Earth Science and Federal Issues

D.J. McLaren
Department of Energy, Mines and Resources
580 Booth Street
Ottawa, Ontario K1A 0E4

Introduction

Scientists, managers and officials from the Federal Department of Energy, Mines and Resources met between May 27 and 29 at Gray Rocks Inn, St. Jovite, Quebec, to discuss the earth science issues facing the nation today and in the future and the role that the Department should play. Other members of the earth science community were invited: Canadian Geoscience Council, university earth science departments, provincial geological surveys, the geophysical community and the surveying community together with representatives of the central agencies of the federal government concerned with science. The scientific activities of the department were reviewed in relation to social, political and economic problems. It was found that current issues of ministerial concern can be grouped under "resources and the land", that is, energy supply, mineral supply and environment (its use and protection). Departmental activities were seen as part of a greater unit - the earth science needs of the nation. The Department contributes to the whole, not in competition but in a necessary symbiotic association with the university, the province and industry. To contribute, it must concern itself with maintaining a continually expanding knowledge base.

The earth sciences are complex and empirical. Theory, such as the plate tectonic revolution, is applicable everywhere but detailed regional and local knowledge is essential for national benefit. Complex activities lead to practical, mission-oriented and cost-effective results. Canada is unique in being a very large country with a small population, still developing in relation to industrial strategy, and must continue to base its economy on nonrenewable resources for the foreseeable future. In addition to traditional concerns, we face new and urgent challenges in attempting to predict the future. Such vital issues include natural hazards, radioactive waste disposal, climatic change, sea level changes, resource estimates and acquifer depletion or contamination. New techniques are required to meet the challenge of the future. Given adequate resources, we have the capacity to improve the science and respond to emerging needs.

Government involvement is required for co-ordinated survey activities leading to economic benefits to multiple consumers. Disinterested data interpretation is essential for policy formulation in a resource-dependent nation. Geoscience is required for encouragement of exploration and exploitation as well as control and policy decision-making. In size of effort Canada lags seriously in comparison with more economically developed countries. How much is enough?

Certain major federal issues were identified in regard to resource appraisal, on and offshore; energy, including alternate energy sources; minerals and water, including shortage of strategic minerals, systems of understanding mineral occurrence deep below the ground surface, and the concept of energy use in mineral production; the land and the sea, including essential requirements for topography, geography, geodesy, use and protection, and natural hazards.

Specific new thrusts were identified and are described below. The "thrusts" are the work of many, but have been pulled together and presented for this paper by the following:

The Territorial Information Base, L.M. Sebert
Geological Hazards and Constraints on Development, P.W. Basham
The Mineral Domain, J.C. McGlynn
Where We Live - The Sedimentary Basins, B.V. Sanford
The Deep Earth, A.G. Green

The Territorial Information Base

The world is moving into an era where major decisions on government policy will be made after the "electronic study" of masses of statistics stored in a variety of data bases. This will certainly be true in the field of natural resources development. Increasingly sophisticated field instruments enable the acquisition of many varieties of data at growing rates. To be useful, most such data must be related to known positions on the ground. The topography itself becomes the common denominator of all geological and geophysical investigations, and the co-ordinate grid of the topographic maps becomes the frame of reference.

The Nature of the Territorial Information Base. To a certain extent this reference grid together with its physical marking on the ground in the form of survey monuments is already in place, and is being used. The present monumentation is sufficiently widespread that no point in Canada is now more than 80 km from a survey marker. This distance needs to be reduced to 20 km to be fully effective. Topographic maps at a scale of 1:50,000 have been prepared for 70 per cent of the Canadian landmass. Complete coverage is essential; this cartographic data base should be converted to digital form as quickly as possible.

The Accuracy and Precision of the Base. The accuracy of the survey monumentation must be sufficient to meet the demands of modern geophysical instrumentation. The accuracy of the cartographic data base must be sufficient to answer questions on pipeline location, hydroelectric power potential, environmental problems that may be encountered during resource development, and a host of other terrain-related questions. As the sensitivity, precision and accuracy of geophysical instrumentation increases, so does the demand for increased precision and accuracy in location data.

The Completion of the Base. The completion of the Territorial Information Base will be done in three concurrent activities: 1) completion of the field-survey base, 2) completion of the graphic information base at 1:50,000, and 3) digitization of the existing topographic base and the conversion to digital cartography for all future maps. The first two activities should be completed within five years. To fail in this timing will mean that important decisions will be made on the basis of incomplete information. The digitization can be extended over ten years.

Although there are compelling reasons for the quick completion of the basic survey and mapping of Canada for the general good, in the context of earth science this work is an essential underpinning for the other "thrusts" that are described in this paper.

Geological Hazards and Constraints on Development

Many of Canada's major new industrial developments will be in frontier regions of the North and offshore, and will create environmental concerns. Such activities will proceed safely and economically only if adequate information is available on the nature of surficial geology and natural hazards.

Geological Constraints Offshore. Geological constraints to offshore development include: 1) the static physical characteristics of the seafloor, e.g., its geotechnical properties and the presence of permafrost; 2) the response of the seabed to perturbing phenomena such as sediment movement, ice scouring (see cover) and earthquake-induced mass movement; and 3) the response of seabed materials to man-induced disturbances such as the melting of permafrost and gas hydrates by drilling fluids and sedimentation behind a tidal barrage. Understanding and quantifying these phenomena require regional seabed mapping and research on seabed processes.

Regional surficial geological mapping using acoustical techniques and bottom sampling has been completed on the Scotian Shelf and parts of the Grand Banks and Labrador Shelf. Figure 1 shows a side-scan sonar and an echogram of iceberg scours in the Labrador Sea sediments. Systematic seabed mapping and process studies in the Beaufort Sea and Hibernia area are in progress in co-operation with industry. However, an expanded program to include prediction of geotechnical properties is required in these areas and new programs must be initiated for the western Canada offshore and the Arctic Island channels where current effort is nonexistent or minimal.

Coastal Geology. Canada has the longest coastline of any nation. Information on coastal geology is needed for harbour development, dredging of navigation channels, extraction of aggregates, disposal of wastes and mine tailings, construction of pipeline terminals and assessment of the effects of oil spills.

Maps of the coastal geological regime are available for much of Nova Scotia and New Brunswick, parts of the northeastern coast and scattered areas of the Arctic Islands. New programs are required for the development and application of efficient remote sensing techniques in the high-priority, environmentally sensitive coastal regimes of the Arctic Islands and in areas of potential oil spills such as off Newfoundland and the Straits of Juan de Fuca.

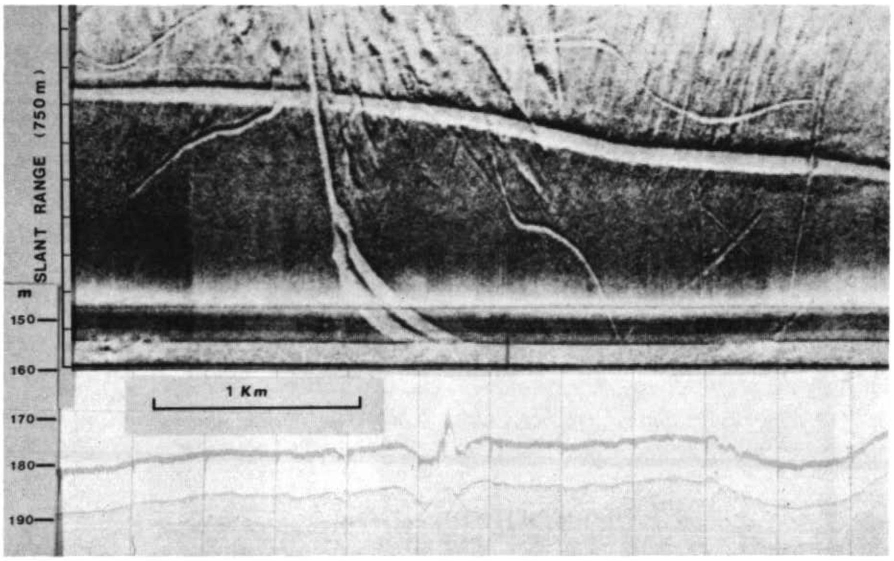

Figure 1 *Side-scan sonar and echogram of iceberg scouring on the seabed, Saglek Bank, northern Labrador Shelf.*

Northern Development in Permafrost Terrain. Approximately one half of the Canadian landmass and an unknown area of the near offshore is underlain by permafrost. This climatic phenomenon greatly influences geological processes and the properties of earth materials.

The cost of the Alyeska pipeline inflated to some eight times the original estimate because the engineering consequences of frost-related effects on buried pipelines were underestimated. As the mining industry moves northward for new resources it encounters increasing difficulty with permafrost. Problems believed attributable to aggrading and degrading permafrost and the occurrences of gas hydrates have been encountered during exploration drilling. The eventual production of oil and gas is expected to be even more difficult because of the prolonged thermal imbalance caused by the production system. Figure 2 shows permafrost and ice lenses in the Beaufort seafloor.

A significant improvement in knowledge of these phenomena requires an expanded regional field program to study the distribution of permafrost and an expanded program of laboratory and field-scale research to predict the response of permafrost to natural and man-made disturbances. Among the areas critical to northern resource development are the Beaufort Sea and Arctic Islands, the proposed Alcan pipeline corridor and the mining areas of Baffin Island, Keewatin and northern Quebec.

Earthquake Hazards. All known earthquake-related fatalities in Canada and much of all known property damage occurred in the quarter-century between 1925 and 1949. During this same period earthquakes as large as magnitude 7 occurred in the then remote areas of Baffin Bay and Queen Charlotte Sound. Since 1949, only the great Alaska earthquake of 1964 caused significant damage in Canada, the result of a tsunami that crossed the North Pacific from the Gulf of Alaska.

Neither the monitoring nor the understanding of possible future occurrences of similar earthquakes are sufficient to assess earthquake hazards in resource development areas of Queen Charlotte Sound, Beaufort Sea, Arctic Islands and the eastern offshore. New research programs involving improved land-based networks and short-term deployment of ocean-bottom seismographs are required. The Grand Banks earthquake of 1929 (see Fig. 3) illustrates the importance of also understanding the potential for seismically induced failure of unconsolidated seafloor materials.

An associated new program that would furnish important data over the longer term is the development of a Canadian capability to use space-oriented techniques to monitor small motions and deformations distributed over long distances. This would include the development of a mobile system to be used in conjunction with radiotelescopes for long-baseline surveying to centimetre accuracy.

Volcanic Hazards. Volcanoes in Canada are confined to four fairly well defined belts that extend across B.C. and the southern Yukon. There is no program designed specifically to evaluate potential hazards. A new Canadian program is required to integrate the available data on these volcanoes, establish an early warning system of geophysical measurements and develop procedures in areas of greatest risk. A USGS hazards report served as a basis for evacuation and restricted access prior to the May 1980 eruption of Mt. St. Helens. As a result between 2000 and 5000 lives were saved.

Environmental Geochemistry. The chemical and mineralogical properties of surficial deposits vary greatly according to the variation in types and properties of underlying bedrock. In the 95 per cent of Canada that has been glaciated, the signature of underlying bedrock in surficial sediments is deformed by glacial transport (e.g., Fig. 4). This natural chemical variation is often misinterpreted as being anthropogenic; conversely, many of man's activities impinge on the terrain in ways that can be assessed through an understanding of natural geological and geochemical variations.

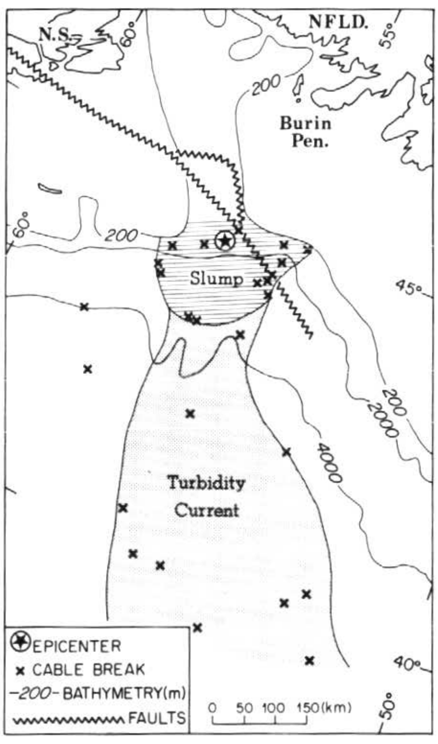

Figure 3 *The 1929 Grand Banks earthquake of magnitude 7 caused a massive slump on the continental slope and a turbidity current which flowed for 600 km onto the abyssal plain. Evidence for extent of slump and current came from numerous breaks in trans-Atlantic cables.*

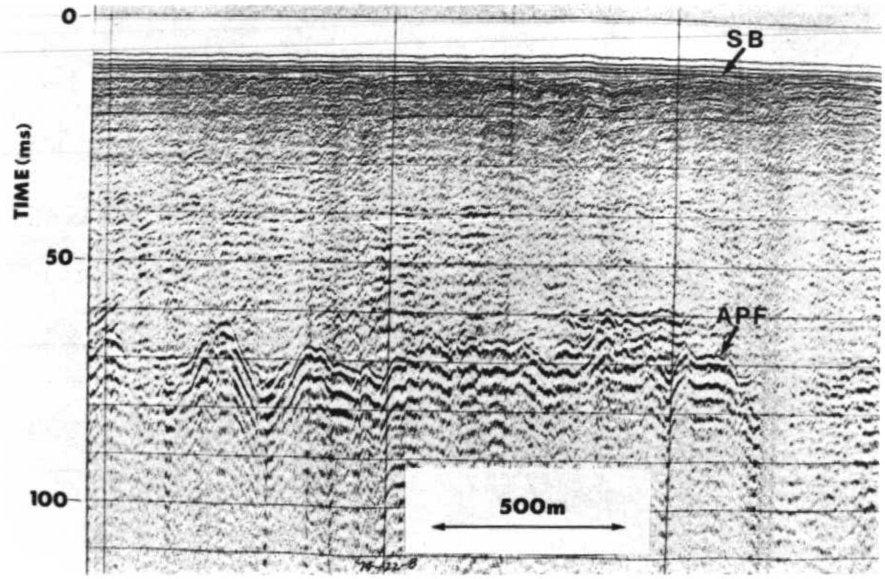

Figure 2 *Seismic reflection profile from the Beaufort Sea, showing the hummocky nature of the top of acoustic permafrost table (APF) at 40 to 50 m below seabed (SB).*

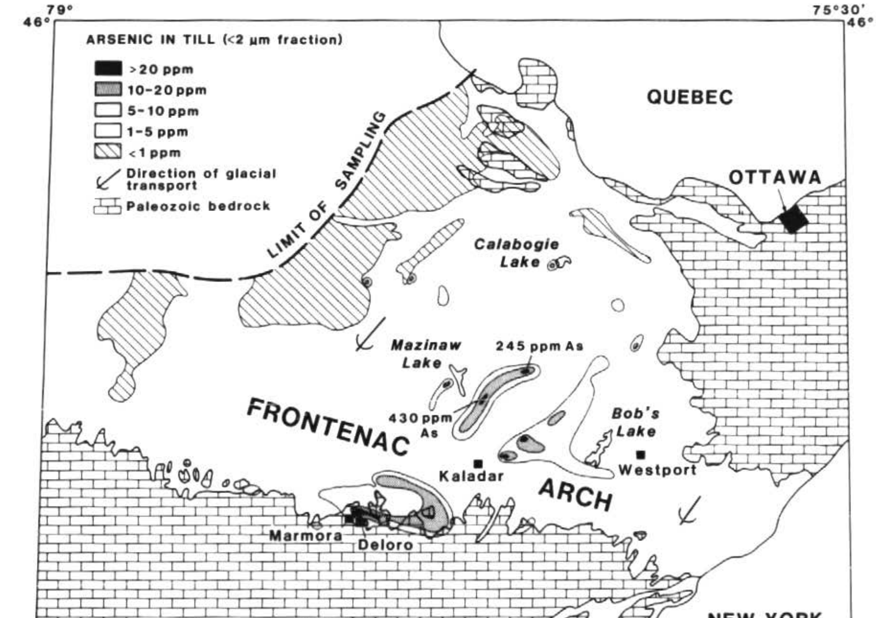

Figure 4 *Arsenic concentration in glacial drift on the Precambrian terrain of the Frontenac Arch. These are natural variations spread by glacial transport from arsenic-rich outcrops.*

Knowledge of natural chemical variations has been gained through more than 20 years of geochemical programs directed toward mineral prospecting. New programs are required, directed toward the geological aspects of environmental problems such as acid rain and metals in the food chain. Expanded sampling programs are required where environmental problems are present or imminent. Analytical facilities need to be upgraded to cover a wider range of potentially noxious elements.

The Mineral Domain

Introduction. Canada's mineral production, excluding fossil fuels, was about 15 billion dollars in 1980; the value-added worth was about 4 per cent of the GNP. More important, minerals make up about 20 per cent of our exports. Although Canada's mineral wealth remains impressive, the country must maintain its reserves in order to support our export position in a world market in which demand will ultimately increase. Recent studies indicate that between 200 and 250 new mines will have to be developed in the next 20 years if Canada is to achieve this goal.

Most discoveries over the past 25 years have been made by ground prospecting, airborne geophysical soundings that penetrate to a depth of about 100 metres, and geochemical surveys. Exploration programs were based on generalized, empirically derived, geological models of ore deposit formation. Most of the potentially productive parts of Canada have been surveyed by these methods. We are entering an era in which mineral deposits will be increasingly difficult and more costly to discover.

To meet the challenge of maintaining our rate of discovery as difficulty of discovery increases, two research programs are proposed, one to improve our understanding of the formation of mineral deposits, and the other on exploration technology, to provide new tools for their discovery.

Mineral Deposit Research. Mineral deposit research will be concentrated on metallogenesis and mineralization. The object is to provide more sophisticated, practical, predictive geological models of ore formation.

Regional metallogenic studies will focus on the origin of mineral deposits with emphasis on their relationship in space and time to regional geological and tectonic features. Such studies will also provide an analysis of the metallogenic significance and characteristics of various plate tectonic environments as they are defined by regional geological studies. A national inventory of the geology of mineral depostis will be maintained as a basis for resource assessment for government planning as well as a data base for research programs.

Future research requires an approach that moves beyond description and compilation and is oriented toward defining the processes that concentrate elements into ore deposits. Such studies would, for example, be designed to determine the nature and origin of fluids involved in the concentrating process, their chemistry, temperature and source, as well as their movement patterns. The interrelationships of metallogenic and process-oriented research are illustrated schematically in Figure 5.

Exploration Technology. As discovery of ore deposits becomes more difficult and exploration more costly, new or improved exploration methods and instruments are required. They must be capable of locating concealed deposits that are at greater depths or that present more subtle indications of their presence.

Examples of proposed projects include high-power variable-frequency airborne EM systems to obtain increased depth penetration, and self-contained, continuous-reading, precise positioning systems for airborne surveying, to be developed from existing military systems. Research is needed in borehole drilling technology. Little or no such research is done in this country, yet about half of all exploration costs is used for drilling. Enhanced efforts to develop slim-line borehole probes for various geophysical and analytical methods are required to make maximum use of expensive boreholes.

Where We Live - The Sedimentary Basins

Several problems are of major concern in sedimentary basins. Perhaps the two most serious are: 1) the current decline of conventional petroleum reserves, and 2) the decline and deterioration of water resources.

The known, immediately accessible reserves of conventional oil are currently being depleted at a faster rate than they are being added to by new discoveries. As a result, production is not keeping pace with the country's requirements, and the substantial shortfall must be made up from nonconventional sources and imports. To reduce the shortfall, indigenous natural gas is being substituted wherever practicable. This is a practical alternative, although greatly increased utilization of this resource will eventually also lead to shortages unless new discoveries are systematically made and brought into production over the next few years.

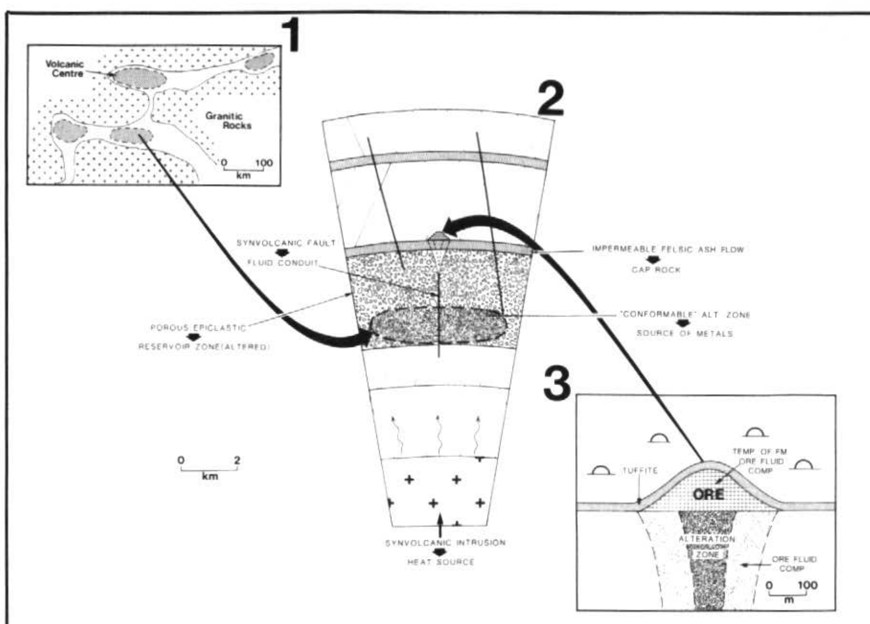

Figure 5 *Highly simplified illustration of the methodology and application of mineral resource research. Field and laboratory observations are merged to form a practical genetic model from which specific characteristics that are useful in designing an exploration program are identified. Diagram 2 illustrates some essential geological components of a genetic model, and the interpretation of these components are part of the model. Diagram 1 illustrates the principal environment of occurrence, and diagram 3 illustrates a few examples of the type of information gained from detailed studies of a deposit, which are used in establishing and refining a genetic model.*

No less important than energy supply are the social and environmental problems relating to water resources - their future supply and the potential for further deterioration by acid rain and by industrial and other wastes. Some parts of Canada are experiencing the initial phases of serious groundwater shortages. In addition, water quality has deteriorated in some localities and the more industrialized regions of the country are threatened by an even greater risk from underground injection of industrial and other wastes.

The current contributions of earth science research to the solution of these problems is inadequate. Accelerated activities are thus warranted in two principal realms of investigation, basin evolution and resources, and basin fluids.

Basin Evolution and Resources. Canada, with its enormous areal distribution of sedimentary terrain (Fig. 6), not only contains a large variety of basin types, but also a record of basin development that spans long periods of geological time. Understanding more fully why and how these basin types were initiated and evolved would provide a basis for more accurate estimation of hydrocarbon and mineral potential of Canada's frontier regions, improved forecasts of when and where the resources are likely to become available, and new "exploration play" concepts to stimulate the search for new resources in some of the more geologically complex regions of the country.

The proposed activity should include all basin types, with specific emphasis on the poorly known but potentially prospective Mesozoic-Tertiary basins identified in Figure 6. Included are the continental slopes and rises, which are expected to be technologically accessible for development during the next decade. The methods to be applied are multidisciplinary geological and geophysical techniques, with emphasis on concepts of basin evolution, including basin inception, development and modification processes, in that order.

Some of the younger basin types contain excellent records of all of these processes, the Scotian Margin being one of the best documented examples (Fig. 7). Understanding the mechanisms that triggered some of the processes illustrated in this diagram, for example basement block faulting, the deposition of blanket sands and carbonate platforms, the initiation of salt doming and down-to-basin growth faults is the key to defining the type and areal distribution of "exploration plays" likely to be encountered in any given basin configuration. For these investigations to have any practical value, there is a requirement for a much improved geoscience data base, which can only be obtained by accelerated geological and geophysical activities. This applies particularly to the continental slopes and rises, and Arctic offshore regions where information is currently sparse or nonexistent.

Basin Fluids. Hydraulic flow systems, as illustrated in the highly schematic diagram of Figure 8, are important in sedimentary basins because of the widespread stratigraphic uniformity and continuity of the rock strata, and the multiple uses to which the various systems can be put.

To evaluate groundwater potential and ensure the avoidance of the kinds of catastrophes suggested in Figure 8, a thorough understanding of the compositional and structural framework of selected sedimentary basins is needed. This will enable accurate three-dimensional modelling of hydraulic flow systems, reconstructing the processes of the generation and migration of ancient flow systems (water, oil and gas), as an aid to predicting their eventual localization in structural and stratigraphic trapping mechanisms, and predicting the long-term environmental effects of deep underground waste disposal, primary and secondary oil recovery, and energy storage on groundwater systems.

The study of deep formation fluids in conjunction with oil and gas appraisal should include all of the Canadian basins that have significant potential to yield these commodities. Geological framework studies in support of groundwater assessment and related environmental considerations, should be focussed, initially at least, on the more densely populated and industrialized regions of the country.

In many of the basins where there are potential groundwater problems, the stratigraphic successions are well known, and facies and structural studies have already been carried out in selected areas. These findings should be integrated and expanded to a broader scale to more accurately define regional flow systems, and to model potential pathways through the rock mass that could conceivably interconnect one water-bearing zone to another and contaminate it (Fig. 8).

The Deep Earth

Integrated multidisciplinary studies in the oceans led to the formulation and widespread acceptance of the theory of plate tectonics, a new concept of profound importance, which has revolutionized

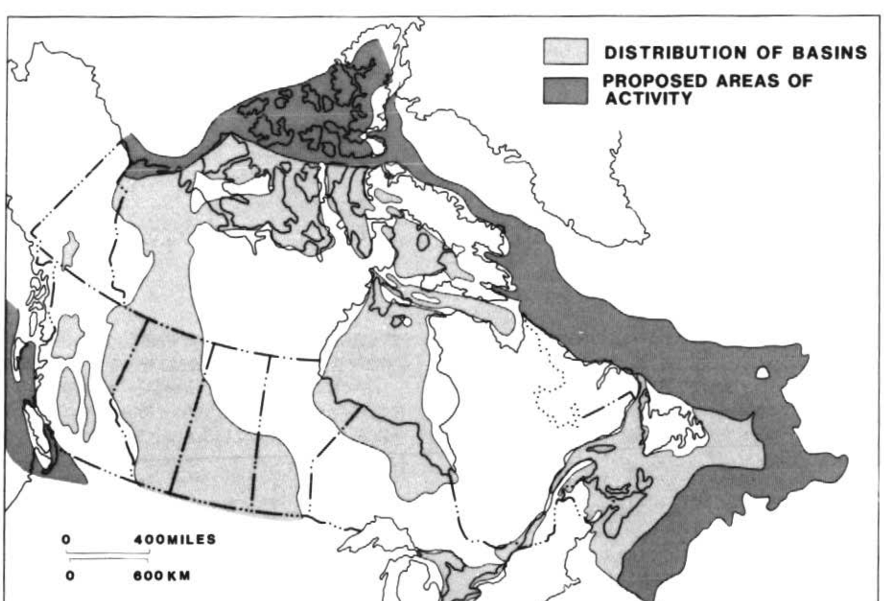

Figure 6 *Sedimentary basins of Canada.*

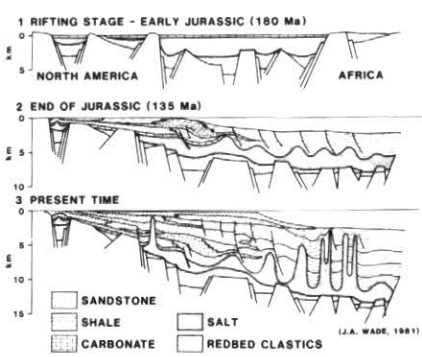

Figure 7 *Basin evolution processes - Scotian Margin.*

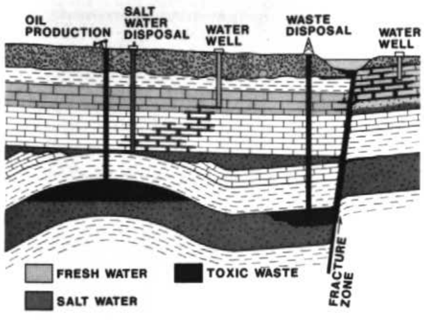

Figure 8 *Basin fluids - potential interaction.*

thinking about the evolution of the earth's crust. This theory has been remarkably successful in explaining geological processes in the oceans but has been less effective in explaining those of the continents. It has provided some insights into the evolution of the continents but much about the geological framework of the continental crust remains poorly understood. Yet the structure and evolution of the continents control the composition and distribution of our natural resources.

The task is to provide a sophisticated framework of crustal structure and evolution that may be used as a basis for natural resource exploration and evaluation. Fortunately, many innovative concepts and techniques are ready to be applied. Now is the time to take advantage of these new tools in combination with traditional geological and geophysical methods.

Two outstanding deficiencies that seriously impede the development of an accurate geological framework of the continental crust in Canada have been identified. These are the critical shortage of high-quality geochronological and other data in most regions of the Canadian Shield and the absence of precise information throughout most of the country on how the geology varies in the third dimension (depth). Two major activities are proposed, which will provide the necessary information that can lead to a substantially improved geological framework. Both would involve closely integrated multidisciplinary studies across important regional geological targets and both are designed to provide information on the deep crust.

The Canadian Shield. Less progress has been made in understanding the processes that have shaped the mineral rich Canadian Shield than in most geological regions of Canada. It is proposed, therefore, that a concerted effort be made to unravel the complex tectonic history of a few critical areas of the Shield, with emphasis on determining the boundaries of the ancient terrains and the processes that have shaped them. Some of the studies will follow the style of the highly successful investigation of the Wopmay Orogen in the Northwest Territories (Hoffman, 1980). There, plate tectonic concepts, together with a program of accurate radiometric age determinations, have guided geological mapping and interpretation (Fig. 9).

This activity will have two components. First, geophysical techniques will be used to determine the three-dimensional structure of the crust in the region of the Wopmay Orogen to test and refine the current model that is based on surface geological observations. Second, the systematic approach developed for the Wopmay study will be applied to other critical structures with a view to greatly improving our understanding of Precambrian tectonic processes.

Geology in the Third Dimension. The second activity is designed to determine accurately the three-dimensional structure and evolutionary history of key regional geological targets by conducting integrated multidisciplinary studies along a number of selected transects. The resultant geological models may then be used as a guide for resource exploration in the less accessible and inhospitable terrains of the landmass and adjacent offshore continental margins.

Priority will be placed on applying new deep probe methods, highlighted by the powerful seismic reflection techniques. In recent years, crustal Vibroseis (Trademark of the Continental Oil Corporation) reflection surveys across regional geological structures in the United States have produced some spectacular results. One notable example has lead to a radically new interpretation of the southern Appalachian mountain belt, and may have far-reaching implications for the general structure and evolution of the continental crust (Cook *et al.*, 1979). Evidence from the deep Vibroseis data (Fig. 10) suggests that the surface crystalline rocks have been thrust at least 250 km west of their original location to overlie younger sedimentary rocks that once covered an extensive area of the southern and central Appalachians. The existence of these younger sediments at depth was completely unexpected. Some U.S. geologists (Friedman and Reekman, 1980) have predicted that these sediments may be a viable target for hydrocarbon exploration and a recently discovered gas showing in the central Appalachians supports this hypothesis. Targets within Canada's young mountain belts also have this potential.

Seismic reflection techniques, complemented by modern seismic refraction and new electromagnetic methods, can now provide a high degree of resolution

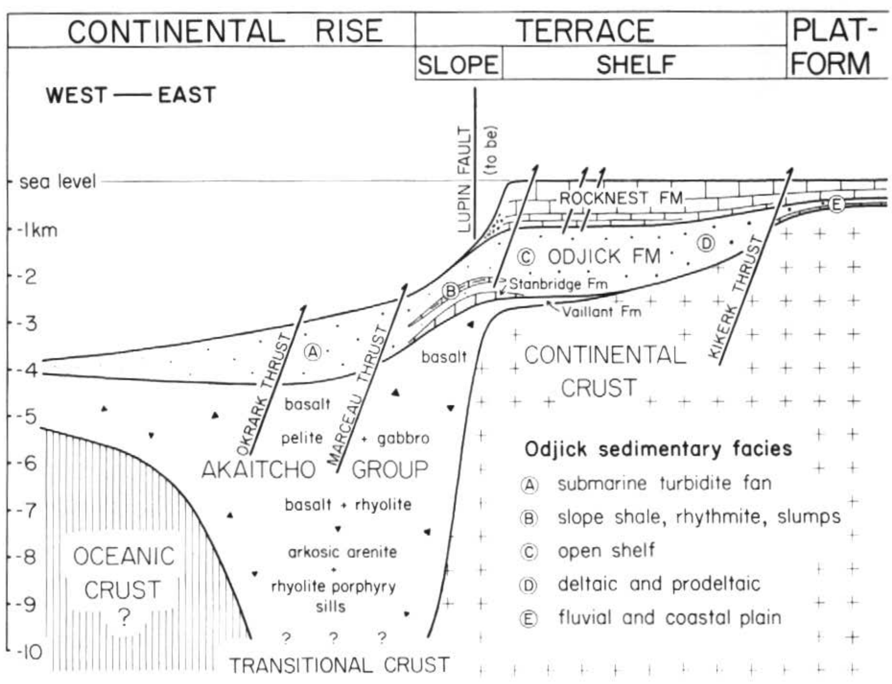

Figure 9 *Pre-orgenic reconstruction of the mature Wopmay continental margin, based on surface geological observations (Hoffman, 1980). The depth of the continental rise is drawn the same as in modern oceans. Subsequent to the opening of a wide ocean basin one or two subduction zones developed, resulting in the closing of the ocean basin and the eventual collision of two Precambrian continents. For further details see Hoffman (1980).*

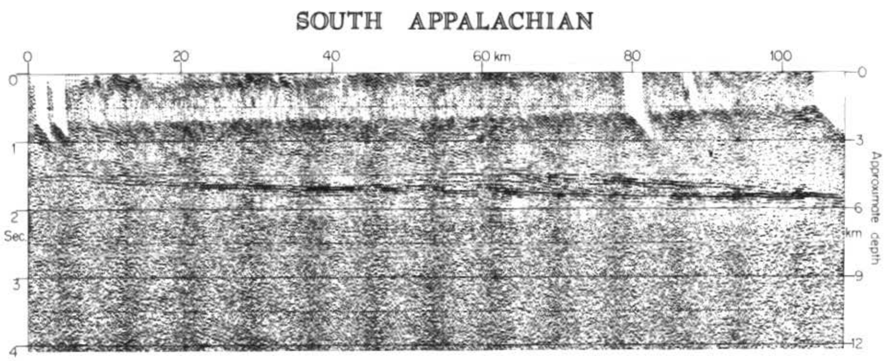

Figure 10 *Deep Vibroseis reflection section across the southern Appalachians. Shown beneath the highly metamorphosed Blue Ridge rocks are a series of laminated reflections dipping down from a depth of approximately 4½ km on the west to 5½ km on the east. To the west of this section the reflections have been correlated with the relatively unmetamorphosed sediments of the Valley and Ridge province and to the east they have been traced to the end of the seismic recording line to a maximum depth of approximately 18 km (Published with permission of J.E. Oliver, COCORP).*

from the near surface to depths in excess of 50 km. These new methods, in combination with traditional geological and geophysical techniques, have the potential for resolving the structures and evolutionary histories of many of Canada's complex geological terrains.

Conclusions

These new thrusts are considered of immediate major importance for extension or development of new systems in support of national needs. They are designed to enhance the geoscience information base so that effective solutions can be provided to perceived problems. These thrusts must be looked on only as a modest part of the total new needs for earth science activities in this country. The roles of each of the "estates" - government (provincial and federal), university and industry must be more clearly defined. Through mutual understanding and support a strong case can be made to our legislators and the public for the importance of our activities to the national well-being, and to alert them to the crisis that is already upon us.

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