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Article abstract

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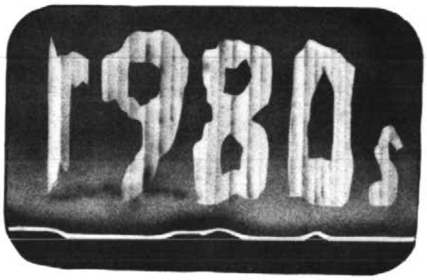

Arctic Research for the 1980s, an Exposé of Problems

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Summary
A recent survey of geoscientists working in Arctic Canada indicates that major research interest in the north is focused on the structure and development of the polar margin, early Paleozoic tectonics, sedimentary processes and the geodynamic history of the northern Yukon region. A summary of major Arctic geoscientific problems is presented here along with recommended future directions of study.

Introduction - Advances and Difficulties
Polar Canada contains a full range of geological settings that extend, north to south, from a deep-sea basin and a passive continental margin through one or more orogenic belts and successor basins to platform and cratonic rocks (Fig. 1). Over the past 10 years knowledge of these regions has advanced significantly on most fronts. The Canada Basin, for example, is now known to be floored by oceanic crust and covered by as much as 5 km of sediments (e.g., Mair and Lyons, 1981). The polar continental shelf appears to be composed of downfaulted blocks, partly early Paleozoic in age, that are unconformably covered by a seaward-thickening largely Tertiary clastic wedge (e.g., Meneley *et al.*, 1975). The identification and age of individual structural and thermal events have been outlined within the major early Paleozoic (Innuitian), Late Mesozoic (Columbian-Laramide) and Tertiary (Eurekan) orogenic episodes that affected the Canadian Arctic (Trettin *et al.*, 1972; Young *et al.*, 1976; Trettin and Balkwill, 1979). The more regional aspects of basin geodynamics, chiefly within the Mackenzie Delta-Beaufort Shelf complex and Sverdrup Basin, are beginning to be understood (Lerand, 1973; Sweeney, 1977; Balkwill, 1978).

Despite this progress, our understanding of the structure and development of the north remains primitive compared to what is known about more accessible areas in southern Canada. Much of the polar shelf and seafloor are virtually unexplored; the age and mode of origin of each has been the subject of much speculation. The thickness and distribution of sediments along the margin is poorly understood and the history of vertical motions related to margin development is largely unknown. Although well exposed on Ellesmere Island, the character and extent of the Innuitian orogen is not clear beneath the Sverdrup Basin and along the continental margin. The pattern of lithospheric plate motions that formed this mobile belt is still a mystery.

It is widely believed that the structural complexity of the northern Yukon and Beaufort Shelf zones is genetically related to events that opened Canada Basin. Beyond this there is little certainty. Eurekan tectonism in the northeastern Arctic Archipelago has been well described (e.g., Balkwill and Bustin, 1980) but a regional picture has not emerged to connect this activity with nearby contemporary events such as the opening of Baffin Bay or the origin of Makarov Basin.

It is obvious that a wide range of field and laboratory investigations can be undertaken to reduce our present ignorance in most areas of Arctic geoscience. The large number of research targets plus the expense and difficulty of Arctic work require that future projects be considered, first and foremost, on the basis of the greatest benefit to the largest number of disciplines. To determine what projects and which sites fall into this category, 103 industry, government and university groups were contacted by letter in the fall of 1980 and asked (a) to outline the main scientific problems facing them in the north and (b) to propose means of resolving these problems. A significant number, over a third, replied, an indication of the strong interest in the Arctic held by the Canadian earth science community. The results of this survey follow with emphasis placed on the problems most frequently mentioned and on the regions most often cited as places for study. Future study areas are proposed in a final recommendations section.

Problems for the 1980s - Survey Results
From many points of view, four subject areas stand out as research targets. They are the polar margin, the early Paleozoic, basin sediments and the northern Cordillera-northern Yukon region. Discussion of each of these subjects follows in order.

Polar Margin. Knowledge of the polar margin and adjacent zones is the concern of by far the largest number of Arctic workers. Much of this region has never been studied, even in reconnaissance fashion, largely because of the logistic difficulties involved. These problems are gradually being overcome with the introduction of advanced polar navigation and positioning aids, better aircraft and improved measuring techniques and instruments.

Interest in the continental boundary falls into two categories, margin structure and margin geodynamics. Structural studies include mapping the variations in sediment thickness along the shelf and slope and assessing the influence of basement structures on these variations. Of special importance is the identification of lateral changes in margin structure that may be associated with geophysical anomalies such as the apparent spatial correlation between thick deposits of Cenozoic clastics, contemporary margin seismicity and free-air gravity peaks (see Sobczak, 1985; Basham *et al.*, 1977).

Little is understood about structural relations at deep levels anywhere in the Arctic. Outside of the Mackenzie Delta area, boreholes to even moderate depths along the polar shelf would provide a first look at margin geology. Among the questions to be addressed by such a drilling program are sediment thickness and age distributions, history of margin vertical motions, pre-Aptian history of the Beaufort Shelf, thickness trends together with provenance and facies trends of upper Paleozoic rocks northwest of the Sverdrup Basin, and the location of the early Paleozoic continental margin. Borehole data combined with seismic results and more detailed knowledge of gravity, magnetic and induction fields can be used to identify major structural trends offshore, such as the possible extension of the Nares Strait lineament onto the Lincoln Shelf, the nature of the junction between the margin and the Alpha and Lomonosov ridges, and the continuation of the major onshore fault and aulacogen structures across the Beaufort Shelf.

Commercial interests are particularly interested in modern seabed conditions. Most important is knowledge of the degree and distribution of ice scour and the distribution and effects of bottom currents/seasonal variations on the thickness of permafrost in the offshore.

Knowledge of margin structure in any case is prerequisite to understanding margin geodynamics. Southwest of

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Alpha Ridge, margin development and the opening of Canada Basin share a common beginning. Studies conducted along the polar boundary may tell us what work in the deep basin has so far failed to reveal, namely, the time and manner of seafloor creation. Mapping the pattern of changes in structural style and complexity within basement rocks and bracketing in time the basement-cover hiatus across the polar shelf can tell us whether shearing or rifting was the dominant initiating event, whether the margin results from more than a single opening episode and, possibly, whether the adjacent landmass was separated by rotation rather than translation. The latter will require careful reading of the structural pattern, especially along the Beaufort Shelf and adjacent areas in the northern Yukon.

Early Paleozoic. Although tectonism in the north was most intense and widespread during Devonian and early Paleozoic time, it is not well understood in several respects because of the complexity and incompleteness of the preserved record. Studies to date have concentrated on the structural and depositional framework within exposed Innuitian terrains and compilation of integrated structural cross-sections has only just begun (H.P. Trettin, pers. commun., 1981). Improved age control and structural resolution to deeper crustal levels are needed to complement the mapping program.

One major uncertainty centres around the history of plate dynamics associated with the Innuitian orogen. Tentatively, it is suggested from paleomagnetic data (Morel and Irving, 1978) that the Siberian Shield approached the ancestral polar margin of the Laurentian Shield from the east during the early Paleozoic and that the intervening oceanic crust was probably eliminated during Devonian time. To date the question of the existence of displaced or accreted terrains within the Innuitian orogen has not been addressed by paleomagnetic work. On largely stratigraphic grounds, it is thought that exotic terrains, if present, are limited to pre-late Middle Ordovician metamorphic complexes on northernmost Ellesmere and Axel Heiberg islands (Trettin and Balkwill, 1979).

Geochemical and petrologic studies of plutonic and metamorphic rocks in northern Ellesmere and Axel Heiberg islands are needed to examine the nature of early Phranerozoic plate interactions along the ancestral active margin. Possibilities include subduction and lateral displacement of adjacent terrains. The latter may be indicated by the relative absence of intrusive and high-grade metamorphic assemblages exposed within the orogen, and possibly by the presence of lateral offsets subparallel with the polar margin. The faulting is of uncertain age and extent, however (H.P. Trettin, pers. commun., 1981).

Less tractable perhaps is the question of the extent and deformation style of early Paleozoic rocks associated with the largely buried Antler orogen in the northern Yukon-Beaufort Shelf area and westwards. How are these rocks related to contemporary Innuitian events in the Arctic Islands? Do these rocks represent an Innuitian terrain displaced southwestwards in mid-Paleozoic time from their initial orogenic site?

As previously mentioned, early Paleozoic rocks are buried beneath at least parts of the polar shelf and Sverdrup Basin. The role played by these rocks in the development of the present continental margin or in the evolution of the sedimentary basin can only be speculated upon at this point. What is needed is

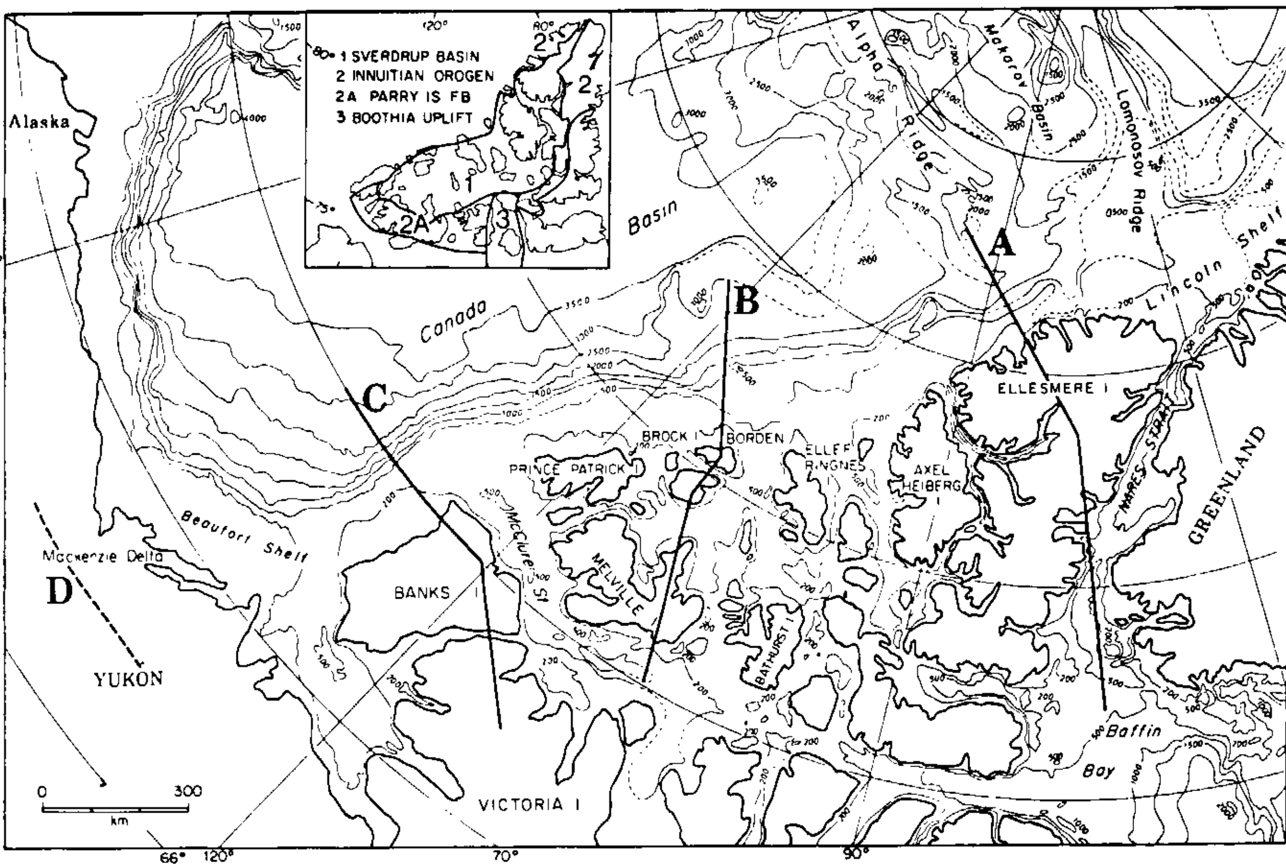

Figure 1 *Arctic place names and major geologic provinces. Centrelines of proposed geoscientific research corridors are indicated.*

deep drilling and the application of improved techniques for deep seismic resolution to delineate basement structures and facies relationships in each of these regions.

Deformed Devonian clastic sediments border the Sverdrup Basin along its south and east sides. Although the gross geometry and provenance of this syntectonic deposit are documented (e.g., Embry and Klovan, 1976), patterns of sediment transport and distribution of structures within Devonian rocks throughout the Arctic generally are not well defined. Understanding the processes that initiated the Sverdrup Basin depend to a large degree on detailed knowledge of these final aspects in the development of the Innuition orogen.

Basin Sediments. Interest in northern basins is focused on shelf deposits, particularly in the Mackenzie Delta zone, on sequences within the Sverdrup Basin and on sediment accumulations at the north end of Baffin Bay. Broadly speaking, what is sought is more precise knowledge of the processes that affect sediments during and after their deposition. To date, conceptual models of basin evolution have dealt mainly with long term regional components such as the isostatic response of the lithosphere to sediment loading. New studies should be geared toward achieving conceptual advances in two major areas: one, the role of tectonism in basin initiation, development and rejuvenation and, two, the role of fluids within basin sediments.

Tectonic influences can be divided into internal factors (processes that normally occur within a basin during the course of its development) and external factors. The former includes the distribution both in space and in time of igneous activity, diapirism, burial metamorphism and sediment compaction and their effects on basin structure and overall basin geometry. External factors deal with the relation of interplate or intraplate tectonics to basin evolution. That is, what are the connections between horizontal and vertical plate motions? For instance, are changes in seafloor spreading rates coupled in any way to changes in basin subsidence rates.

The second major thrust is to understand the internal structure of basins in terms of migration patterns and the driving forces behind fluid transfer within the stratigraphic column. What is the role of artesian effects, compaction, structure, facies changes and chemical precipitation in both long term (mainly hydrocarbon) and short term (mainly water solutions) fluid migration?

The present data base is clearly not adequate to answer these questions in detail. Greater knowledge of the pattern and distribution of basin subsidence rates, structures and thermal history is needed, especially at intermediate and deep levels and in areas offshore. First in this regard, improved age control is vital for calibration of subsidence rates and proper location of tectonic disturbances in time and also for paleogeographic purposes including facies correlations and paleocurrent studies. Accordingly, in future basin studies, emphasis should be placed on paleontological analysis and isotope dating techniques for age control on sedimentary and igneous rocks respectively. This need goes hand in hand with correlative studies of stratigraphic thickness, regional analysis of stratigraphic/structural relations and more specific problems such as the location of carbonate reef edges. A key item is better identification of regional gaps in the stratigraphic record, in space as well as in time.

Northern Cordillera - Yukon region. The mainland south and east of the Beaufort Sea is one of the most structurally complicated regions in polar Canada. It is also one of the most important from both a resource and a scientific point of view. The structural character of the region was acquired mainly during Late Jurassic to early Tertiary time but the mechanics of the orogenic events responsible are not well understood. Because the time and especially the mode of origin of Canada Basin have probably been recorded by the deformations within this belt, it is important to decipher the structural geometry of the region as well as the driving forces responsible for its development including connections, not well established, between events here and contemporary tectonism in the nearby Cordillera.

Reconnaissance mapping in the northern Yukon-northwestern District of Mackenzie, now essentially completed, has delineated the major surface structures of the region. The next step is to look inside the earth and define the major penetrative features within this zone. For instance, are there major through-going fault systems or fracture zones that extend from polar Alaska across the northern Yukon and Beaufort shelf as suggested by Yorath and Norris (1975); does the structural complexity of the region decrease with depth; what role have thermal events played in the tectonic evolution of the region?

Improved seismic resolution, especially at deeper crustal levels, offers the best means for addressing most of these problems. Gravity, magnetic and induction studies can also be useful provided that tectonic activity generated displacements in density and magnetic susceptibility structure and gave rise to conductivity anomalies.

Recommendations

As can be seen, the four categories have many common points. The overall goals are better understanding of the geodynamic history of the Arctic as a region, improved control in placing north polar tectonic development in a global context and moving toward these ends by extending geoscientific knowledge of the north to deeper crustal levels on both a local and a regional scale. Following the dictum of finite resources and the principle of the greatest benefit to the largest number of disciplines, the recommended way to proceed is to collect new data in several parameters along common corridors that traverse the features of interest so that maximum constraints can be brought to bear on the modelling and interpretation of the resulting data. Four corridor lines are proposed and their rationale is outlined below.

The polar margin is divided into three parts: the structurally complicated Beaufort Shelf from the Alaska border to McClure Strait, the poorly mapped segment known from reconnaissance geophysical measurements that faces Canada Basin northwest of Sverdrup Basin, and the virtually unexplored margin that adjoins the Arctic submarine ridges between Axel Heiberg Island and the Lincoln Shelf. Proposed corridor lines are arranged so that each margin segment is traversed (Figure 1).

Baffin - Ellesmere - Alpha corridor (Line A). This line is routed to transverse the polar margin and its junction with the Alpha Ridge and, in the south, to cross the Nares Strait lineament and the zone of thick sediments at the head of Baffin Bay. Very little is known about sediment age, sediment thickness, structure or basement rocks in either of these areas.

The main feature of this line, however, is its complete traverse of the exposed Innuitian orogen from Precambrian basement in the south to Precambrian rocks along the north coast of Ellesmere Island. The importance of early Paleozoic events within this belt to later developments such as the initiation of the Sverdrup Basin and the siting of the present polar margin are given in the preceding section.

Melville - Borden - Canada Basin corridor (Line B). This line traverses deformed Devonian rocks of the Parry Islands Fold Belt and also crosses the Sverdrup Basin, its northwest rim and the polar margin into the abyssal basin. The route chosen includes minimum stretches across inter-island channels and crosses the Parry Islands section completely. The Sverdrup Basin section is less thick and structurally less complicated here than it is further east. Basin facies relations and basement structure should therefore be easier to delineate along this profile.

One problem is that Eurekan structures do not extend as far west as Line B and therefore cannot be studied along this traverse. However, Tertiary deformations are included in a section across Bathurst and Ellef Ringness islands which is presently the subject of multidisciplinary interpretation as part of the North American Continent-Ocean Transects Program.

Victoria - Banks - Beaufort Sea corridor (Line C). The main interest along this line is to examine Beaufort margin/Banks Island structure and basement-cover relations away from the masking effect of the thick Mackenzie Delta sediment cone. The position of the line offshore is arbitrary and instead might well be a series of ship traverses along the entire Banks Island segment, ice conditions permitting. These results, when compared with margin studies already completed north of Alaska (Grantz *et al.*, 1979) and proposed margin work along line B, should zero in on the time and, with luck, the mode of origin of Canada Basin. The profile is extended landward to Proterozoic rocks on Victoria Island to allow a closer look at undeformed Devonian and older Paleozoic rocks that lie between the Innuitian and Antler orogens (e.g., Miall, 1976).

Mackenzie - Yukon corridor (Line D). The profile is drawn normal to the north-northeast trending complex of uplifts and (mainly right lateral) offsets that lead into the Mackenzie Delta region. Because knowledge of the deep structure here is critical, the precise route chosen will depend on logistic requirements, particularly those related to seismic experiments. Line D is therefore dashed indicating that adjustments in its position may be desirable. The profile is located away from the coast to avoid the thicker stratigraphic successions there and it extends to the southeast across the disrupted section and onto the relatively undeformed foreland succession of the Northern Interior Platform.

The most desirable corridor transects are centred along lines A and B as both cross several key features. Line B is favored as it crosses a Devonian foldbelt, a major sedimentary basin and the polar margin, three of the four overall subject areas of interest. Terrain along line B is also more amenable to profiling than are the areas of high relief found along much of line A.

In addition to the reasons given earlier for routing line B, the shelf portion of the profile is well located away from the disturbing influence of both the Mackenzie Delta sediment cone and the polar margin junction with the Alpha Ridge. The chances of clearly relating margin history to the origin of Canada Basin should therefore be best along this part of the continental boundary.

The margin portion of the profile is the first priority and offshore measurements are most effectively carried out from a CESAR-style (Weber *et al.*, 1981) camp. Studies along this segment should include bathymetry, gravity, marine geology, shallow and intermediate reflection seismic, geothermal studies, crustal refraction seismic, magnetic studies, including magnetotelluric and induction methods, and oceanographic experiments. Personnel and cost estimates including logistical support for these programs are based on projections for the CESAR 1983 Alpha Ridge expedition and are about 1400 person days and $1.7 million respectively.

Onshore programs along line B should include detailed refraction profiling with complementary reflection studies in key but limited areas. Detailed gravity (1 km spacing) and selected magnetic studies should be included along with paleomagnetic, heat flow, geochronologic and structure-facies studies where feasible.

Costs for studies along the onshore segment of line B depend mainly on the magnitude of the seismic programs. Minimum expenses are estimated at one million dollars and as much as four million dollars could be spent if extensive reflection/refraction profiling were carried out.

Deep drilling, onshore or offshore, is enormously expensive (between $12 and $22 million in 1980 dollars, D.C. Waylett, written commun., 1981) and is not presently cost effective in terms of the scientific returns provided. Interest in the hydrocarbon potential of the polar shelf is steadily increasing, however, and it is anticipated that this will lead to test drilling along the margin by exploration groups within the next decade. Our best chance to obtain "ground truth" core samples and geological measurements in the offshore probably lies in our ability to advocate and plan, with close cooperation and support from commercial interests, a joint geoscience - resource exploratory drilling program on the polar shelf.

Finally, there is a widely perceived need for more logistic support of Arctic research activities and for better communication among Arctic workers. The extensive support network required for polar operations has, in particular, limited the role of universities in northern field projects. Canada's present leadership in polar research will be maintained only by continuing to mount adequately funded, well conceived and efficiently conducted programs. Towards this end, an effort needs to be made by both industry and government groups to encourage increased university involvement in the planning and execution of future large-budget research projects in the north. The universities themselves have the potential to play a leading role in Arctic research in their own right by emphasizing interdepartmental-interuniversity coordination and planning. Organizations such as the Polar Continental Shelf Project or the Association of Canadian Universities for Northern Studies may be good places to start.

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