ma ago, but our core shows several alternating positive and negative magnetic reversals similar to those found in the latest Cretaceous period from 65 to 72 Ma ago.

The dominant silicoflagellates in CESAR Core 6 are species of *Lyramula* and *Vallacerta* which have been found by paleontologist David Bukry, USGS, in Late Cretaceous sediments from California to Cornwall Island in the Canadian Arctic. Bukry believes these genera became extinct at or near the Cretaceous-Tertiary boundary, which suggests an upper age limit for the siliceous ooze. This age determination is further supported by the presence of some well preserved dinoflagellates (*Spongiodinium delitiense*, *Paleoperidinium pyrophorum* and *Laciniadinium* sp.) which were identified by AGC paleontologist Graham Williams in a sample from the base of CESAR Core 6. These dinoflagellate species have also been found in Upper Cretaceous marine shale on Banks Island. Pollen in the CESAR core, however, are quite different from the Arctic Island flora and suggest a deeper water, more oceanic environment for the Alpha Ridge site.

Further study of the CESAR cores may provide some answers to our questions about how the Arctic Ocean evolved. This study will complement ongoing analyses of geological records and volcanic rocks obtained from the Alpha Ridge during CESAR.

Les plus longues carottes de sondage du fond marin de l'océan Arctique ont été rassemblées lors de l'expédition CESAR. Seize pistons et 14 carottiers à gravité furent prélevés de la dorsale Alpha, une chaîne de montagnes sous-marine, par le personnel technique et scientifique du Centre géoscientifique de l'Atlantique (CGA) et d'autres groupes. L'étude de ces carottes de sondage a montré qu'elles contiennent des marques qui témoignent de toute la période remontant jusqu'à il y a trois millions d'années. Au cours de cet intervalle, une vase brune s'est lentement déposée dans l'océan Arctique froid et couvert de glace, habité par une faune et une flore éparses. Entre autres, une carotte de sondage contient abondamment de plancton fossile datant de 65 millions d'années. À cette époque, il existait une mer chaude, riche en plancton, dans l'Arctique; les sédiments ont parfaitement conservé les marques du biote siliceux qui vivait dans cet océan.

Cet article est disponible en français

Radiographier les roches

La spectrométrie de fluorescence X permet de calculer la concentration des éléments de la roche à partir de leur intensité

par Annie Beaudoin

Lorsque les géologues reviennent du terrain avec des centaines d'échantillons de roches, ils sont immédiatement anxieux de connaître les éléments qui constituent ces roches, ou plus précisément leur proportion en poids, appelée concentration.

À cette fin, ils ont recours à plusieurs techniques d'analyse quantitative des roches, dont l'une, la spectrométrie de fluorescence X utilise les rayons X. Cette technique, relativement récente, est l'aboutissement de longues années de recherche théorique et ne peut être saisie, dans sa complexité, qu'en retracant d'abord son élaboration scientifique.

Depuis la découverte des rayons X par Wilhelm Röntgen en 1895, de grands noms de la Physique atomique se sont penchés sur l'étude des propriétés lumineuses de cette « radiation X » qu'ils entrevoient comme une fantastique contribution à l'avancement de la Science.

Ainsi, en irradiant un cristal, l'Allemand Max von Laue put évaluer que les rayons X

nécessitaient des ouvertures très petites pour créer un effet de diffraction. En 1912, il découvrait, par pur hasard, que l'effet de diffraction pouvait nous renseigner sur la nature et le diamètre des atomes constituant le cristal. Un an plus tard, le physicien anglais William H. Bragg convertissait en équations mathématiques les observations de von Laue et en faisait l'interprétation physique.

Mais la découverte la plus pertinente à la spectrométrie de fluorescence X revient à un autre physicien anglais, H.G.J. Moseley, en 1913. Moseley découvrit que toute substance irradiée par des rayons X suffisamment puissants permet aux atomes qui constituent la substance de réemettre séparément leur propre rayon X caractéristique (processus de conservation de l'énergie). En d'autres termes, en exposant une

Figure 1 Absorption d'un faisceau incident et émission d'un rayonnement de fluorescence X
Incident beam absorption and emission of an X-ray fluorescent radiation



M. Rousseau chargeant des échantillons dans le spectromètre à rayons X

Mr. Rousseau loading samples in an X-ray spectrometer

roche aux rayons X, on est capable d'identifier les éléments qui la constituent, grâce aux rayons X réémis par celle-ci.

Moseley posait ainsi une nouvelle « pierre » à l'édifice de la connaissance et ouvrait la voie à des recherches prometteuses.

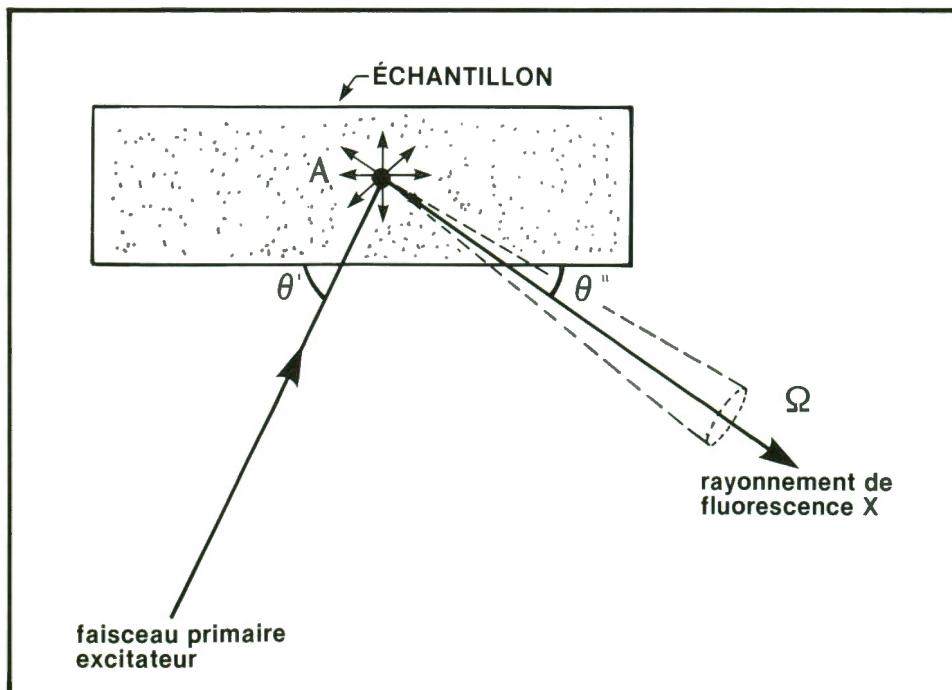
Quelques années plus tard, une deuxième propriété fut découverte. La hauteur du signal émis par chaque élément pouvait nous renseigner sur la teneur de cet élément. On entend par hauteur du signal, le taux de réponse fort ou faible dépendamment de la teneur de l'élément dans la roche.

Dès les années 30, toutes les théories, concernant l'intensité du rayonnement émis par les éléments d'une roche étaient découvertes et traduites en équations. Il restait à mettre au point l'équipement, ce qui prit une vingtaine d'années. Les premiers spectromètres à rayons X, bien que très rudimentaires, firent leur apparition à partir des années 50.

L'analyse quantitative par fluorescence X repose sur le fait que toute substance irradiée par un faisceau de rayons X suffisamment énergétique devient la source d'un nouveau rayonnement X dit de « fluorescence ». Les longueurs d'ondes du rayonnement X sont fonction des éléments de la substance (ou matrice) et les intensités du rayonnement sont en corrélation avec la concentration des éléments de la substance.

Généralement, la relation entre intensité et concentration n'est pas linéaire dû au fait que la matrice affecte le faisceau incident et le rayonnement de fluorescence X. Cet effet est appelé « effet de matrice » (figure 1).

Cependant, comme le souligne M. Richard Rousseau, physicien à la Commission géologique du Canada (CGC) et respon-



Annie Beaudoin est rédactrice adjointe de GEOS

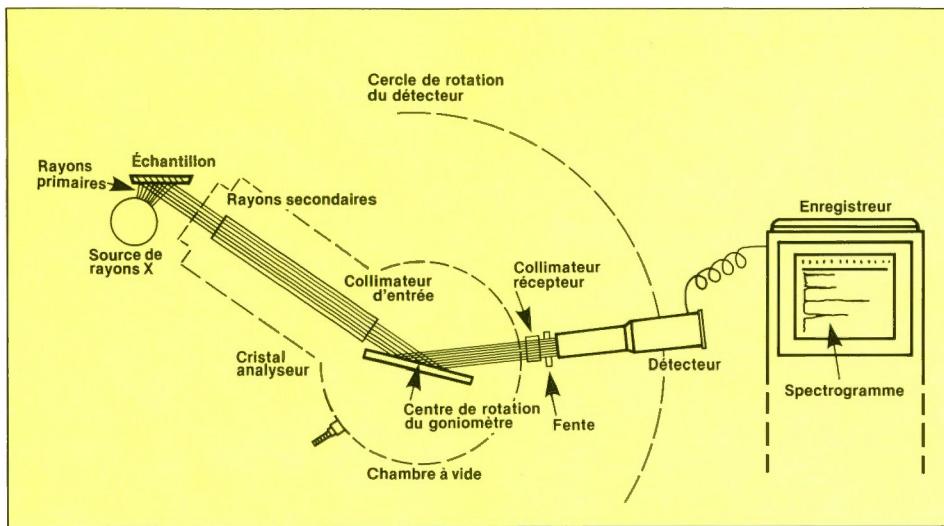


Figure 2 Schéma d'ensemble d'un spectromètre de fluorescence X
Schematic illustration of X-ray spectrometer

sable du laboratoire d'analyse des roches par fluorescence X, un des problèmes majeurs en analyse quantitative par fluorescence X est la correction des effets de matrice. Seule la méthode de calibration peut permettre de rattacher la théorie à la pratique. C'est pourquoi, le travail du physicien a porté pendant de longues années sur la conversion de l'intensité en concentration, à partir d'équations mathématiques suffisamment complexes pour traduire toutes ces opérations.

Grâce à l'apparition des ordinateurs, stockant en mémoire les équations, il a été possible d'adapter ce formalisme théorique à des situations pratiques. En effet, l'ordinateur traduit les intensités, enregistrées par le spectromètre, en concentrations dans des délais très courts.

Aujourd'hui, les géologues disposent de toutes les techniques et équipements nécessaires pour répondre à leurs besoins. Le laboratoire d'analyse des roches par fluorescence X fait partie intégrante des autres unités de la Division des laboratoires centraux de la CGC. Les différentes techniques d'analyse quantitative qui y sont expérimentées permettent, par leur complémentarité, d'atteindre des taux de précision et de diversification optimales.

Première méthode utilisée en analyse quantitative des roches, l'analyse par voie chimique n'en reste pas moins toujours aussi présente et importante. Une des approches par voie chimique consiste à diluer l'échantillon dans une solution acide qui a pour effet de le rendre homogène avant de procéder à la filtration de l'élément à doser.

L'absorption atomique permet d'identifier certains éléments traces, tels que le plomb, le zinc, en excitant la roche aux rayons ultra-violets.

La spectroscopie d'émission optique consiste à brûler l'échantillon et à mesurer les radiations spécifiques émises par chaque atome. Ces radiations sont dans la région de lumière visible.

L'analyseur par infrarouge permet de faire réagir la roche sous forme de poudre. En brûlant cette poudre avec un fondant, l'analyseur peut évaluer les gaz (carbonique, eau, soufre) qui s'en dégagent.

Enfin, l'analyse quantitative de fluorescence X s'appuie sur la technique de spectrométrie de rayons X (à énergie dispersive et à longueurs d'onde dispersives), appelée également « spectrométrie de fluorescence X ». C'est une des techniques les plus prometteuses, car elle permet de déterminer pratiquement tous les éléments d'une roche dans une gamme de concentrations variant de quelques parties par million à 100 %. En effet, il lui est possible de détecter les éléments atomiques de 11 à 92, du sodium à l'uranium. À cela s'ajoute l'avantage que l'analyse peut être effectuée dans des délais relativement courts et avec beaucoup de précision.

En fait, la spectrométrie de fluorescence X a fait l'objet d'un perfectionnement spectaculaire depuis une vingtaine d'années puisque les appareils tendent de plus en plus vers un automatisme complet. La figure 2 illustre un montage typique d'un spectromètre à fluorescence X.

Lorsque les échantillons de roches arrivent au laboratoire, ils ont auparavant été broyés et se présentent sous forme de poudre. Les géologues ont le choix entre une analyse par élément et une analyse totale.

L'analyse totale consiste à déterminer tous les éléments majeurs et mineurs, c'est-à-dire ayant une teneur supérieure à 0,1 %, ainsi que quelques traces, inférieures à 0,1 %.

L'équipement utilisé au laboratoire d'analyse des roches par rayons X consiste

en un spectromètre à rayons X, relié à l'ordinateur central de la CGC, et en un spectromètre à énergie dispersive.

Le spectromètre à rayons X mesure les intensités émises par chaque élément constituant la roche et ces données sont emmagasinées sur disquette. L'appareil est chargé toutes les quatre heures de 12 nouveaux échantillons et lit 18 éléments, correspondant aux 12 éléments majeurs et à 6 traces, dans chaque échantillon. L'ordinateur convertit ensuite les intensités enregistrées en concentrations et imprime un rapport où figure l'analyse quantitative complète des 12 échantillons. La proportion en poids de chaque élément constituant la roche est indiquée en pourcentage.

Le spectromètre à énergie dispersive est plus perfectionné. Il permet d'analyser les traces de 24 échantillons différents sans intervention humaine. Il enregistre le spectre émis par l'échantillon et le reproduit sur un écran cathodique. Cet appareil offre une analyse qualitative très appréciée par les géologues, car ceux-ci peuvent immédiatement visualiser quels éléments sont présents dans la roche. Cet appareil peut également donner le pourcentage de la concentration de certaines traces.

Comme toute technique, la spectrométrie de fluorescence X présente certaines faiblesses. Ainsi, il existe des éléments dans la roche qui échappent à l'analyse par rayons X, tels les éléments de numéros atomiques 1 à 10, qui incluent, entre autres, l'oxygène, le carbone, le fluore.

Il est également impossible aux rayons X de dépasser deux mélanges d'éléments, tels l'oxyde de fer ferreux et l'oxyde de fer ferrique.

Certaines améliorations techniques pourraient être apportées aux spectromètres pour qu'ils traitent un plus grand nombre d'échantillons sans l'intervention humaine et pour qu'ils lisent les radiations émises par les éléments très légers. Les logiciels nécessiteraient aussi certains perfectionnements pour le traitement des données.

Quantitative X-ray fluorescence analysis determines the actual weight of each element concentrated in a rock. It is based on a technique called X-ray fluorescence spectrometry, which measures radiation intensity issued by each element of the rock with a device called a spectrometer, and converts intensities to concentrations through a computer.

X-ray fluorescence spectrometry helps determine all the elements from sodium to uranium, in a concentration range varying from a few ppm to 100 per cent. The technique is especially appreciated by geologists because it is accurate and quick.

This article is also available in English

Canada Helps Map the Third World

EMR's Surveys and Mapping Branch has acted as advisor, monitor and inspector for Canadian air survey contractors in 20 developing nations since 1958

By Don W. Thomson

Any historical account of Canadian participation in overseas aid involves the science of photogrammetry: obtaining reliable, precise measurements of terrain by photography. Nowadays this means aerial photography, which by a system of technical procedures is transformed into maps and charts.

Developing nations need to know the true extent of their natural resources of water, timber and minerals. They also need indications of the type of land-use policies suitable for their national economies. In the 1950s Canadian external aid was mainly directed to Ceylon, India, Pakistan and Malaysia. Resource mapping was an indispensable part of these projects.

As an industrialized country good at solving its own surveying and mapping problems

with photo aircraft, Canada was in a good position to give advice. Moreover, like many Third World nations, Canada is a vast land, with some regions that are hard to reach.

The Canadian International Development Agency (CIDA) early approached experts at EMR's Surveys and Mapping Branch about control surveys, mapping and charting on land, water and in the air. A quarter of a century later, the Branch can look back to service in 20 nations, five in Asia, nine in Africa and six in the Commonwealth Caribbean.

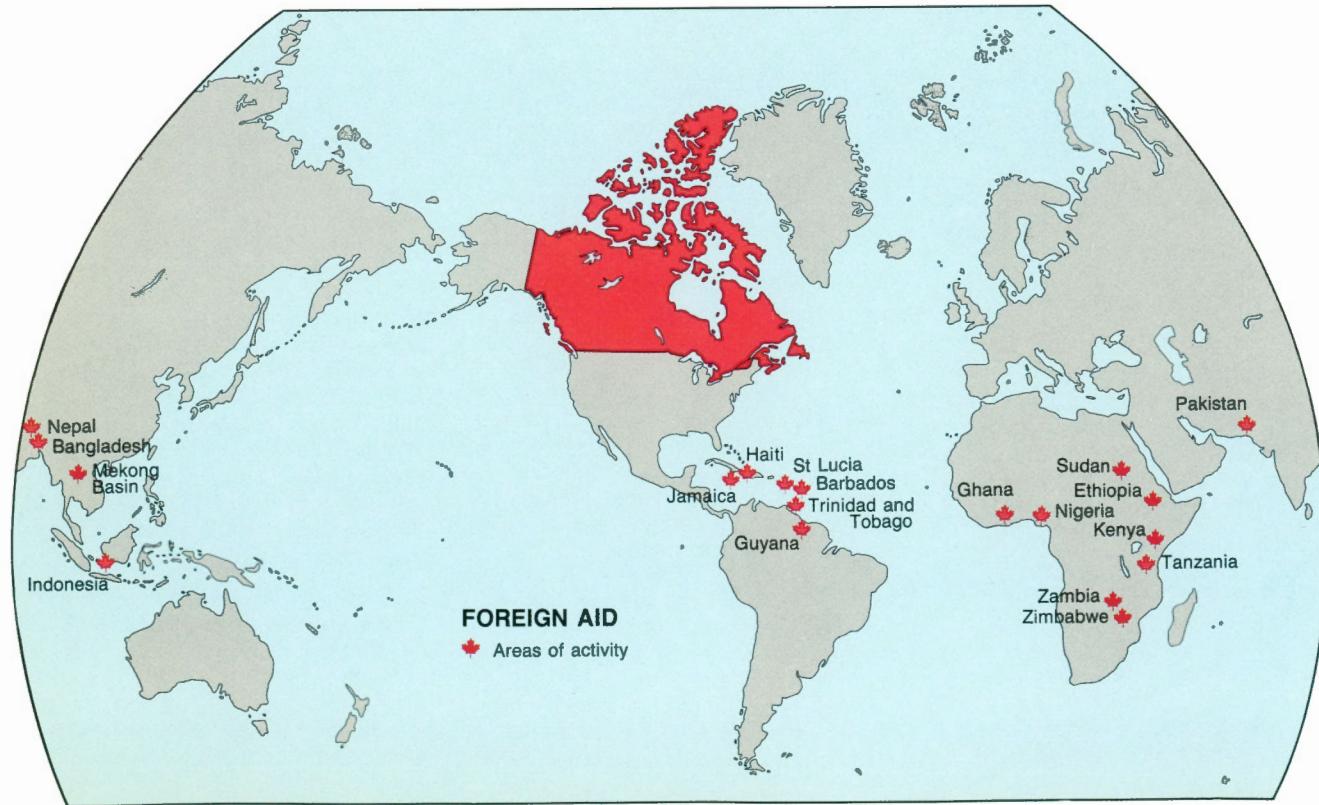
Foreign aid activities by EMR's Surveys and Mapping Branch, 1958 - 1983

Activités consacrées à l'aide étrangère, Direction des levés et de la cartographie, EMR, 1958 - 1983

Under Branch directors Dr. S.G. Gamble and R.E. Moore, staff members often acted as special consultants for private firms operating in aid-recipient countries. These men formed an impartial referee agency, monitoring and inspecting the work and maintaining a standard which would reflect favourably on Canadian industry and international reputation. They also performed a variety of functions for Canadian contractors. For example, they compiled specifications in advance of the type of "surround information" required: style of printed legend, scales and symbols, and spelling of place names. These could be different for each country.

Branch officials also advised about food and water, housing and transportation for Canadian personnel, who had to adjust to local work habits, purchasing procedures and customs clearances.

FOREIGN AID ACTIVITIES OF THE SURVEYS AND MAPPING BRANCH 1958-1983



Typical of some of the conditions under which they worked is this description in a memorandum from a representative in Africa: "There is one main road through the project area and it is unpaved. Roads through smaller villages are not often wide enough to take a Land Rover vehicle The only river in the photo mapping area forms the boundary with another country. In the dry season the river has little or no water in it. An attempt will be made to mark the main channel on photographs."

Trails and many of the smaller villages have changed locations to be near a water source. It is quite common for a village to move several miles each year as land becomes less productive and water resources disappear."

Common to all projects was the resourcefulness of the professionals in meeting and solving formidable difficulties under conditions very strange to them.

In Tanzania, for example, they met an unexpected hazard: war. In the early 1960s Tanganyika (renamed Tanzania in 1964) requested Canada to provide aerial photography, a profile of the land, and photogrammetric compilation. Topographical maps of the area to be covered were to be printed at a scale of 1 : 50 000. The cost of these services was estimated by Surveys and Mapping experts at \$1 000 000, spread over five years from 1964 to 1968. The contractor, Spartan Air Services of Ottawa, brought in helicopters and a DC-3 survey aircraft but tensions along the river boundary dividing Tanzania from Portuguese Mozambique were high. The Portuguese were sending fighter aircraft along that boundary and no one could be sure what they might shoot at. They had refused to permit overflights of their territory, which were vital to completion of the photo survey of southern Tanzania. Spartan Air Services went ahead anyway and finished its coverage, fortunately without encounters with fighter aircraft.

The infrastructure needed and assumed in Canada often did not in fact exist. In 1977 Nepal awarded an air survey contract to Capital Air Services of Ottawa through CIDA. The firm was to mobilize three aircraft to complete aerial photography in three months.

The Branch Foreign Aid Coordinator, James I. (Bing) Thompson, who had been to Nepal previously to study the project feasibility, had warned Ottawa authorities.

Weather reporting facilities were virtually nonexistent. Even the three aircraft were



delayed because they happened to arrive on a religious holiday with no border officials on hand to validate their entry. The air base building was incomplete, with inadequate electrical and water facilities. Canadians had to construct special filtration equipment to enable the project to proceed.

Sometimes the climate was a problem. In March 1962 Canadian Aero Service of Ottawa and Pathfinder Engineering of Vancouver were awarded a contract with Nigeria to map 73 555.66 km² for \$1 300 000. Clear skies are essential for satisfactory aerial photography but in this part of Africa clouds often form in the morning and persist throughout the day. A haze rises when winds carrying fine particles of sand blow off the Sahara.

Engineers of the firm, under direction of Dr. J.M. Zarzycki, now Director of Surveys and Mapping Development Division, met this challenge with two approaches. First, by aerial triangulation a horizon camera determined the tip and tilt of the aerial camera at the moment of exposure. Se-

Canadian Lear Jet 24 on air survey over Nepal in 1978. The single-camera pod bears the name of the survey company

Lear Jet-24 de fabrication canadienne lors de levés aériens au-dessus du Népal, en 1978. Le boîtier de la caméra porte le nom de la Société d'arpentage

Photo: IDA, Capital Air Surveys

cond, a camera with a special super-wide lens enabled 1 : 40 000 scale photography at 3538 m² just below the main belt of haze. A Doppler instrument in the aircraft guided it on a predetermined flight path and measured distances. In addition special Kodak infrared aerographic film allowed some penetration of the haze, substantially increasing the number of possible days for aerial photography.

Lack of adequate air-conditioned storage for preserving photographic materials was often a problem in tropical climates. In one instance seven large boxes of priceless photo plates were left exposed to heavy rainfall and high humidity. As a result, films were flown to Ottawa for suitable storage



Doppler satellite surveys in northeastern Nigeria, 1977. Consortium activity by Photographic Surveys Inc., by Marshall, Macklin, Monaghan, and by Terra Surveys Ltd

Levés par satellite Doppler au nord-est du Nigéria, 1977, par le consortium Photographic Surveys Inc., Marshall, Macklin, Monaghan et Terra Surveys Ltd.

even if they were not to be processed here. However, one Asian nation for security reasons refused to authorize the export of aerial film for processing, although they had no suitable photogrammetric equipment of their own.

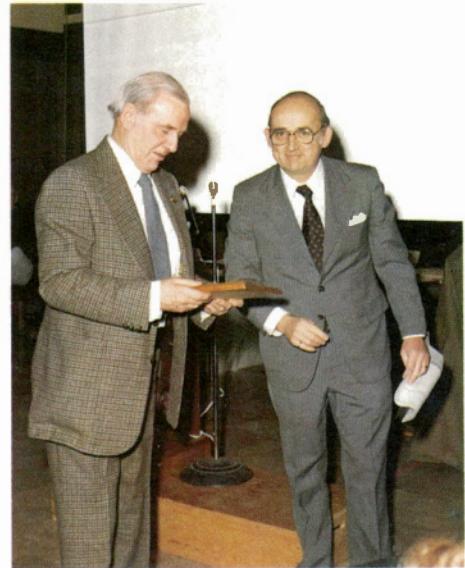
Whatever the challenges, the benefits from Canada's foreign aid work flow to both donor and recipient nations. Canadian engineers, surveyors, pilots, aircrew and mappers, as well as professors and teachers, have been sent abroad. And many foreign personnel have been brought to Canada for university training and for practical experience. Third World students have come to Canadian universities for training in surveying and mapping, under the auspices of CIDA and its predecessors. From 1968 to 1972 they were invited to attend summer survey training schools staffed and operated by Surveys and Mapping Branch. Staff members were invited on an exchange basis to developing countries to share their Canadian knowledge and know-how.

Foreign aid work provides Canadian air survey firms with a chance to keep men and

aircraft, usually inactive during the winter, in use the year round. They expand their knowledge and skill, especially in mapping, to meet and overcome new challenges, improving their effectiveness back home. And EMR's Surveys and Mapping Branch, through its inspection and reporting functions for CIDA, has widened its own perspective on the world.

Ottawa files are filled with communications conveying satisfaction with our help in solving surveying and mapping problems in the Third World. Third World government departments refer to the results daily, as Canadian airphotos are used not only for topographical mapping but also for building and improving roads, and building dams and irrigation systems. Forest inventories, mineral and oil exploration, water resource assessment and land use programs all depend on Canadian air surveys.

Moreover, bonds of friendship arising out of a spirit of practical partnership are bound to promote better international understanding and cooperation in a world which nowadays desperately needs both.



A quarter-century of Surveys and Mapping aid to developing nations was initiated by former EMR Assistant Deputy Minister Dr. S.G. Gamble, who died in 1977, and R.E. Moore, now Director General of the Branch

L'aide de Levés et Cartographie aux pays en développement se poursuit depuis un quart de siècle. Il s'agit d'une initiative entreprise par MM. S. G. Gamble, ancien sous-ministre adjoint, décédé en 1977, et R. E. Moore, directeur général actuel de la Direction

La photogrammétrie représente un aspect vital de la participation canadienne à l'aide au Tiers Monde. L'Agence canadienne de développement international a fait appel à l'expertise de la Direction des levés et de la cartographie d'EMR, afin de conseiller les firmes canadiennes s'engageant par contrat à effectuer des levés de photographie aérienne et de les utiliser pour dresser des cartes. De plus, la Direction est devenue une agence d'arbitrage impartiale, surveillant et inspectant le travail. Depuis 1958, elle a offert ce service à 20 pays en Asie, en Afrique et aux Caraïbes. Tous ces projets ont démontré sa capacité à résoudre des difficultés dans des situations exceptionnelles.

Cet article est disponible en français.



Burning the traditionally unburnable

By Joan Beshai

Fluidized bed combustion cuts coal's contribution to acid rain

Joan Beshai is coal information officer for CANMET's Technology Information Division. She was previously a scientific editor and a bench chemist in the Energy Research Laboratories.

Fluidized bed technology was developed in Germany in the 1920s, but it was not applied to combustion until the 1960s, when the United Kingdom and China pioneered it. This application has now become a standard technique for burning low-grade fuels with high sulphur or nitrogen content and high levels of moisture and ash, in an environmentally acceptable manner. As sulphur dioxide and nitrogen oxide emissions are reduced, so is their contribution to acid rain. This technique is therefore particularly important to regions that have large resources of coal with high sulphur and ash contents.

Fluidized bed combustors have been used commercially in Canada as incinerators for waste materials such as wood wastes, sewage sludge and sulphide liquor. Yet it is only in the last decade that Canadian suppliers have offered fluidized bed boilers designed to burn coal.

Energy, Mines and Resources recognized the technique's potential for utilizing the

Figure 1 Fluidized bed combustion demonstration project at Summerside, P.E.I.

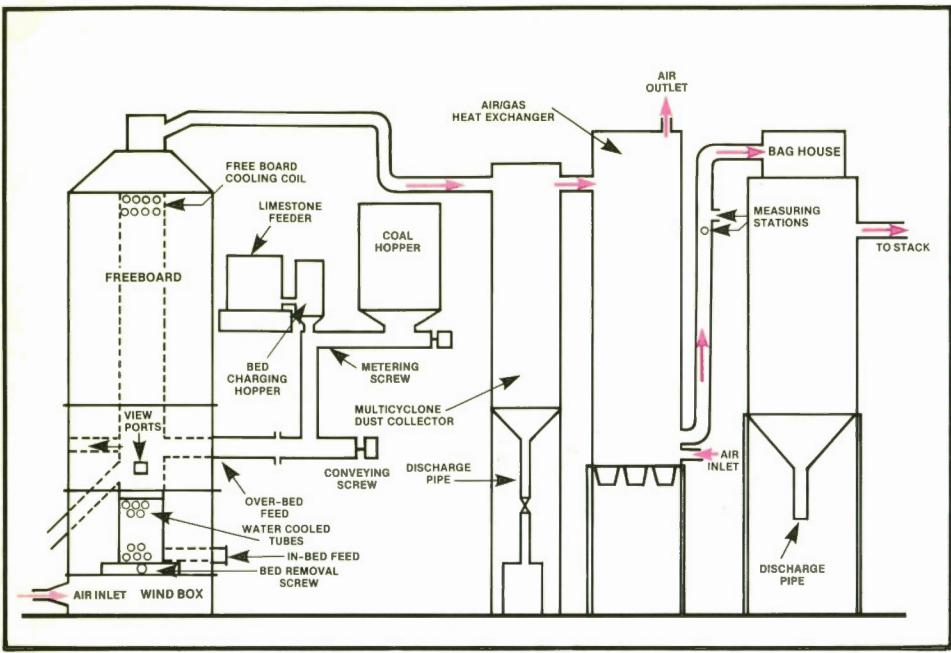
Projet de démonstration de combustion sur lit fluidisé à Summerside, Î.-P.-É.

Fluidized bed technology is a process in which a solid phase behaves as a fluid (e.g., liquid, gas). A gas is passed through solid particles, creating a fluidlike mixture. The solid particles suspended in the gas create the 'fluid'. The process can be used in procedures like catalytic cracking and drying operations, as well as in combustion.

high-sulphur, high-ash coals of Atlantic Canada, the forest industry's large quantities of wood waste, and western Canada's coal wastes and oil sands byproducts, which are difficult to burn.

EMR's technological branch, the Canada Centre for Mineral and Energy Technology (CANMET) has initiated a comprehensive program to research, develop and demonstrate this technology in Nova Scotia, Prince Edward Island and British Columbia. Because this technology is potentially so important in the Atlantic provinces, the most significant demonstration project now under way is at Summerside, P.E.I. (Fig. 1). The project, cofunded by the Department of National Defence, uses high-sulphur coal from Cape Breton.

Fluidized bed combustion (FBC) brings gases and solids into intimate contact, creating a mixture which behaves very much like a fluid. Fluidization allows com-



bustion at relatively low temperatures — generally 750°C to 950°C. Sulphur dioxide reacts with limestone most effectively within this temperature range and calcium sulphate can be removed as a dry solid. These low combustion temperatures also minimize formation of nitrogen oxides and greatly reduce the vaporization of alkali salts, so that they remain as solids rather than convert to corrosives. A soft ash is produced, instead of slag and clinker, allowing comparatively trouble-free operation.

There are two main types of fluidized bed combustors, classified according to the pressure maintained in the freeboard space above the bed. They are atmospheric (AFBC) and pressurized (PFBC). Atmospheric combustors may be subdivided into cooled and uncooled, and bubbling bed (Fig. 2) and circulating bed.

The uncooled, bubbling bed AFBC is the simplest form of fluidized bed combustor. It has a refractory-lined combustor and freeboard able to resist high and changing temperatures, and the action of molten metals, slags and hot gases carrying solid particles. The heat is carried away by the gases released by combustion. Already in commercial use, it burns mainly fuels such as wood waste or sewage sludge, which have low heating value or high moisture content. Heat in the exhaust gases can be used directly in drying operations, or heat exchangers can be used to generate hot air, hot water or steam.

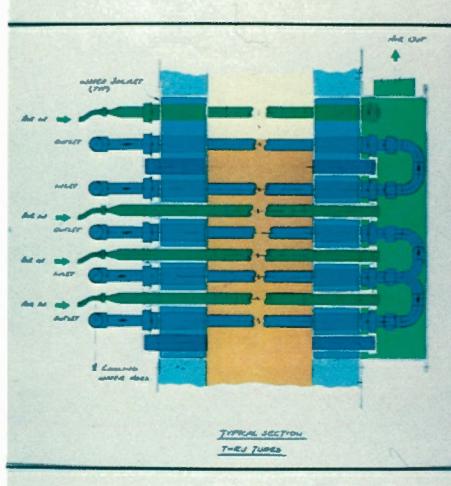
In cooled AFBCs, now in commercial use, much of the heat in the combustion products is absorbed by in-bed tubes cooled by water, air or steam.

Circulating AFBCs, whether cooled or uncooled, are more efficient than bubbling

bed combustors, operating at about three times the fluidizing velocity, and recycling spent fuel. They are being demonstrated commercially, although not yet in Canada.

Theoretically PFBC systems operating at high pressure offer several advantages, including high combustion rates and heat transfer, fewer nitrogen oxides, lower limestone to sulphur ratios. Most important, PFBCs can be used in high-efficiency

Arrangement of Bed Cooling Tubes



combined-cycle power generation using gas and steam turbines.

EMR and B.C. Hydro have sponsored long-term studies for generating 70 MW of electricity from British Columbia's low-grade Hat Creek coal, using PFBCs.

CANMET has a pilot-scale facility in Ottawa to evaluate Canadian fuels and limestones for use in FBCs. Two AFBC boilers, each capable of producing 18 000 kg/h of steam, are being tested at the Canadian Forces

Figure 2 Pilot-scale bubbling bed fluidized bed combustor

Chambre à combustion sur lit fluidisé et sur lit de bulage à l'échelle-pilote

base at Summerside. The boilers will burn high-sulphur (5%) Cape Breton coal, and use New Brunswick limestone as a sulphur absorbent. The boilers are designed to provide up to 30 per cent of the heat at the base.

EMR is also sponsoring a joint program with Nova Scotia Power Corporation to enable utility companies to use AFBCs for power generation. A 10 000-hour corrosion trial in a 1 m² pilot-scale AFBC is under way. If successful, an AFBC will be used to generate 150 MW of electricity with high-sulphur Nova Scotia coal.

The potential contribution of FBC technology to Canada's energy self-reliance becomes more apparent as conventional fuel supplies diminish and we rely more on coal. It will be an advantage to be able to burn coals traditionally considered unsuitable for burning.

CANMET, EMR, met actuellement au point et s'apprête à faire la démonstration d'une technologie de combustion sur lit fluidisé à l'Île-du-Prince-Édouard, en Nouvelle-Écosse et en Colombie-Britannique. Étant donné que cette technique est très importante dans les régions où l'on retrouve un charbon riche en soufre, le projet témoin le plus important est en cours à Summerside, I.-P.-É. et on y utilise le charbon du Cap-Breton, N.-É. et le calcaire du Nouveau-Brunswick.

Cet article est aussi disponible en français.



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

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