GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2789

Mineral Resource Assessment of the Neoproterozoic Franklin Igneous Events of Arctic Canada: Comparison with the Permo-Triassic Noril'sk-Talnakh Ni-Cu-PGE Deposits of Russia

C.W. Jefferson, L.J. Hulbert, R.H. Rainbird, G.E.M. Hall, D.C. Grégoire, L.I. Grinenko

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Mineral Resource Assessment of the Neoproterozoic Franklin Igneous Events of Arctic Canada: Comparison with the Permo-Triassic Noril'sk - Talnakh Ni-Cu-PGE Deposits of Russia[2]

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April, 1994

[1] Although this report has received cursory proof reading from its authors and from reviewers on selected portions, it has not been fully refereed and has not undergone the customary Geological Survey of Canada editorial process for formal publications. This release is for the purpose of public review; any comments received by the first author and/or MERA committees (see INTRODUCTION) will be considered as part of the MERA process.

[2] Contribution to Canada-Northwest Territories Minerals Initiatives 1991-1996, and to the MERA process, jointly funded by Indian Affairs and Northern Development, Parks Canada and Geological Survey of Canada.

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EXECUTIVE SUMMARY

This report responds to critical reviews of a low-to-moderate assessment rating in Open File 2434 (Jones et al., 1992) for the Brock Inlier Domain of the proposed Tuktut Nogait National Park area (Bluenose Study Area), and to new scientific knowledge regarding the gabbro-dolerite-associated nickel (Ni) - copper (Cu) - platinum-group-element (PGE) deposit type. The 1992 assessment was based on scant data with moderate **uncertainty**. In this report we present evidence for the **same low-to-moderate rating** in most of the **Bluenose study area**, but with moderate **certainty**. A *moderate-to-high rating* is assigned to the *Darnley Bay gravity and magnetic anomaly*, which underlies an irregular area around Paulatuk and the lower Hornaday River (Fig. 1). A high rating is also assigned to the Minto Inlier of northern Victoria Island (Figs. 2, 3). Other ratings in Open File 2434 remain unchanged. The remainder of this summary explains these new ratings in non-technical to technical terms.

Comprehensive new data were collected for both the park study area and the western Arctic region, which provides context for the park study. The specific rocks which were investigated for Ni, Cu and PGE are called gabbro-dolerites of the Neoproterozoic Franklin Events. The gabbro-dolerites form black layers which are generally vertical (dykes) or horizontal (sills) and range from a few to tens of metres thick. At about 723 to 718 Ma (1 Ma = 1 million years ago) these gabbro-dolerites were injected as hot liquids (magmas) from the earth's mantle into sedimentary rocks of the Shaler Supergroup, which had been deposited in a broad shallow sea termed the Amundsen Basin. The magmas injected their way upward through the sedimentary rocks, partly melting and incorporating some of them. The magmas then broke through the surface to erupt several kilometres of dark volcanic rocks (basalts), called the Natkusiak Formation, which probably covered thousands of hectares but is now found only in Minto Inlier.

The area of Minto Inlier was close to a source of the Franklin magmas, because here we found evidence that the earth's crust was swelling before the eruption of the lavas. Here also are preserved the greatest number, thicknesses, sulfide contents and compositional range of sills; the largest faults; and the only explosive breccias made by the Franklin eruptions. The magmas in the upper sills were changed by the addition of sulfur, selenium and other elements from the sedimentary rocks. Depleted Ni, Cu and PGE in the same sills suggests that these metals combined with sulfur and sank from the magmas like water droplets sink through oil. These "fingerprints" of the ore-forming process indicate that Ni-Cu-PGE deposits may occur in northern Victoria Island.

The lower Shaler Supergroup and sills are present in the Bluenose area, on southern Banks Island and around Coppermine. However, sills in these areas are thinner, fewer and lack the chemical and physical "fingerprints" of the ore-forming process. Ni-Cu-PGE deposits may have been created here in the upper sills but probably were uplifted and eroded, 723 to 550 Ma ago.

The above geological history and resource assessments were deduced by comparing recently published information on the Russian Noril'sk-Talnakh Ni-Cu-PGE deposits, with detailed 1993 maps, new microscopic analyses, and precise sulfur, whole rock, trace-element and PGE analyses of >350 samples of the Franklin gabbro-dolerite sills and dykes in the Amundsen Basin. Similarities include:

1) Carbon- and sulfur-rich strata hosting the sills,
2) Continental platform with syn-magmatic faults,
3) Sills strongly differentiated (ultramafic to granitoid), with common plagioclase - olivine cumulates.
4) Spatially associated large intrusions inferred from gravity and magnetic anomalies.
5) Thick continental basalts with early and late olivine,
6) Irregular and very large gabbro-dolerite bodies feeding into sills with 10 m-wide thermal alteration aureoles,
7) Contamination of sills with crustal materials recorded by heavy sulfur isotopes ($\delta^{34}S$ up to +20‰), and high sulfur (S), selenium (Se) and arsenic (As).
8) Depletion of Ni, Cu and PGE in upper sills,
9) Contact skarns with up to 470 ppb palladium + platinum and >10 m-wide alteration effects.

Similarities 1) to 4) apply to the entire Amundsen Basin, but 5) to 9) are lesser to absent in the Bluenose and Coppermine areas, which appear to be more distant from the magmatic centre of the Franklin Events. Further structural-stratigraphic mapping, petrochemical studies (e.g. sulfur isotopes), surficial geochemical, and airborne / satellite spectral to geophysical surveys are recommended for exploration. Noril'sk-Talnakh-type deposits are very high grade, small exploration targets that, if discovered in Minto Inlier, could make a significant contribution to northern development. INCO has applied modern technology to derive metals from such deposits, benefiting society with minor impact on the environment (CIM, 1992).

A large dense, completely buried mafic intrusion is inferred from the Darnley Bay gravity and aeromagnetic anomalies northwest of Brock Inlier. This intrusion may also contain Ni-Cu-PGE, but the thin and sparse nature of Franklin sills and dykes in the adjacent Brock Inlier suggest that they came from a distal source, unrelated to the Darnley Bay intrusion. It is thus interpreted as an intrusive component of the ~1270 Ma Mackenzie Event. Seismic data over the anomaly can be interpreted in two ways - one that it is buried by more than 7 km of Neoproterozoic (1000 to 500 Ma) and Phanerozoic (bearing abundant fossils) strata; the other that it is within 2 km (1.2 miles) of the surface. Gravity and aeromagnetic data have been interpreted to give a specific amoeboid shape and a density of 2.995 g/cc with a 3.095 core, assuming a 3 km depth. Slightly greater but still reasonable densities have been modelled assuming a 7 km depth.

Deep electromagnetic and seismic profiles from Darnley Bay to the exposed strata of Brock Inlier are required to define the depth of the inferred mafic body, to resolve its possible linkages with the 723 Ma Franklin event, a 779 Ma event or the ~1270 Ma Mackenzie event, and to Proterozoic deformation under the northern part of Western Canada Sedimentary Basin.

The body of this report summarizes the Mineral and Energy Resource Assessment (MERA) process, the field and laboratory results, and interpretations. This information is for public review as part of the national park establishment process (see title page).

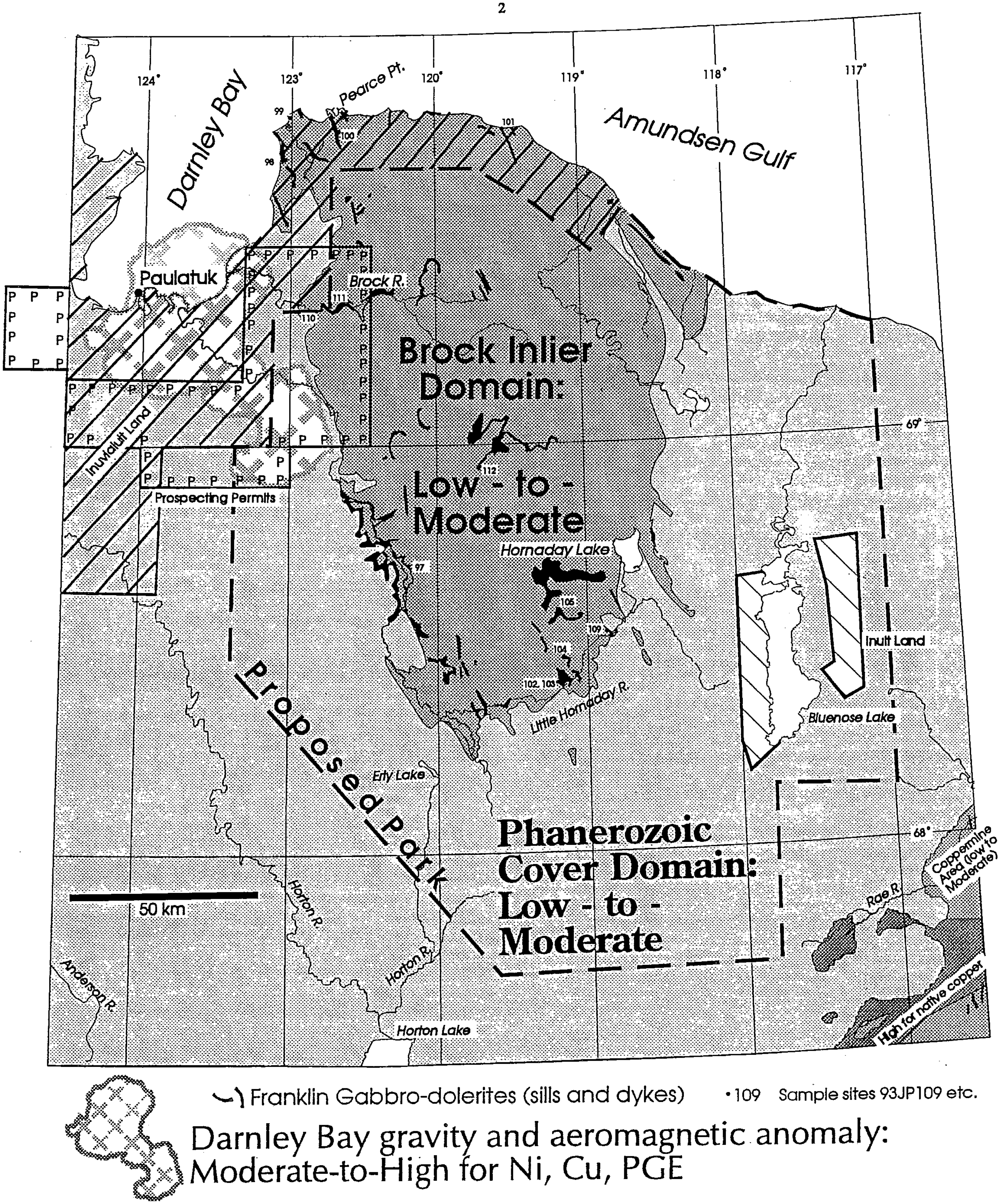


Figure 1. Nickel (Ni) - copper (Cu) - platinum-group element (PGE) potential of the study area for the proposed Tuktut Nogait National Park. Assessment domains are explained in text and ratings in Tables 1 and 2. Further explanation of the Darnley Bay anomalies and details of the geology in Brock Inlier are provided in text and in Figs. 9, 10 and 11. Locations of exploration permits, Inuvialuit and Inuit lands are approximate, shown only for illustrative purposes.

Table 1. History of MERA ratings by selected resource assessment domain in Western Arctic Canada. Each group of numbers gives the assessments as explained in Table 2, according to sources in the following order: Geological Survey of Canada (1980)[1] / Jefferson et al. (1988) / Jones et al. (1992) and / **this report (only for Ni-Cu-PGE-Au)**. Locations of areas are shown in Figs. 1 and 3.

Deposit Type[2]	Bluenose Area, Brock Inlier	Bluenose Area, Phanerozoic Cover	Bluenose Area, Darnley Anomaly	Coppermine - Duke of York Paleoprot.	Victoria Is., Minto Inlier
Ni,Cu,PGE,Au (Gabbro) (12.2)	6 / n / 5 / 5	n / n / 7 / 7	n / n / 5 / 3[3]	n / n / 5 / 4	5 / 5 / n / 2
Ag, U (Arsenide Vein) (22)	n / n / 5	n / n / 7	n / n / 7	n / n / 5	5 / 3 / n
Au (Carlin Type) (8.1)	n / n / 5	n / n / 6	n / n / 7	7 / n / 6	n / n / n
Cu (Kupferschiefer) (6.3a)	6 / n / 5	6 / n / 6	6 / n / 7	n / n / 5	n / 2 / n
Cu (Red Bed) (6.3b)	6 / n / 5	6 / n / 5	6 / n / 7	n / n / 2	n / 2 / n
Cu (Volcanic Redbed) (10)	7 / n / 7	7 / n / 7	7 / n / 7	n / 6 / 2	6 / 2 / n
Fe (Sedimentary) (2)	7 / n / 6	n / n / 7	n / n / 7	n / n / 6	n / 6 / n
Salt & Gypsum (1)	n / n / 2	n / n / 2	n / n / 2	n / n / 7	n / n / n
Phosphate (Strata) (4)	n / n / 6	n / n / 7	n / n / 7	n / n / 6	n / 4 / n
Pb, Zn (Mississippi) (6.1)	7 / n / 5	6 / n / 5	6 / n / 5	n / n / 5	6 / 3 / n
Pb, Zn (Sedex) (9.2)	7 / n / 6	n / n / 7	n / n / 7	n / n / 7	n / n / n
U (Sandstone) (6.4)	6 / n / 6	4 / n / 5	4 / n / 5	n / n / 5	6 / 4 / n
U (Unconformity) (21)	7 / n / 6	n / n / 6	n / n / 6	n / n / 6	n / n / n
Carving Stone	n / n / 4	n / n / 7	n / n / 7	n / n / 4	n / n / n
Aggregate	n / n / 7	n / n / 7	n / n / 7	n / n / 7	n / n / n
Coal	n / n / 7	n / n / 7	n / n / 2	n / n / 7	n / n / n
Oil, Gas	7 / n / 7	6 / n / 5	6 / n / 5	7 / n / 7	7 / n / n

[1] The ratings for the 1980 (their Table 4 and Appendix 3) assessment were done by commodity.
- Subjective judgement was used by the first author of this report to convert the commodities to deposit types.
- The rating table used in the 1980 assessments had only 5 categories with some blending.
- The 1980 ratings were converted to the present system as follows: VH=1, H=2, M-H=3, M=4, L-M=5, L=6, N-L=6, N=7.
[2] Numbers in brackets refer to identification numbers used in Eckstrand (1984).
[3] Depth of body is unknown; about 2 km or more.

Table 2. Explanation of rating categories for mineral, hydrocarbon potential (after Scoates et al., 1986). For mineral potential, the rating is based on the application of mineral deposit types (models, analogues; e.g. Eckstrand, 1984) to the geological setting.

Symbol	Potential	Criteria
1	Very High	- Geological environment is very favourable. - Significant deposits/accumulations[1] are known. - Presence of undiscovered deposits/accumulations is very likely.
2	High	- Geological environment is very favourable. Occurrences[2] are often present but significant deposits/accumulations may not be known to be present. - Presence of undiscovered deposits/accumulations is likely.
3	Moderate to high	- Intermediate between moderate and high potential - Reflects greater uncertainty[3].
4	Moderate	- Geological environment is favourable, occurrences may or may not be known. - Presence of undiscovered deposits/accumulations is possible.
5	Low to moderate	- Intermediate between low and moderate potential. - Reflects greater uncertainty[3].
6	Low	- Some aspects of the geological environment may be favourable but are limited in extent. - Few, if any, occurrences are known. - Low probability that undiscovered deposits/accumulations are present.
7	Very low	- Geological environment is unfavourable. - No occurrences are known. - Very low probability that undiscovered deposits/accumulations are present.
n	Not Assessed	- Deposit type unknown, overlooked, beyond the scope of the assessment, or not worth mentioning at the time the assessment was done (could be a high rating in the future).

1 "Deposit/accumulation" is a mineral or energy resource of a size that is conceivably developable.

2 "Occurrence" refers to a mineral or energy resource of a size that is noticeable; may or may not include part of a hidden deposit/accumulation (e.g. sulfide showings, trace hydrocarbon seeps or stains in wells).

3 "Uncertainty" results from insufficient data.

INTRODUCTION

Mineral and Energy Resource Assessment (MERA) Terms of Reference and Acronyms

The Mineral and Energy[1] Resource Assessment (MERA) process in northern Canada has been described by Sangster (1983), Scoates et al. (1986) and continues to evolve (Jefferson 1992). The purposes of MERA are:

(1) to ensure that the economic and strategic significance of mineral and energy resource potential is duly considered in the national park establishment process in the Yukon and N.W.T.;

(2) to ensure that, in making recommendations regarding the withdrawal of land for parks purposes, the Minister of Indian Affairs and Northern Development (DIAND) is advised on the balance between the values of the land with respect to park establishment criteria and the potential for the exploration, development and use of mineral and energy resources which may inhere in the land;

(3) to prepare an assessment of the mineral and energy resource potential of areas in the Yukon and N.W.T. which are being considered for administration as national parks.

Purposes (1) and (2) are met by the Senior MERA Committee: Assistant Deputy Ministers or Deputy Ministers of:

° Northern Affairs, DIAND (Chair)
° Parks Canada, Department of Heritage
° Mining Sector, Natural Resources Canada (NRCan)
° Geological Survey of Canada (GSC), NRCan
° Appropriate agency, Yukon Government
° Appropriate agency, N.W.T. Government (GNWT).

A parallel MERA Working Group, comprising officers of the same agencies, is directed by the Senior MERA Committee.

This Open File was prepared to fulfil purpose (3) above. The park establishment process includes on-going public and internal government consultations at local, community, territorial and national levels. MERA results herein will contribute to the public information base for consultations on the proposed Tuktut Nogait national park. Criticisms and additional information are welcomed by the authors and MERA committees.

MERA History, Northwestern Arctic Canada and Status of Tuktut Nogait National Park Proposal (Bluenose Study Area)

In 1978, GSC Open File 492 was released to provide mineral and energy resource information for assistance to those negotiating the Inuvialuit land settlement in the westen Arctic. A variety of commodities were assessed as summarized in Table 2. Among them, the potential for Ni-Cu in the Franklin gabbro-dolerites (Fig. 2) was rated as low-to-moderate.

Jefferson et al. (1988) conducted a more focussed assessment of Banks Island and northwestern Victoria Island (summarized in Table 2) to provide more detailed information for those negotiating Aulavik National Park which was established on Northern Banks Island in 1993. Open File 1695 (Jefferson et al., 1988) assigned a rating of low-to-moderate to the nickel-copper-platinum potential of Paleoproterozoic rocks at Cape Lambton (southern Banks Island) and in the western part of Minto Inlier (northern Victoria Island) (Fig. 3).

The Brock Inlier is the core of the proposed Tuktut Nogait National Park (Figure 1), hereafter referred to as the Bluenose Study Area. As part of the MERA process (see above) Jones et al. (1992) prepared and released an assessment as Open File 2434 for public review. Among a variety of ratings for 18 different deposit types (Table 2), the potential for the gabbroid associated Ni-Cu-PGE-Au deposit type was rated as low-to-moderate (5 on a 1-7 scale, Table 1).

Since the release of Open File 2434, public consultation, peer review, new geophysical surveys (McGrath et al., 1993) and English language synopses of Russian data, for example the Sudbury-Noril'sk Symposium held in the fall of 1992, Lightfoot et al. (1990, 1993) and Naldrett et al. (1992), have provided new data and ideas. Concern has been expressed in letters by the NWT Chamber of Mines and a number of exploration companies about the low Cu-Ni-PGE-Au rating. This Open File, in response to that concern, is a continuation of the MERA process and serves as an update to Open Files 1695 and 2434. These ratings and public responses to them will be considered by the Senior MERA Committee at its next deliberations on the Bluenose study area.

[1]In this report the term "energy" refers to non-renewable energy. Renewable energy is dealt with on a case-by case basis by the Senior MERA Committee.

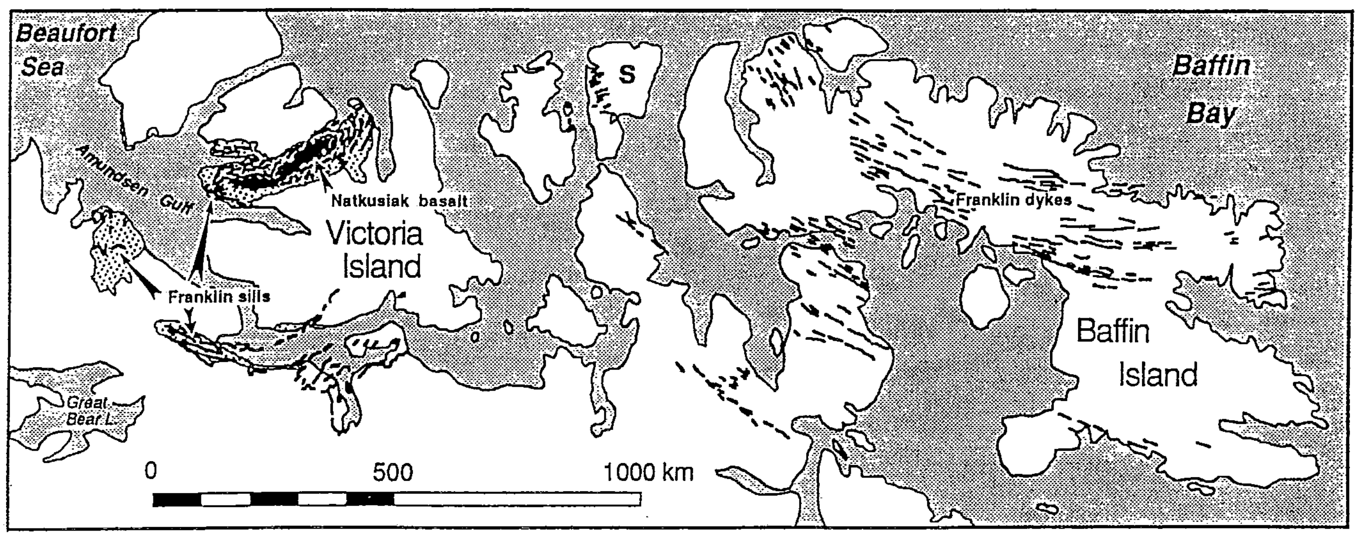


Figure 2. Regional extent of the Franklin Events (after Heaman et al., 1992).

Method 1 - Applying the Noril'sk Model

The rocks investigated for Ni, Cu and PGE have been called gabbros (coarse granular texture) and diabases (criss-cross medium to fine texture) of the Franklin Events (Fahrig et al., 1971; Heaman et al., 1992). More recently (e.g. Lightfoot et al., 1991) the term gabbro-dolerite has been used for the whole range of such rocks and is used in this report. The gabbro-dolerites form black layers of generally vertical (dykes) or horizontal (sills) attitudes, ranging from a few to tens of metres thick. At about 723 to 718 MA these gabbro-dolerites were injected as hot liquids (magmas) from the earth's mantle into a broad area of the Canadian Shield from northern Baffin Island to the western Arctic islands (Fig. 2). The host rocks for sills in the western Arctic are sedimentary rocks of the Shaler Supergroup, which had been deposited just before the Franklin Events (Rainbird, 1993) in a broad shallow sea termed the Amundsen Basin (Fig. 3; see **Resource Assessment Domains** below). The magmas were injected upward through the sedimentary rocks, broke through to the earth's surface and erupted several kilometres of dark volcanic rocks, called the Natkusiak basalts, which probably covered thousands of hectares but are now preserved only in the core of Minto Inlier. The thicknesses of gabbro-dolerites, host Neoproterozoic strata and basalts are shown to scale in Fig. 4.

The above geological setting, except the basalts, is recognized in the Bluenose study area (Jones et al. 1992; Rainbird et al., 1994a) and is similar to that of the Russian Noril'sk-Talnakh Ni-Cu-PGE deposits (e.g. Naldrett et al., 1992). Several industry and government geologists who reviewed Jones et al. (1992) felt that this analogy had not been adequately tested. Noril'sk-Talnakh-type deposits are very high grade, small exploration targets that, if discovered in Minto Inlier, could make a significant contribution to northern development. INCO has developed new technology to cleanly derive metals from similar deposits in Sudbury, benefiting society with far less impact on the environment than in the past (CIM, 1992). Therefore the present study was designed to comprehesively test the Noril'sk analogy by doing field work over the entire area where the Franklin magmas intruded Amundsen Basin.

Fieldwork began with mapping and sampling of northeastern Minto Inlier from June 25 to July 14, continued around Coppermine from July 15 to 21, and concluded in Brock Inlier from July 22 to July 27. In each area, sills were selected from the complete range of exposed stratigraphy. The freshest possible samples were taken at 10 m intervals and additional samples taken at lithologic boundaries. In August, emphasis was placed on preparation of the unexpectedly large number of samples. Proper assessment to improve confidence levels required high-quality whole rock and selected trace element analyses provided by a combination of laboratories at GSC, and commercial laboratories with proven results. All batches of analyses included international standards (CANMET TDB1) for control.

More than 350 samples were cut, sand blasted (to remove surface impurities) and selected portions pulverized for chemical analyses. Thin and/or polished sections were made of every sample. Pulverized portions were split into unbiased aliquots for different laboratories. Analyses were distributed as follows: sulfur and sulfur isotopes of all gabbro-dolerites and some sedimentary rocks at the University of Calgary, Pt, Pd, Rh, Au by Acme Analytical Laboratories in Vancouver, whole rock and a variety of trace elments at the Geological Survey of Canada in Ottawa, and other sulfur isotopes by K. Telmer at the Ottawa-Carleton Stable Isotope Facility at the University of Ottawa.

Method 2 - Applying the Sudbury Model

A large dense mafic body, inferred from the Darnley Bay gravity anomaly and coincident aeromagnetic anomaly (McGrath et al., 1993) on the western margin of Brock Inlier (Fig. 3), has been inferred for decades but is buried by an uncertain thickness of flat lying sedimentary rocks which give no obvious indication of what lies beneath. This body could not be sampled without deep drilling, but the history of geophysical interpretations was compiled and interpreted in light of the surrounding exposed geology. A new detailed gravity survey and a recompiled aeromagnetic survey (Geophysics Division, 1992) were completed after Jones et al. (1992) prepared their report. McGrath et al. (1993) and McGrath (pers comm., 1994) have modelled these data using 3 and 7 km depths of the body.

For this resource assessment, the geophysical models are compared on a very simple basis - size and density - with other large, mineralized, exposed mafic to ultramafic igneous bodies such as the nearby Muskox intrusion (Fig. 3) (e.g. Hulbert, 1992), the Au + PGE - bearing Skaergaard intrusion of Greenland (Brooks et al., 1991), the Jinchuan intrusion (Gang Chai and Naldrett, 1992a; b) and the Sudbury irruptive (Pye et al., 1984). All of these, as known, are tabular bodies, either sub-horizontal (lopoliths) or steeply dipping (dykes). In addition, the Sudbury structure has a large gravity anomaly, suggesting the presence of a larger dense body beneath the mineralized layer.

Linkages of MERA and NWT Geoscience Initiatives

MERA fieldwork by C.W.J. and L.J.H. was integrated with NWT Geoscience Initiative (NWT GI) mapping by R.H.R. in 1993, in order to enhance the logistics and scientific breadth of both projects and conduct both detailed and regional studies of the Proterozoic Franklin Events (Fig. 2) in Amundsen Basin (Fig. 3). The NWT GI project was broadened to incude Ni-Cu-PGE because of its apparent prospectivity in Minto Inlier, and the requirement of R.H.R.'s ongoing mapping project to examine all aspects of mineral potential in northeastern Minto Inlier.

Confidence in This Assessment

Previous assessments were based either on literature compilations with no specific field work and few samples (Geological Survey of Canada, 1980) or on limited reconnaissance field and laboratory studies (Jefferson et al., 1988; Jones et al., 1992) during which the Ni-Cu-PGE deposit type was given equal attention with a large number of other deposit types. Special attention was paid in these previous studies only to those deposit types which appeared to be prospective based on exposures seen by the authors and/or based on literature and exploration interest.

In the case of the Ni-Cu-PGE deposit type; no large exploration projects had yet been undertaken; the authors were aware that a number of exploration geologists had examined the gabbro-dolerites in the field but there was no evidence of staking; and all sills reported in the literature and/or examined in the field by the authors appeared to be relatively uniform and unmineralized. Thus, only a limited number of representative samples were taken of the gabbro-dolerites, and a limited number of analyses performed.

Because the industry concerns about the assessments by Jones et al. (1992) were provided in writing, it was clear to the Senior MERA Committee that the Ni-Cu-PGE issue was of more than academic interest, therefore additional resources were directed to specific study of the Ni-Cu-PGE potential. A team of GSC scientists was assembled with expertise covering all of the factors in this deposit type: regional stratigraphic and tectonic setting (CWJ and RHR), mafic-ultramafic suites and the Noril'sk-Talnakh camp itself (LJH), precise analyses of hydride elements (G.E.M.H); whole rock and trace elements (D.C.G.) and low-level sulfur, carbon and sulfur isotopes (L.I.G.).

The new mapping of Franklin gabbro-dolerites and the large number of samples analysed, together with the increased expertise, have accorded a much higher degree of confidence to the assessments made herein, particularly in the relative comparisons of the various inliers of Amundsen Basin to the Brock Inlier (Bluenose Study Area). Nevertheless, uncertainty still remains in the absolute sense, and only with continued mapping by GSC and extensive exploration by private industry will the Noril'sk model be fully tested.

Reporting of This Study

C.W. Jefferson briefed the Paulatuk Parks Committee on the 1993 field results on July 27, at the conclusion of the field work. He provided the same briefing to G. Ruben (Paulatuk resident located in Yellowknife) on July 28; and to members of the MERA Working Group as well as to W.A. Padgham (Chief Geologist, DIAND Northern Affairs Program in Yellowknife) and T. Hoeffer (Manager, NWT Chamber of Mines) in later July and early August. Dr. Jefferson also provided to the GNWT, his opinion on two potential hydroelectric power sites on the Hornaday River which appear to be competent enough to sustain dam construction. The hydroelectric power study was commissioned by Parks Canada with guidance by the Government of the NWT and its results will also be provided to the public for discussion of the proposed park boundaries.

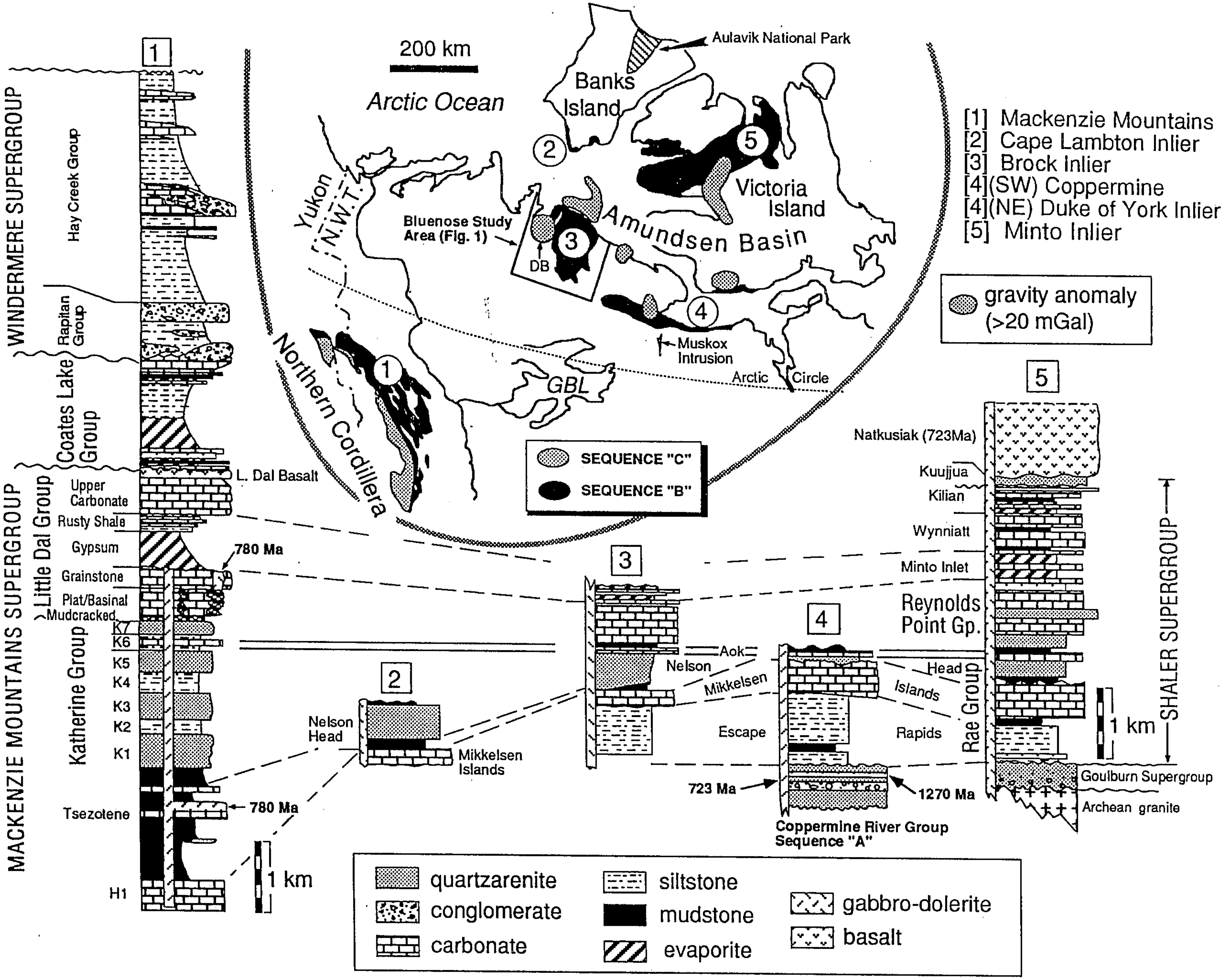


Figure 3. Location and stratigraphic correlations of Neoproterozoic rocks, gravity anomalies and Muskox intrusion, northwestern (Arctic) Canada. After Young et al. (1979), Jefferson and Young (1989), Heaman et al. (1992) and LeCheminant and Heaman (1989). Details of stratigraphy are in Table 3.

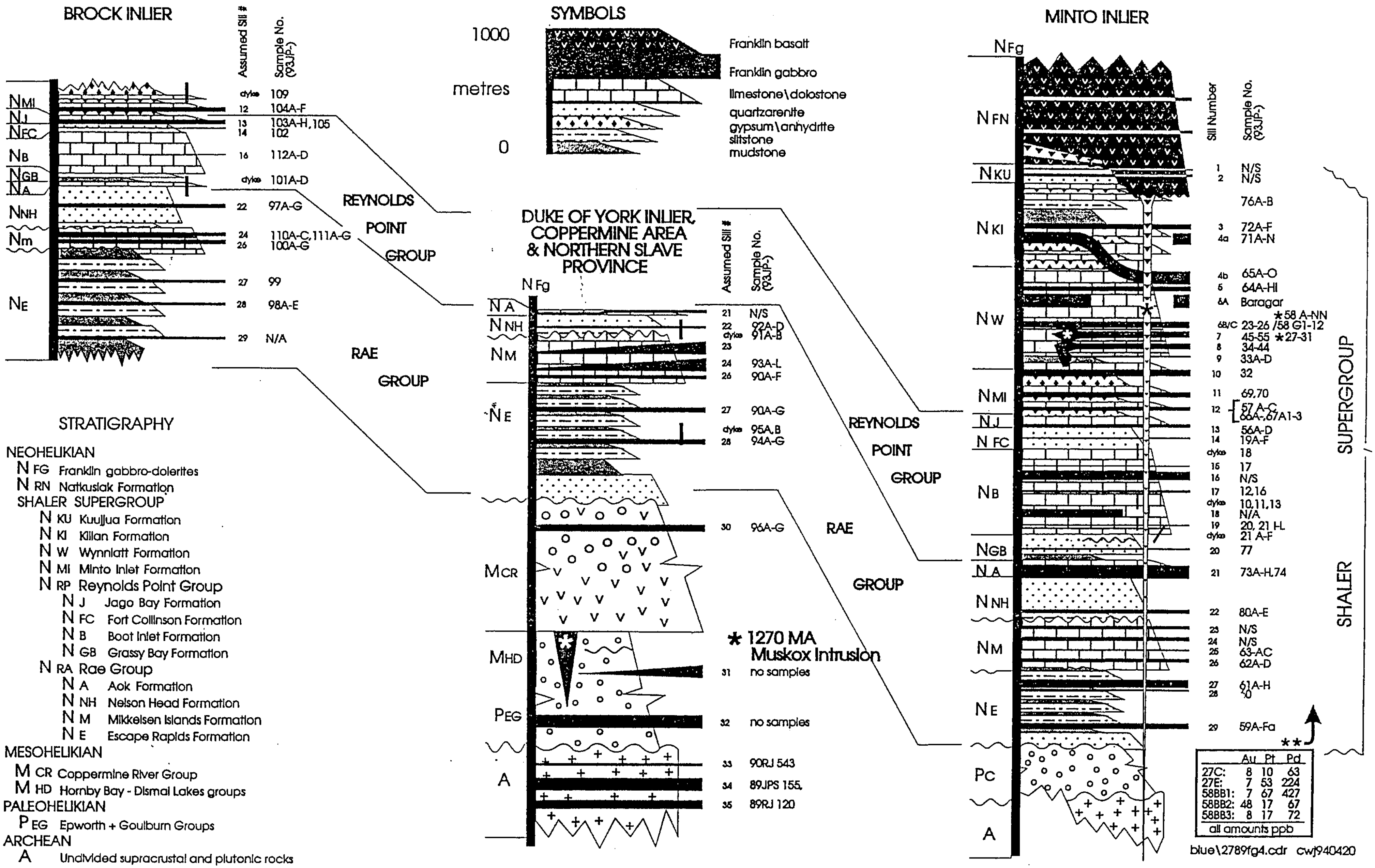


Figure 4. Stratigraphic setting and thicknesses of sills and dykes examined in this study. Stratigraphic details and references provided in Table 2.

An unpublished progress report entitled "Report on Bluenose MERA Fieldwork to Assess the Potential for Nickel, Copper and Platinum Group Elements, June-August 1993" was circulated in September to the MERA Working Group and Paulatuk parks committee. An oral and poster presentation at the Yellowknife Geoscience Forum (Jefferson et al., 1993) was based on that report.

Additional geochemical information and most of the figures contained herein were presented at the GSC Minerals Colloquium in Ottawa, January 17, 1994 (Jefferson et al., 1994). A journal paper with L.J. Hulbert as senior author is also planned, as are related regional geology papers and maps by R.H. Rainbird (the first is Rainbird et al., 1994b). The Yellowknife and Ottawa presentations were paired with ones by Rainbird and Jefferson (1993, 1994) on the regional geology and resource potential of the Amundsen Basin with highlights from the Minto Inlier.

Responsibilities of the Authors

The first author is responsible for the initiation of the project, leading the MERA fieldwork in Brock Inlier and supervising the MERA component of field work in other parts of Amundsen Basin, writing of the resource assessment, and overall report preparation. L.J.H. provided expertise on Ni-Cu-PGE deposits during planning and conducting of field work; directed sample preparation and quality control of laboratory analyses; wrote the Noril'sk analogue and summarized and interpreted all petrochemical work on the gabbro-dolerites as figures and text. R.H.R. led field work funded under the N.W.T. Geoscience Initiative in Minto Inlier and around Coppermine. R.H.R. also provided the regional stratigraphic synopsis of the Shaler Supergroup (Table 3) and contributed to the mapping and sampling in Brock Inlier.

Acknowledgments

The potential for gabbro-hosted Ni-Cu-PGE deposits associated with the Franklin sills was early recognized by Roger Eckstrand (in Geological Survey of Canada, 1980). The present study would not have been initiated without both the MERA process described above, and the written and orally expressed concerns and interest of a number of exploration geologists and their representatives, especially Dan Evans (Westminer Canada), Tom Hoeffer (NWT Chamber of Mines), Ken Pride (Cominco Ltd.), Hank Vuori (consultant), Leon LaPrairie (Leon LaPrairie Ltd.), Peter LeCouteur (formerly Cominco Ltd.) and George Wallace (consultant). Furthermore, credit for recognizing and acting on the Ni-Cu-PGE potential of the sills before this study was initiated should go to Ian Mason and Gren Thomas (Aber Resources) who had already started to test the Noril'sk model in northeastern Minto Inlier in 1993. Darnley Bay Resources Ltd. (1994) announced their acquisition of prospecting permits around the Darnley Bay gravity anomaly. They proposed a cooperative program with Inuvialuit Regional Corporation to conduct geophysical surveys, define and diamond-drill potential targets.

Field and laboratory studies by GSC in the Brock Inlier were cost-shared in 1990, 1991 and 1993 with DIAND and Parks Canada under the MERA process. Logistical support within GSC was bolstered by Polar Continental Shelf Project.

Work on Victoria Island and in the Coppermine River area was supported by the planning committees for the NWT Geoscience Initiative. They recognized the stratigraphic and metallogenic correlations between the Brock Inlier (MERA work led by C.W.J.) and the Minto Inlier (geological mapping project for the NWT Geoscience Initiative led by R.H.R.). Both the MERA and mapping results were enhanced by the regional scientific links of the two projects. Fuel caching coordinated by Government of the NWT further enhanced field logistics, as did sharing with Noranda (M. Wunder) and Unocal (Hans Weilans and Ross Pitman) of twin otter and helicopter flights.

L.J.H. acknowledges the friendly hospitality and exchange of information provided by his hosts at Noril'sk, Russia during his visit there. We are grateful for open discussions and information on seismic and geophysical constraints for the Darnley Bay body which were provided by Peter McGrath, John Broome, Richard Gibb, Paul Keating, Tony LeCheminant, Don Cook and Tim Jones during this research. Samples, field descriptions and petrographic data were generously provided by Rob Johnstone and Susan Schaan for the northern Slave Province and by Tony LeCheminant for Somerset Island. Tony LeCheminant also provided pre-publication data on the 779 Ma igneous event.

General assistance by Floyd Kuptana of Paulatuk, Kelli Powis, Mark Samborski, Antoine Richer and Robin Wyllie was much appreciated. Kitty Etegik of Cambridge Bay provided reliable and varied food services. Excellent piloting, logistical advice and additional field observations were provided by Woody McBride of Okanagan Helicopters. We appreciated the friendly hospitality and generous assistance of Adam Reuben (Paulatuk Parks Committee), and of Ken Thompson (Paulatuk Manager).

GSC laboratory staff under the supervision of D.C.G. and Peter Bélanger provided timely and accurate, whole rock, trace element and rare earth analyses. GSC laboratory staff under the supervision of G.E.M.H. provided timely and accurate analyses of antimony, arsenic, bismuth, tellurium and selenium. The University of Calgary, in particular Roy Krouse and the Physics Department, are thanked for their collegial support and laboratory facilities for the sulfur and carbon analyses by L.I.G.

Specific portions of this Open File were perceptively reviewed by John Broome, Don Cook, Roger Eckstrand, Tony LeCheminant, Peter McGrath, Richard Gibb, Doug Harvey, Jim Johnston, Paul Keating, Elizabeth Seale and Wayne Wagner.

REGIONAL GEOLOGICAL SETTING

Amundsen Basin (Neoproterozoic Shaler Supergroup)

The Amundsen Basin (see review by Young, 1981) is a sedimentary depositional basin interpreted from a number of Neoproterozoic inliers (older rocks surrounded by younger rocks) located on Victoria and Banks islands and along the western Arctic coast (Fig. 3). Previously comprising the Shaler and Rae groups, these sequences of sandstones, stromatolitic carbonates and evaporites have been combined into the Shaler Supergroup by Rainbird et al. (1994a). Lithostratigraphic correlations of these inliers with the Mackenzie Mountains Supergroup (Young et al., 1979; Jefferson and Young, 1988; Rainbird, in press) and strata exposed farther west (with Alaska by Rainbird, in prep.; and with Australia by Bell and Jefferson, 1987) have strengthened previous interpretations of the Amundsen Basin as a large embayment of a warm, very extensive shallow sea, and have interpreted its position as within the supercontinent Rodinia.

Franklin, Hayhook and Mackenzie Magmatic Events

The 718 - 723 Ma Franklin Igneous Event (Heaman et al., 1992) is represented in the Amundsen Basin by the Natkusiak Formation basalts, related dykes and sills which intrude Neoproterozoic platformal strata of the Shaler Supergroup on Banks and Victoria islands, around Coppermine, and in Brock Inlier which lies just east of the Darnley Bay gravity anomaly (Figure 1). More details on the Franklin Events are provided in the chapter: "THE NORIL'SK MODEL AND ITS APPLICATION TO NORTHWESTERN CANADA..."

Resource Assessment Domains

Domain synopses provided below include all known locations of the Franklin Events. Most of the domains are separated by their geographic positions and geological context - surrounded by Phanerozoic cover and water. Further details of domains in the Amundsen Basin area are provided in subsequent chapters of this report as needed to describe and interpret the Franklin Events there.

<u>Minto Inlier</u> domain (on Victoria Island, Fig. 3) is a northeast-trending belt of the Shaler Supergroup (Table 3) which was originally mapped by Thorsteinsson and Tozer (1962) as gently folded sedimentary strata, capped by the Natkusiak basalts and intruded by an extensive suite of gabbro-dolerite sills (Christie, 1964). Stratigraphic analysis of the sills (Fig. 4), and detailed mapping of selected parts of northeastern Minto Inlier (Figs. 5 to 8) here documents a considerably greater areal extent, variety of shapes and thicknesses of gabbro-dolerites than previously recognized. Cross-cutting breccias are located approximately axial to the Holman Island

Syncline (Figs. 4, 5, 7). Deformation in the Glenelg Bay area is recorded by dips up to 30° and northeast-trending faults with map offsets in the order of kilometers (Fig. 6).

Brock Inlier (Bluenose Study Area) domain (Figs. 9 - 11) is the core of the proposed Tuktut Nogait National Park, located on the Arctic coast southeast of Paulatuk, and was originally correlated with Minto Inlier by O'Neil (1924). Cook and Aitken (1969) and Balkwill and Yorath (1971) later mapped the Brock Inlier at 1:250,000 scale and assigned its strata to the Shaler Group as defined by Thorsteinsson and Tozer (1962). Aitken et al. (1973) also correlated the Shaler Group in a general way with rocks of similar age and lithology in Mackenzie Mountains. Young et al. (1979) increased the detail of these correlations to the scale of formations and members in the Shaler Group and Mackenzie Mountains Supergroup. Jones et al. (1992) remapped parts of the Inlier and strengthened the correlations, pointing out that the youngest Proterozoic strata in Brock Inlier are sulfate evaporites of the Minto Inlet Formation, Shaler Group. Detailed mapping and sampling for this study has further confirmed the correlations at the member level, permitted formal assigment of formation and group names as parts of the Shaler Supergroup in Brock Inlier (Figs. 3, 4; Rainbird et al., 1994a) and indicated thinner and less extensive gabbro-dolerites than previously thought.

Phanerozoic Cover domain underlies most parts of the Bluenose Study Area (Figs. 9-12), including the Darnley Bay anomalies. These surface strata are flat-lying, fossiliferous carbonate and clastic rocks and unconsolidated fluvial-glacial deposits (detail in Jones et al., 1992). The Phanerozoic cover varies in thickness from a thin veneer in the east and south, to more than 1 km in the southwest corner of Fig. 9, and is considered to be the northern part of the Western Canada Sedimentary Basin (Jones et al., 1992). The cover is interpreted to be underlain by the same Neoproterozoic stata as are exposed in the Brock Inlier. The Neoproterozoic strata are interpreted to continue under Phanerozoic cover and emerge in the southeast corner of the Bluenose study area. Proterozoic strata here are part of the Coppermine Area assessment domain (Fig. 12).

Darnley Bay Anomalies domain is a kidney-shaped area within Phanerozoic cover in the northwest part of the Bluenose Study Area (Fig. 9). At surface there is no indication of any difference from the rest of the Phanerozoic cover, except possibly in the arcuate shape of Darnley Bay to the north, and the Hornaday River bisecting the anomaly. The kidney shape is the edge of the aeromagnetic anomaly which was mapped in detail by Geophysics Division (1992). A 130 milligal gravity anomaly (Hornal et al., 1973) (one of the largest in North America) is roughly circular in shape and coincides with the northwestern part of the aeromagnetic anomaly. The combined anomalies were intepeted by McGrath et al. (1993) as the result of a large, dense mafic intrusion (Fig. 11).

Other Gravity Anomalies (80-100 mGal; Goodacre et al., 1987) underlie the Amundsen Gulf, southwestern Victoria Island and the mainland northwest of Coppermine (Fig. 3), forming a horseshoe array which was interpreted by LeCheminant and Heaman (1989, their Fig. 4A) to represent buried mafic to ultramafic bodies at the focus of the 1270 Ma Mackenzie Igneous Event. These gravity anomalies differ from the 130 mGal anomaly under Darnley Bay in that they are poorly correlated with magnetic anomalies as outlined by Coles et al. (1976), except for one at the mouth of Rae River. Only one of these anomalies appears to coincide with outcrop indications of a focus of the Franklin Events (Duke of York Inlier, Fig. 3; see descriptions later in this report, e.g. p. 24). It is possible that Paleozoic cover obscures focal indications in other cases. LeCheminant and Heaman suggested that the depositional subsidence recorded by Amundsen basin strata was a result of anomalously heavy lithosphere created by abundant 1270 Ma intrusions.

Duke of York Inlier (Fig. 12A) was considered by the Geological Survey of Canada (1980) as part of one resource assessment domain, continuous with the Rae Group as mapped by Baragar and Donaldson (1973). Rainbird et al. (1994a) supported this continuity of Neoproterozoic strata and Franklin sills along the Duke of York Archipelago, through Coronation Gulf to Coppermine. Nevertheless, the Duke of York Inlier is considered a discrete assessment domain because the Franklin gabbro-dolerites are thicker in, and form a much larger areal percentage of the Duke of York Inlier than the Rae Group around Coppermine (see Fig. 4 and compare Fig. 13A with 13B). A gravity anomaly is coincident with this domain (Fig. 3, area 4 NE).

Coppermine Area (Fig. 3, area 4 SW; Fig. 12B) comprises Neoproterozoic strata of the Rae Group intruded by Franklin gabbro-dolerites, in a gently north-dipping homocline which extends about 300 km east-west, centred on the town of Coppermine. The term "Coppermine Homocline" (obsolete) previously referred to all Meso- to Neoproterozoic strata north of Great Bear Lake. The Rae Group is the only part of this area which could now be termed a homocline, because it unconformably overlies multiply deformed Coppermine River Group and older strata (see Hildebrand and Baragar, 1991). The term Rae Group, used by Baragar and Donaldson (1973) to refer to Hadrynian clastic, carbonate and evaporitic strata, has been re-defined by Rainbird et al. (1994a) as the basal part of the Neoproterozoic Shaler Supergroup. The type area of the Rae Group remains the Coppermine area. The upper part of the Rae Group previously included evaporites and bioturbated siliciclastic strata which are now known to be basal Paleozoic: Mount Clarke, Mount Cap and Saline River formations (see Rainbird et al., 1994a for history). The top of the Rae Group is now set at the Aok Formation, (non-bioturbated stromatolite intruded by Franklin gabbro-dolerites). A gravity anomaly underlies the central part of the Coppermine area (Fig. 3), at the mouth of the Rae River, but there is no thickening of Franklin sills associated with it (Fig. 13A).

Cape Lambton Inlier, the southern tip of Banks Island (Fig. 3), is an isolated exposure of the Nelson Head and Mikkelsen Islands formations (Table 3; see also Rainbird et al., 1994a) which were previously mapped as parts of the Glenelg Formation (Thorsteinsson and Tozer, 1962). Sea cliffs provide classic exposures of the strata and of the Franklin gabbro-dolerite sills (see the frontispiece of Christie, 1964). The Mikkelsen Islands Formation here is also intruded by the gabbro-dolerites, which are spatially associated with massive to disseminated pyrite layers forming extensive gossans. Grab samples of the pyrite taken by Jefferson et al. (1988) were barren. These gossans are interpreted to be contact skarns similar to those in Minto Inlier (see **Contact Metamorphic Effects.....**).

Somerset Island Area (Fig. 2) is cored by crystalline basement: Archean gneisses and granites of suspected Paleoproterozoic age. Proterozoic strata at Aston Bay, on northern Somerset Island, comprise two formations. The lower, siliciclastic, Aston Formation is unconformably overlain by the carbonate-dominant Hunting Formation (Blackadar, 1963; Stewart, 1987), and intruded by two sets of mafic intrusions (the Franklin and Mackenzie igneous events). The Hunting Formation is intruded by Franklin dykes but nonconformably overlies a Mackenzie sill that intrudes the Aston Formation. The Aston Formation is thus older than 1270 Ma (Mackenzie event, LeCheminant and Heaman, 1989) and the Hunting is younger than 1270 Ma but older than 723 Ma, perhaps equivalent to the Shaler Supergroup or the upper part of the Bylot Supergroup of northern Baffin Island (Jackson and Iannelli, 1981). The Proterozoic sequence is overlain by upper Cambrian to lower Ordovician carbonate and clastic rocks of the Turner Cliffs Formation (Stewart, 1987).

Baffin Island and Melville Peninsula region (Fig. 2) is very large and the Franklin suite is relatively unstudied here. Dykes form a northwesterly trending swarm, with a date of 723 Ma on olivine-bearing gabbro of the Cumberland Dyke (Heaman et al., 1992). The radiating Frankin dykes in this region appear to be focussed to the northwest (Fig. 2). Where these dykes cut the Nanisivik Pb-Zn deposit, the lead-zinc ores are enriched in copper and nickel (J. Marshal, Strathcona Mineral Services, pers. comm., 1992). No Franklin sills are known in this area, despite the presence of moderately to gently dipping Proterozoic strata of the Bylot Supergroup (Jackson and Iannelli, 1981).

Mesoproterozoic to Archean Basement in the northern Bear and Slave structural provinces also hosts an extensive suite of gabbro-dolerite sheets which dip gently to >45° to the north and northeast, wrapping around the northeastern part of the Archean Slave Province and intruding Paleoproterozoic strata in the Bathurst Inlet area (Fig. 2). The Quadyuk Island Gabbro, located in Bathurst Inlet, was dated by Heaman et al. (1992) at 723 Ma. Previously, Heaman et al. (1992) included some large northwest-dipping sheets in the Great Bear Lake area in this suite, but these are now known to be part of the 779 Ma suite (LeCheminant and Heaman, in press). Sheets analysed for this study (Fig. 4) cut the Husky Creek Formation (Baragar and Donaldson, 1973) (93JP30), and Archean supracrustal and granitoid rocks in the Hood River Belt (Henderson et al., 1993). Sheets 33 and 34 were sampled by Johnstone (1993) in the Torp Lake area, and Sheet 35 was sampled by Schaan (1991; 1993) in the Turner Lake area.

Gp.	Unit	Thickness	Description	Interpretation
	Kuujjua Formation	120m SW Minto Inlier only	Two principal lithofacies: coarse quartzarenite typified by stacked tabular cosets of simple and compound planar crossbedding, and a less abundant fine-grained assemblage of interbedded fine sandstone, calcareous and dolomitic siltstone and mudstone forming thin lenses up to 20 km wide.	Coarse-grained lithofacies deposited in broad, braided fluvial channels, stacked by repeated lateral migration. Fine-grained lithofacies deposited in abandoned channel playa lakes.
	Kilian Formation	425m in the NE Minto Inlier; 550m in SW Minto Inlier	Eight informal members are recognized and can be correlated along the length of Minto Inlier (Rainbird 1991); lower evaporite, lower cyclic carbonate, middle evaporite, upper cyclic carbonate, clastic-carbonate, tan carbonate, upper evaporite and red shaly carbonate. Upper 2 mbrs absent in NE Minto Inlier. Evaporite and carbonate mbrs. similar to Minto Inlet Formation except that bedded gypsum/anhydrite not common. Carbonate members display small-scale cycles capped by stromatolites.	Carbonate mbrs. deposited in shallow subtidal-intertidal zone. Evaporites + clastic-carbonate mbr. deposited in intertidal-supratidal settings. Three complete emergent-submergent cycles are preserved representing transgressive-regressive episodes (cf. Minto Inlet Fm.)
	Wynniatt Formation	550m in NE Minto Inlier; 800m in SW Minto Inlier	In SW Minto Inlier divisible into 4 members. Member A: interlaminated dolosiltite and dololutite with desiccation features. An overlying unit contains metre-scale cycles consisting of rhythmically-laminated dolosiltite overlain by oölitic dolarenite, intraformational breccia and stromatolitic dolostone. Member B: thin- to thick-laminated black, rusty-weathering mudstone/siltstone with minor quartzarenite and dolosiltite interbeds at top. Desiccation cracks near top and base. Member C: coarsening upward sequence of dolomitic siltstone and sandstone overlain by a series of elongate (normal to shoreline) stromatolitic bioherms Fine-grained microbial laminites and carbonaceous limestones occur at the top of the member. Member D: recessive calcareous mudstones overlain by relatively thin stromatolitic biostromes and desiccated algal-laminated limestones. Members C and D are not differentiated in NW Minto Inlier	Member 1 deposited on a periodically exposed intertidal mudflat. Member 2 is shallow subtidal to intertidal. Member 3 is extensive shelf-marginal reef complex overlain by back-reef algal flat and lagoon deposits. Member 4 records a series of shallow subtidal to intertidal cycles
	Minto Inlet Formation	260m in NE Minto Inlier; >400m in SW Minto Inlier	Five cyclically alternating informal members; lower evaporite, lower carbonate, middle evaporite, upper carbonate and upper evaporite. Evaporite members: laminated to thin bedded and cross-laminated white gypsite and grey anhydrite, red gypsiferous siltstone and buff to grey calcisiltite. Chickenwire, nodular anhydrite and crosscutting satinspar veinlets common in gypsiferous siltstone units. Rip-ups and intraclast beds are common. Rare halite molds and desiccation cracks in calcisiltite. Carbonate members: Grey to buff-grey laminated to thin bedded to massive dolosiltite and fine dolarenite. Hummocky cross-bedding and laterally linked stromatolites in lower member.	Carbonate members interpreted as as shallow subtidal. Evaporite members are shallow subtidal (restricted basin) to supratidal. Three shoaling upward cycles (cf. Kilian Fm.)
Group	Jago Bay Formation	<65m in NE Minto Inlier; 200m in SW Minto Inlier	Interbedded yellow-weathering, cross-bedded quartzarenite, parallel-laminated and mudcracked dolosiltite/magnesisiltite and dololutite. Distinctive, yellow-weathering stromatolite composed of both laterally-linked and digitate forms with abundant inter-columnar quartz occurs within 10 m of base of formation.	Intertidal to lagoonal deposits
	Fort Collinson Formation	50m in SW Minto Inlier; NE Minto Inlier, thickening from 65m in east to170m in west	Medium-bedded, fine- to medium-grained quartzarenite and dolomitic quartzarenite with common herringbone cross-bedding and subordinate sub horizontal planar stratification to low angle cross-bedding. Locally glauconitic.	Shallow subtidal to intertidal. Reworking of fluvial sands

Table 3. Revised Stratigraphy of the Shaler Supergroup, Amundsen Basin (after Rainbird et al., 1994a; see earlier references therein).

Reynolds Point	Boot Inlet Formation	350m to >500m in NE Minto Inlier; only upper 250m exposed in SW Minto Inlier	Cyclically alternating ooid grainstone, stromatolitic dolostone and dolosiltite rhythmite magnafacies (Morin and Rainbird, 1993). Quartzarenite absent from base of formation (by definition) but becomes gradually more abundant toward top.	Ooid grainstone=inner shelf; stromatolite=mid-shelf, dolosiltite rhythmite=outer shelf; all on cyclically prograding, storm-dominated carbonate shelf
	Grassy Bay Formation	60->200m in NE Minto Inlier	Basal mudstone unit of variable thickness (increasing westward), which coarsens abruptly upward to fine- to medium-grained, planar-tabular cross-bedded quartzarenite. Top defined by sporadic erosional unconformity overlain by fining upward succession of hummocky cross-bedded quartzarenite, parallel-bedded dolosiltite and parallel-laminated dololutite.	Marine deltaic at base evolving to fluvial in middle quartzarenite; top is storm-reworked fluvial deposits followed by deeper water marine shelf (carbonates).
Rae Group	Aok Formation	20-30m in NE Minto Inlier	Cream-coloured and orange-brown-weathering sideritic to ankeritic dolostone composed of upright to fanning digitate columnar (elongate in plan) stromatolites. In some areas comprises two biostromes of similar thickness that are separated by wavy laminated dolosiltite and dololutite.	Marine platform, mostly below wave base.
	Nelson Head Formation	up to 25m basal shale with > 275m in NE Minto Inlier	Base is thinly laminated black carbonaceous and pyritic mudstone (locally developed in paleotopographic lows) grading upward into thick-laminated red siltstone and fine ripple cross-laminated quartzarenite. Middle 2/3 (approx.) is fine- to medium-grained, small- to moderate-scale planar-tabular cross-bedded, white to light pink quartzarenite interbedded with thin (<1m) intercalations of red ripple cross-laminated to parallel-bedded siltstone and very fine quartzarenite. Top is parallel to planar hummocky cross-bedded fine-grained pink to green glauconitic quartzarenite interbedded with wavy- to lenticular-bedded very fine sandstone and parallel-laminated green siltstone.	Coarsening-upward section is marine prodelta to prograding river-dominated delta front. Top is barrier island-lagoon (reworked delta top).
	Mikkelsen Islands Formation	400-450m in NE Minto Inlier	Base is well laminated red to cream stromatolitic dolostone with common interbeds of intraformational flat-chip rudite. Upper 2/3 (approx.) is dolosiltite and dolarenite overlain by stromatolitic dolostone composed of columnar digitate forms passing upward into laterally linked domal to plane-laminated forms. Black to frothy white chert patches and layers common within upper half of formation.	Shallow marine, sub- to intertidal (columnar stromatolites) to supratidal (cherts, laminated stromatolites, tepees and beachrock)
	Escape Rapids Formation	550m in NE Minto Inlier	HihotokMember: Fine- to medium-grained, cross-bedded to ripple cross-laminated quartzarenite and litharenite interbedded with ripple cross-laminated to plane-laminated siltstone. Nipartoktuak Mbr (not exposed in Minto Inlier): Maroon to red and grey-green variegated plane laminated mudstone and siltstone with less common interbeds of dark grey-brown ripple cross-laminated to small-scale cross-bedded sandstone. Bloody Fall Member (poorly exposed in Minto Inlier): Fine- to medium-grained, cross-bedded to ripple cross-laminated quartzarenite and litharenite interbedded with ripple cross-laminated to plane-laminated siltstone. Thin (up to 20 cm) interbeds of argillaceous, concretionary limestone and stromatolitic dolostone common near top.	Hihotok: scours and HCS suggest storm activity in marine environment. Nipartoktuak: below wave base to shallow subtidal Bloody Fall: subtidal to intertidal, shallowing up

Table 3. (cont'd) Revised Stratigraphy of Shaler Supergroup, Amundsen Basin.

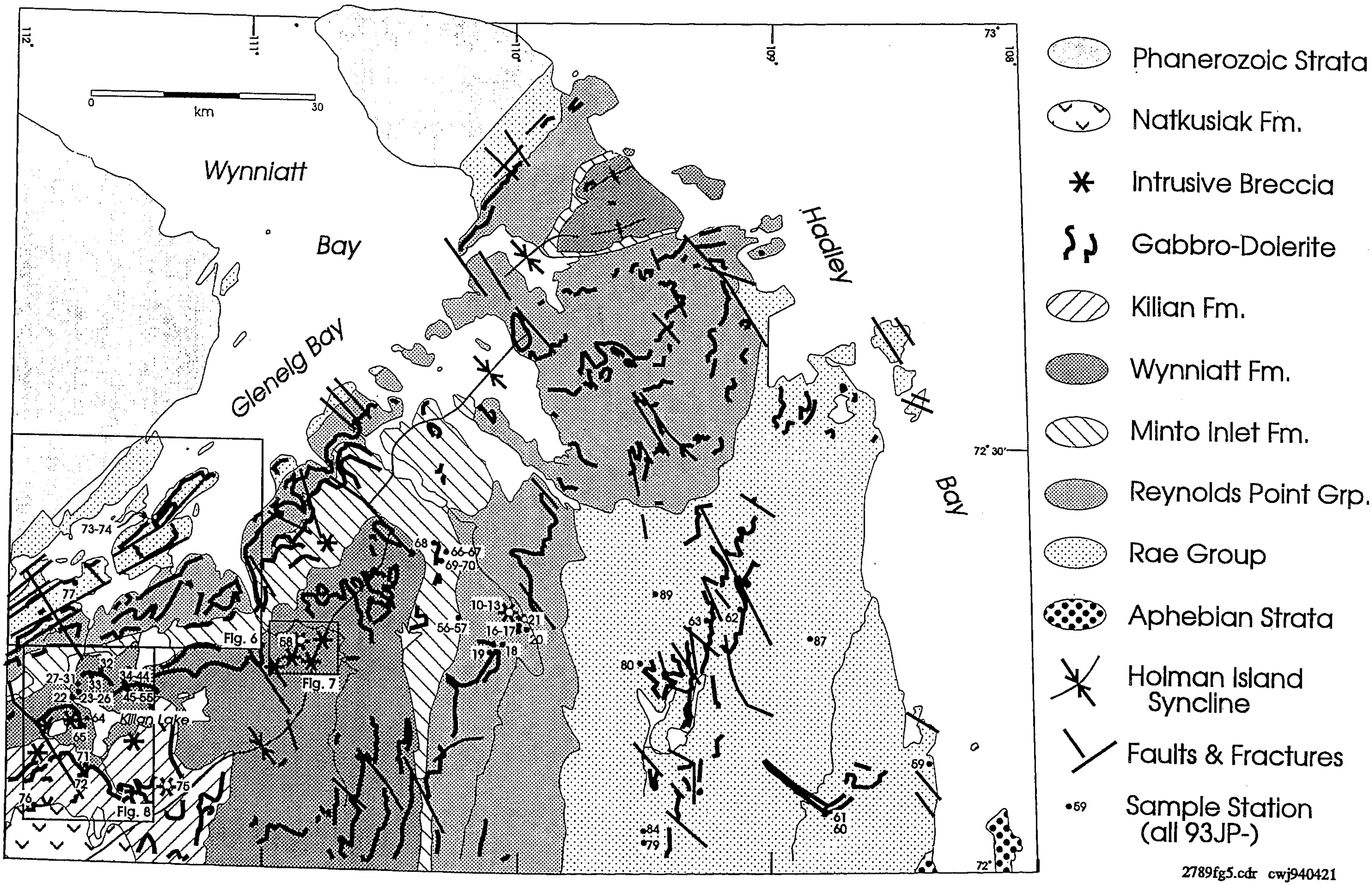


Figure 5. Summary geology and sample locations of northeastern Minto Inlier, Wynniatt Bay Map Sheet, NTS 78B. Sills are actually much more extensive and numerous than shown here. Actual extents and varieties of Franklin gabbro-dolerites are shown in the more detailed maps which are indexed here: GLENELG BAY AREA (Fig. 6), BRECCIA COMPLEX (Fig. 7) and KILIAN LAKE AREA (Fig. 8). The basic geology for this map was compiled in 1974 by M.N. Chernoff (Chevron Canada) at 1:250,000 scale, after Thorsteinsson and Tozer (1962), Christie (1964), and interpretations of the sills and structure based on government aerial photographs. A full 1:250,000-scale version was laminated and taken into the field to double as a research guide and dining table cover. Except for the intrusive breccia locations and some northeasterly faults in Glenelg Bay, this represents the state of mapping before R.H.R. began his mapping and stratigraphic studies in 1991. The legend is revised from Chernoff, based on 1993 fieldwork and the revised stratigraphy of Table 3. Nearly the entire Precambrian area of NTS 78B has now been remapped at 1:50,000 and is in different stages of compilation (e.g. Rainbird et al., 1994b). Sample locations are also shown on the right-hand column (MINTO INLIER) of Fig. 4, and Minto Inlier is located on Fig. 3.

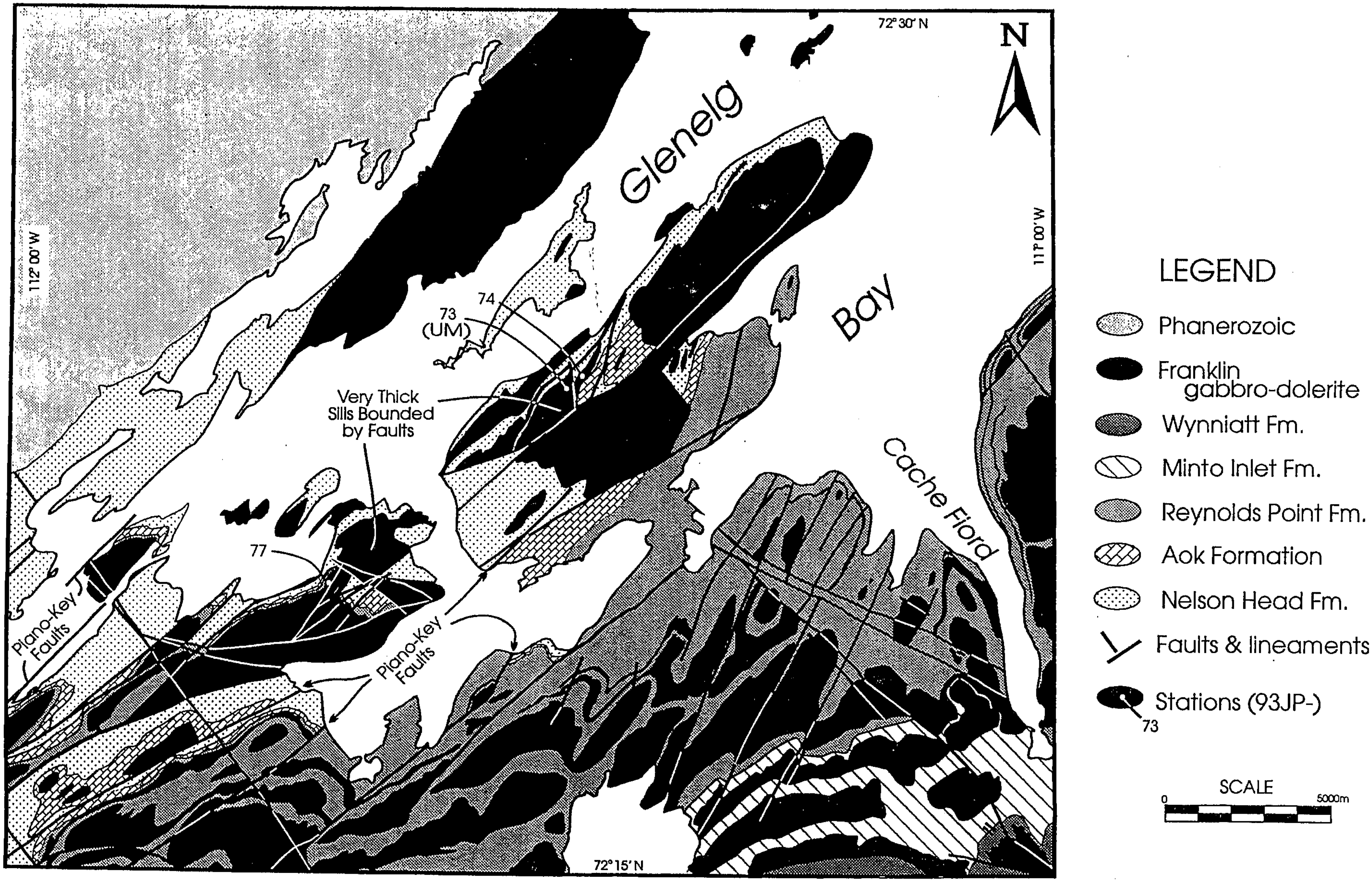
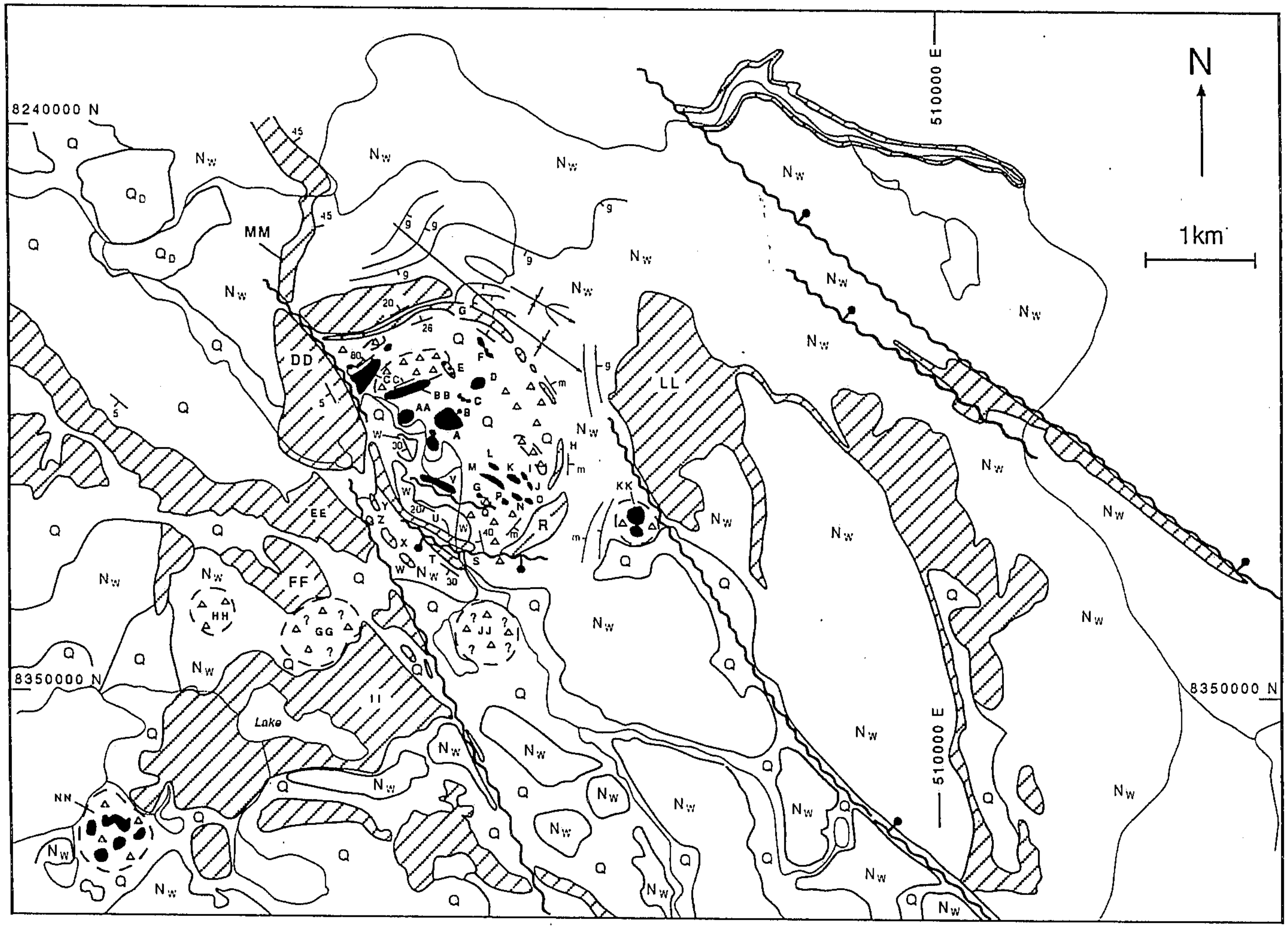


Figure 6. Geology and sample locations, Glenelg Bay area, NTS 78B5. Note northeasterly faults, the abundance and varied thickness of sills. Ultramafic blocks (UM) are described in text.



Bedding or trend with dip, from air photo.

Bedding, sill contact, measured, with dip

Diabase breccia and vesiculated diabase

Tabular gabbro – doleritic sill

Area of breccias
Δ - outcrop of carbonate breccia

Area of breccias
inferred from air photo.

Qu Undifferentiated surficial deposits

QD Delta

w, Nw Wynniatt formation

BB Skarn sulphides + magnetite; up to 48 ppb Au, 67 ppb Pt, 427 ppb Pd (only at this station)

Detail of station 93 JP 58 : volcanic breccia complex South of Glenelg Bay, approximately 72• 16' N, 110• 50' W. Letters A-Z and AA-MM represent different sub-stations for sample reference.

Figure 7. Geology of the breccia complex south of Glenelg Bay (Station 93 JP 58; location of map shown in Fig. 8). Approximate centre of complex (body B) is located at approximately 72°16' N, 110° 50' W. Letters A to Z and AA to OO represent different sub-stations for descriptive and sample purposes. These sub-stations and are further described in Appendix I. At the west end of station BB, grab samples of skarn in dolostone adjacent to a gabbro-dolerite dyke yielded up to 48 ppb Au, 67 ppb Pt and 427 ppb Pd. See text for further descriptions and discussion.

Figure 8. Geology of the Kilian Lake area. Elevated PGE (up to 277 ppb combined) were determined for gossanous pyritic gabbro-dolerite samples taken from the top of the chonolith at station 93JP27, north of Kilian Lake. See further description in text and Fig. 4.

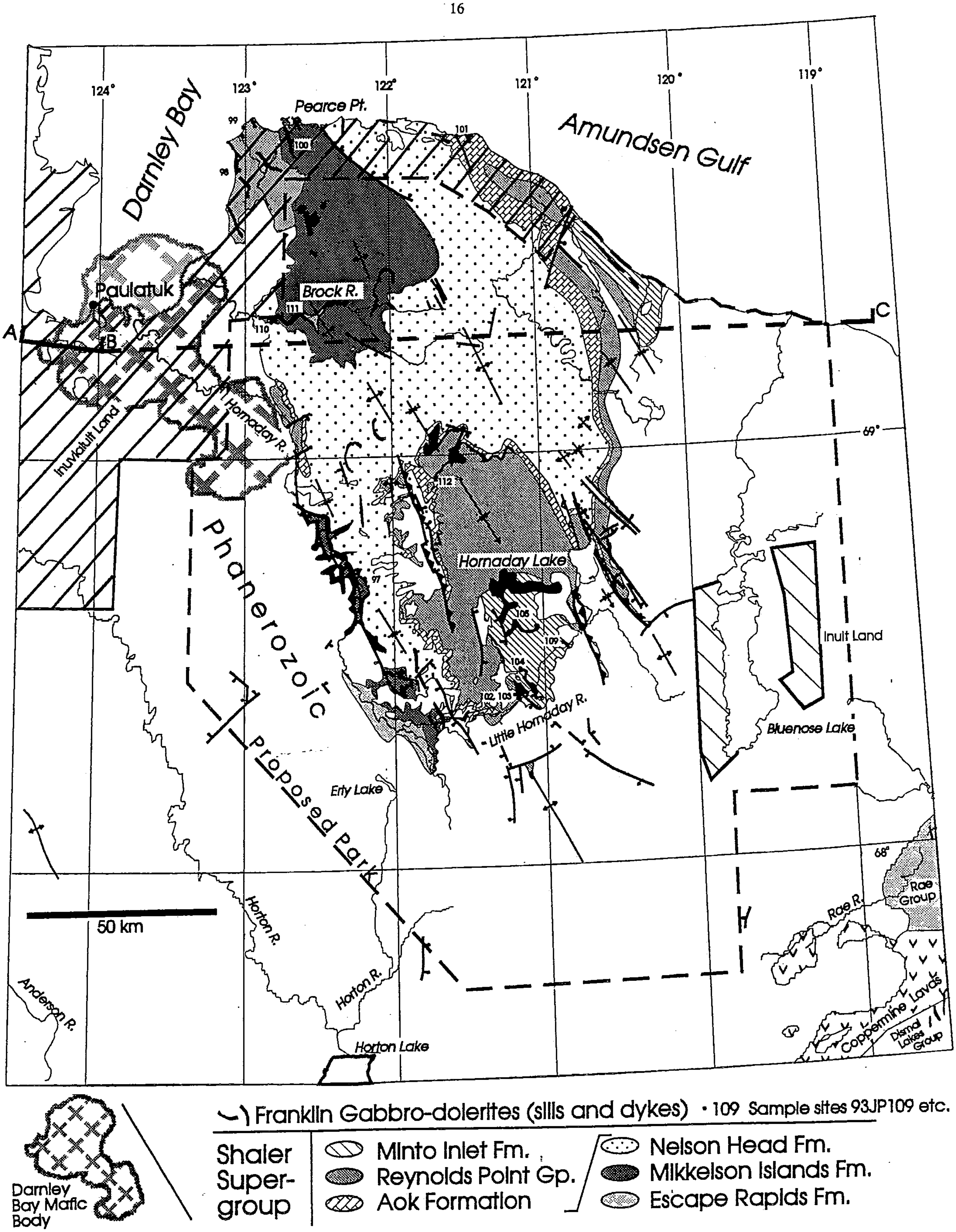


Figure 9. Simplified geology of the study area of the proposed Tuktut Nogait National Park, featuring the Brock Inlier and Darnley Bay geophysical anomalies. Geology is after Jones et al. (1992); the outline of the Darnley Bay body is from the maximum horizontal gradient of the residual magnetic anomaly by McGrath et al. (1993). Line A-B is the location of the seismic section shown in Fig. 10; A-B-C is the location of the geologic cross section of Fig. 11.

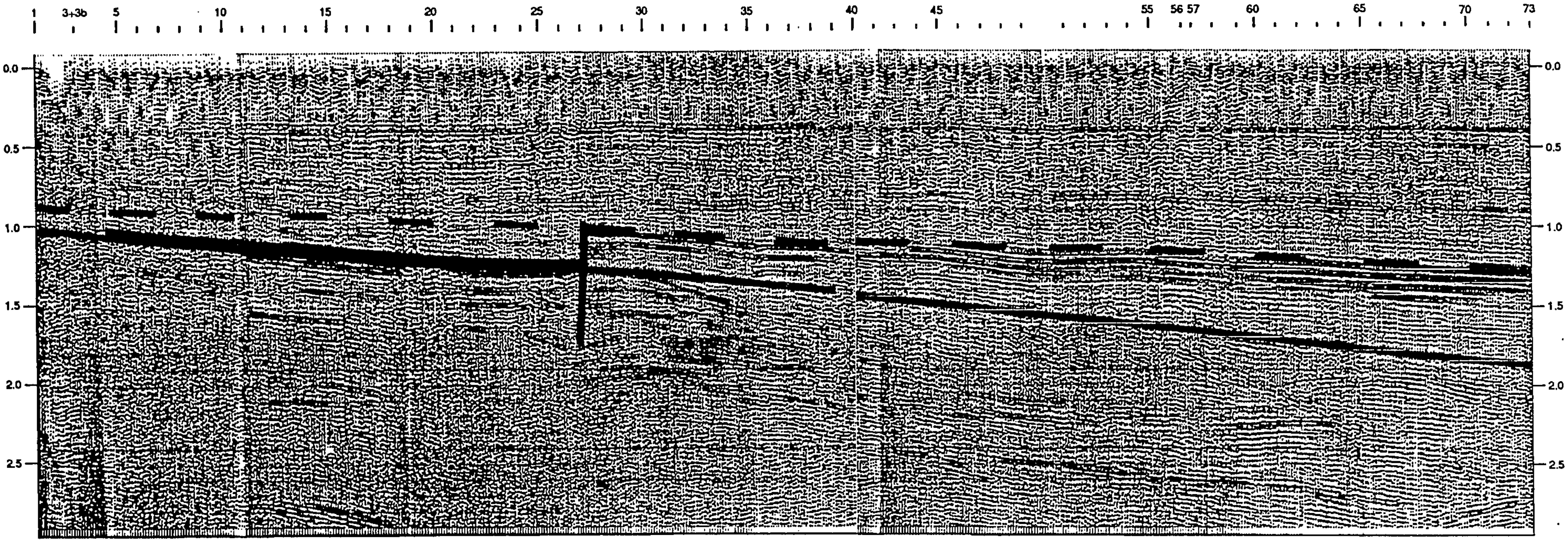


Figure 10. Seismic line cross-section south of Paulatuk from Vye (1972).

Shallower Interpretation: Reflections beneath the dashed line were interpreted by Vye (1972) and Hole and Bradley-Isbell (1990) as the top of a layered intrusion, unconformably overlain by Shaler Supergroup. Following this interpretation through, the short vertical line marks the westward termination of the distinct reflections and their apparent offset down to the west. This termination approximately coincides with the western edge of the geophysical anomalies thus favouring the shallow interpretation (McGrath, pers. comm., 1994). Alternatively, the offset may be interpreted as a fault offsetting the layered intrusion.

Deeper Interpretation: The same reflections were interpreted by D.G. Cook (pers. comm., 1993) as carbonates of the Dismal Lakes Group, lying unconformably below the Shaler Supergroup. Continuing deeper, the solid line would represent the sub-Dismal Lakes Group unconformity (cf. MacLean and Cook, 1992). This interpretation is supported by the variably dipping discontinuous reflections similar to those which McLean and Cook (1992) interpreted as deformed Hornby Bay Group. If this is so, then the mafic intrusion must be at or below the base of this seismic section, about 7 km or deeper.

Vertical scale is in seconds; actual depths depend on seismic velocities chosen for the various strata (see text). Horizontal numbers are shot points (details in Vye, 1972). Location of section is shown in Figs. 1 and 9.

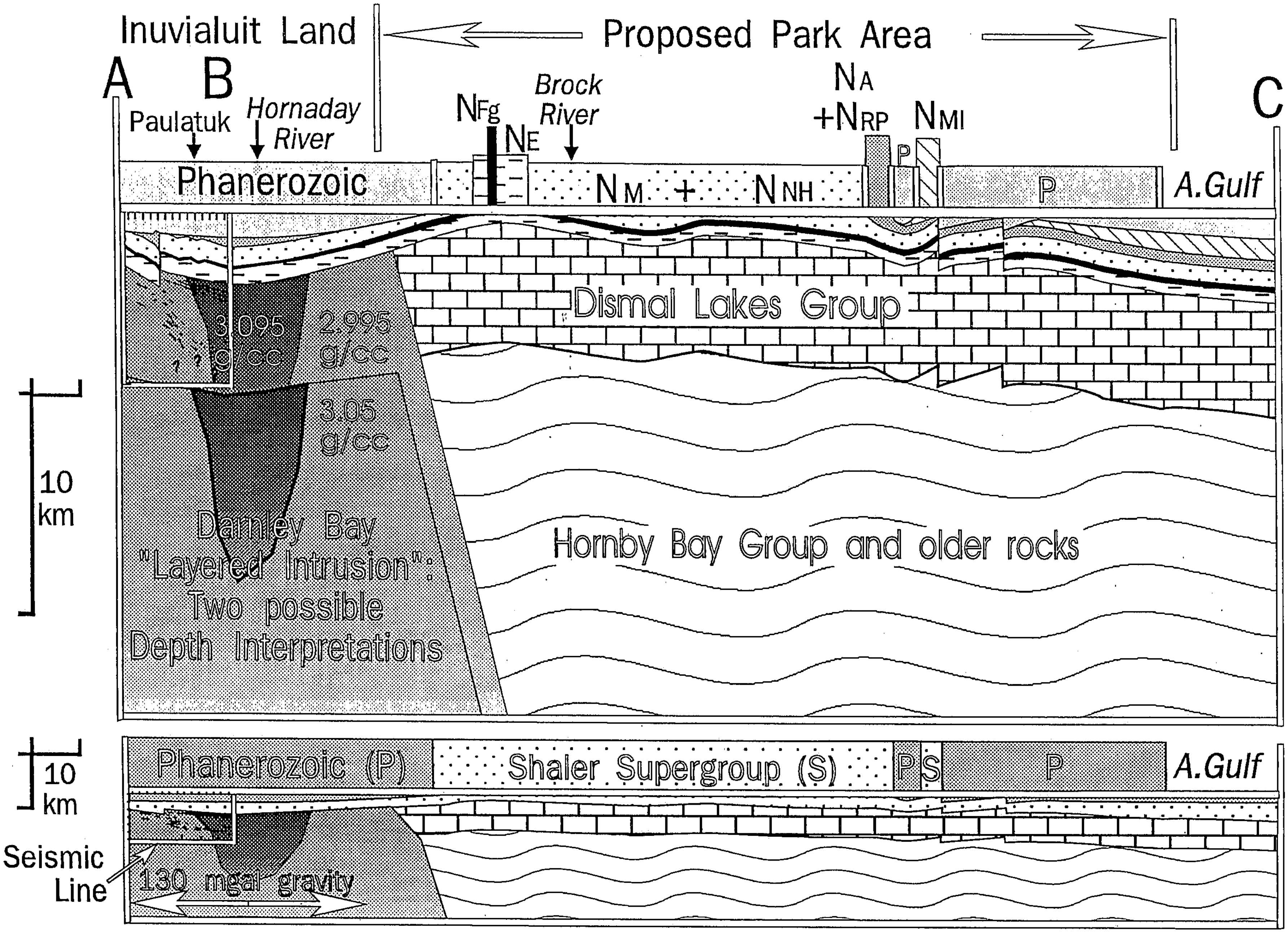


Figure 11. Simplified cross-section interpreting the relationship of the Darnley Bay mafic body to the seismic data (Fig. 10) and exposed geology of Brock Inlier (Fig. 9). The Coppermine River Group is interpreted to have been removed by erosion prior to deposition of the Shaler Supergroup (see text). Thicknesses for the Dismal Lakes (6000 m) and Hornby Bay (7000 m) groups are taken from MacLean and Cook (1992), based on seismic data under Anderson Plain rather than the westward-thickening (>1500 m) exposures of each group south of the Coppermine lavas (Kerans et al., 1981). See text for discussion of two possible depth interpretations. Lower section is to scale; upper is vertically exaggerated. Stratigraphy and abbreviations are as outlined in Figure 4. Structure in Dismal Lakes and Hornby Bay groups is not interpreted except in broad structures observed in Brock Inlier.

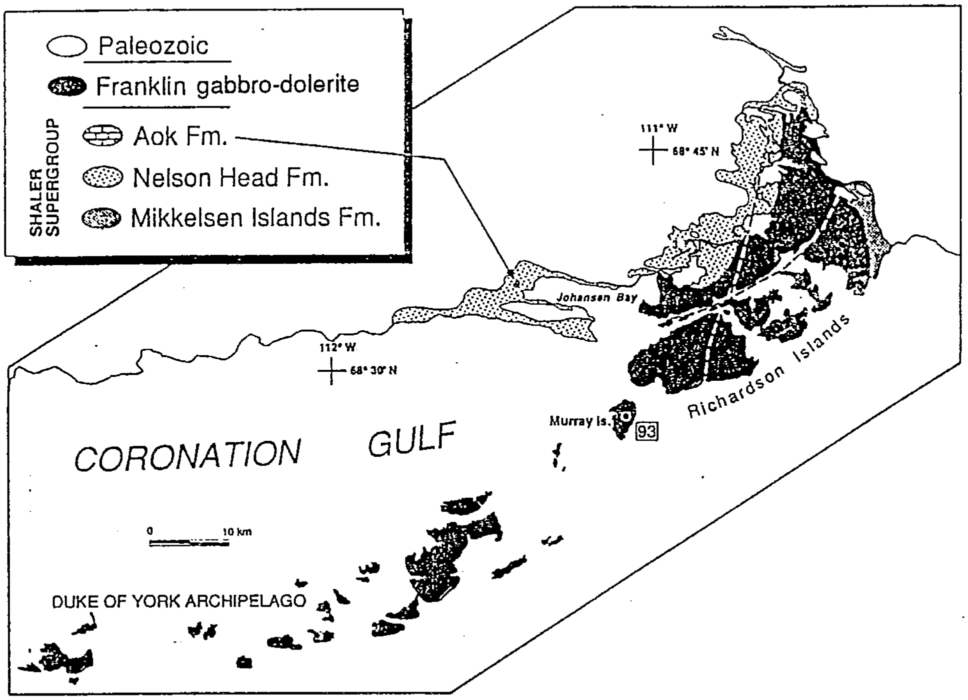


Figure 12A. Geology and sill sample location (station 93JP93) in Duke of York Inlier. Geology is based on unpublished notes by F. Campbell and 1993 mapping by R.H.R. and C.W.J. Gabbro-dolerites form very thick, cross-cutting masses enclosing sedimentary xenoliths with gossanous contacts. Regional location (southern Victoria Island and Coronation Gulf) and stratigraphic context are shown in Figs. 2 and 3 (area 4 NE).

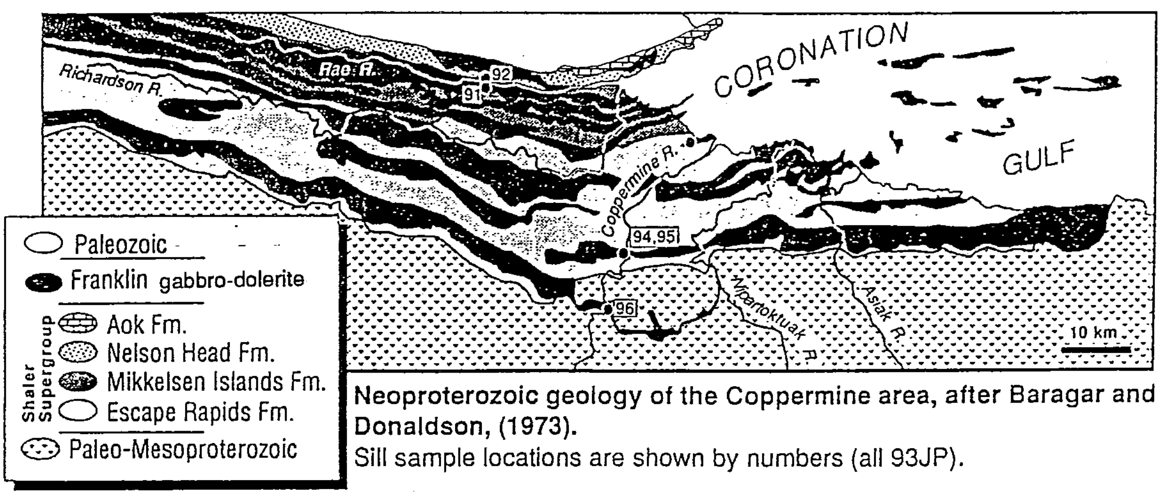


Figure 12B. Geology and sill sample locations (93JP90 to 96) in Coppermine area. Geology after Baragar and Donaldson (1973) and Rainbird et al. (1994a). Sills here are relatively uniform and laterally extensive. Regional setting and stratigraphic context are shown in Figs. 2 and 3.

THE NORIL'SK MODEL AND ITS APPLICATION TO NORTHWESTERN CANADA: GABBRO-HOSTED NICKEL (Ni), COPPER (Cu) AND PLATINUM-GROUP-ELEMENTS (PGE)

Introduction to the Noril'sk Model

It is well recognized that flood basalts and associated mafic intrusions can host Ni-Cu sulfide ores (e.g. Naldrett, 1989). This deposit type was assessed by Eckstrand (p. 67 in Geological Survey of Canada, 1980). He recognized the general similarity in the geological settings of the Franklin sills; Noril'sk, Russia; and Duluth, Minnesota), but downgraded the potential for nickel-copper in the Franklin sills because both Christie (1964) and Thorsteinsson and Tozer (1962) had indicated that the latter were virtually undifferentiated. Jefferson et al. (1988) and Jones et al. (1992) followed Eckstrand's assessments, because they were also uncertain as to the degree of differentiation, and had not observed most of the petrogenetic data presented here. Furthermore, little was known about Noril'sk in previous years, and the potential of flood basalt magmatic provinces to contain world class Ni-Cu-PGE deposits has only recently been fully appreciated outside of Russia (e.g., Naldrett, 1992). Expanded worldwide interest in flood basalt terranes has resulted from the revelations of geologists returning from the Noril'sk - Talnakh Ni-Cu-PGE deposits that are associated with the Permo-Triassic Siberian flood basalts of Russia (e.g. Naldrett et al., 1992).

Visitors to the Noril'sk-Talnakh mining camp are astonished by the superior grade and immense size of these ore deposits. One of many massive sulfide lenses in the Talnakh Deposit area is approximately 1 km x 3 km x 20 metres, containing about 3.8 % Cu, 3.7 % Ni, 1.3 ppm Pt, 6.3 ppm Pd, 0.19 ppm Rh and 14 ppb Ir (Naldrett, 1992). Visitors are equally astonished by the observation that their hosts are superficially unremarkable diabase-gabbro sills similar to those associated with most other flood basalt terranes.

One such flood basalt occurrence, the Natkusiak Formation in Minto Inlier (Thorsteinsson and Tozer, 1962), is the extrusive expression of the Franklin magmatic suite of northern Canada (Fig. 2), which has been regionally described and dated by the U-Pb method on baddeleyite at 718 - 723 Ma (Heaman et al., 1992). In order to assess the proposed Tuktut Nogait National Park area, we must understand the regional nature of the Franklin igneous rocks and their settings not only in Brock Inlier domain (core of the proposed Tuktut Nogait National Park area), but also in Minto, Duke of York and Cape Lambton inliers, and in the mainland Canadian Shield from the Coppermine area to North Slave area (Figs. 2 and 3).

The stratigraphic succession of the Amundsen Basin has been described by Young (1981) and a number of more recent studies referred to in Rainbird et al. (1994a). The complete stratigraphy and depositional history is summarized in Table 3.

Table 4 compares the Franklin and Siberian magmatic provinces in terms of 16 features which could bear on differentiation and Ni-Cu-PGE mineralization of the gabbro-dolerites.

The following sections provide additional information on the Franklin Events, particularly within Amundsen Basin (Figs. 2 - 4). We demonstrate significant areal variations in some of the attributes listed in Table 4, and interpret concommitant variations in mineral potential from high in northeastern Minto Inlier to low-to-moderate in the Brock Inlier (Bluenose area).

Regional Tectonic - Stratigraphic Setting of the Franklin Events

The Franklin dykes form a major northwest-trending swarm on Baffin Island and Melville Peninsula, a northeasterly swarm on Somerset Island, northwesterly swarms in Minto and Brock inliers and in the Coppermine area (Fig. 2; after Heaman et al., 1992; from Fahrig and West, 1986). Jefferson et al. (1985) also noted a northeasterly set of thin, fine-grained dykes which dip 45 to 75° to the southeast or northwest and feed thin sills within the Natkusiak basalts. Observations by R.H.R. and C.W.J. suggest that the "dykes" are actually sills which locally cross stratigraphy. The northwest-striking dykes in Minto and Brock inliers are resistant to weathering and are partly exposed through flat-lying Paleozoic cover. The greatest manifestation of the Franklin Events on the western Arctic mainland and islands is as sills within supracrustal rocks and gently dipping sheets cutting crystalline basement.

Franklin sills in Amundsen Basin are hosted by the Shaler Supergroup (Table 3). The lower two-thirds of the Shaler Supergroup (Rae and Reynolds Point groups) have been correlated in detail with the Mackenzie Mountains Supergroup (Fig. 3). This correlation has been extended to central Australia (Bell and Jefferson, 1986; Hoffman, 1993) and Alaska (R.H. Rainbird, unpublished manuscript). These correlations imply that an extensive intracratonic platform in northwestern North America was once contiguous with Australia and Antarctica, and was blanketted with laterally continuous carbonate, evaporite and mature siliciclastic sediments.

The upper Shaler Supergroup is conformably to unconformably overlain by flood basalts and pyroclastic rocks of the Natkusiak Formation (Baragar, 1976; Young, 1981; Jefferson, 1985; Jefferson et al., 1985; Dostal et al., 1986; Rainbird, 1991, 1993). Other components of the 718-723 Ma Franklin Events include dykes and sills of Brock Inlier (Hb / P6 of Jones et al., 1992) (Fig. 5), the Coronation Sills of Minto Inlier, Cape Lambton Inlier, Duke of York Inlier and Coppermine area, (Christie, 1964), and dykes intruding the Hunting and Aston Formations on Somerset Island and Bylot Supergroup on Baffin Island (Heaman et al., 1992). Sills of the Coronation Gulf region continue to the south and east as gently to moderately north-dipping sheets which cut Paleoproterozoic to Archean basement. The stratigraphic and areal distribution of sills in the Amundsen Basin region is summarized in Fig. 4.

The upper part of the Mackenzie Mountains Supergroup (Figure 3) contains the Little Dal basalts and possibly related intrusions dated at 779 Ma (Jefferson and Parrish, 1989). No 779 Ma ages have been obtained for sills present in exposed strata of Amundsen Basin, although 779 Ma ages have been reported for gabbro sheets exposed east of Great Bear Lake (LeCheminant and Heaman, in press). It is unlikely that any of the sills in Brock Inlier are of 779 Ma vintage, because the chemical analyses reported in this report are all very consistent with others of the Franklin suite, whereas the 779 Ma suite tends to be very iron rich (e.g. analyses reported in Jefferson, 1983, Lustwerk, 1990) and differs in several other ways (Lustwerk, 1992).

From the above we interpret that rifting of the extensive platform was long-lived, and probably propagated from at least two separate sites - the Cordillera initiated at 779 Ma and the Arctic initiated at 723 Ma. The effects of Cordilleran magmatism pinched out toward Brock Inlier; and as reported in the following, Franklin magmatism extended throughout Brock Inlier, but was distal there. Only the 1270 Ma Mackenzie magmatism was proximal to Brock Inlier.

Foci of Franklin Magmatism

In the Minto Inlier, the uppermost formations of the Shaler Supergroup (upper Kilian Kuujjua) pinch out toward the northeast. The Kuujjua Formation is trough-crossbedded quartzarenite which immediately underlies the Natkusiak basalts only in the southwestern sector of Minto Inlier (Jefferson, 1985; Rainbird, 1992). This quartzarenite records part of a major braided river basin which trended northwesterly and was derived in part from the Grenville Orogen (Rainbird et al., 1992b). Truncation of the Kuujjua Formation on its northeast side suggests pre-eruptive uplift in that area. Some of this uplift could have been accommodated along northwest-striking fractures, several being intruded by Franklin dykes. The base of the Natkusiak basalts is an angular unconformity developed on Kilian dolostones in the northwest (Jefferson et al., 1985) but conformable in the southeast, where basalt was erupted onto unlithified quartzarenite of the Kuujjua Formation (Rainbird, 1993). In the extreme northeast, the basalts overlie small, fault-bounded, tilted horsts and grabens which are likely related to breccia complexes (see below) rather than rifting. The other stratigraphic features are interpreted as the sedimentary record of mantle plume-related crustal doming preceding eruption of the Natkusiak basalts (Rainbird, 1993).

This NE-SW differential uplift continued during eruption of the Natkusiak basalts, as documented by Jefferson et al. (1985): the lithic

Table 4. Similarities between Noril'sk-Talnakh Ni-Cu-PGE region and northwestern Canada.

Feature	Noril'sk - Talnakh Region (Permian Siberian Traps); NW Siberia	Amundsen Basin (723 Ma Franklin Event); NW Canada
SCALE: Both were catastrophic mafic magmatic events, comprising thick flood basalts, many, thick, gabbro sills and dykes.	An immense volume (~10^6 km^3) of flood basalts up to 3500 m thick, known as the Siberian Traps. Related sills are also extensive but regional extent not as well documented because covered by Traps.	Large volume of Natkusiak flood basalts (see below). Related gabbroic dykes extend across northern Canada for more than 2500 km from Great Bear Lake to southeastern Baffin Island; sills intrude all of Amundsen Basin and Archean basement (Fig. 2) (Heaman et al., 1992).
	Both of similar regional extent to other major rift-related Proterozoic mafic events such as the 1.10 Ga Keweenawan magmatism (Halls, 1978;), and the Coppermine basalts and diabase dykes of the 1.27 Ma Mackenzie igneous event (LeCheminant and Heaman, 1989).	
DURATION: Ages differ but both represent rapid, short-lived magmatism.	The Siberian Traps were erupted quickly during the Late Permian and Early Triassic and are temporally associated with the Permo-Triassic extinction (Renne and Basu, 1991).	Neoproterozoic: seven widely separated sills and a northwesterly dyke in Amundsen Basin, and one dyke on Baffin Island yielded 723 +4/-2 Ma. One other sill on Victoria Island was dated at 718 +/- 2 Ma (U-Pb on Badelleyite; Heaman et al., 1992).
HOST STRATIGRAPHY: The stratigraphy hosting sills in each region comprises undeformed, unmetamorphosed continental and epicontinental strata immediately below the basalts.	Up to 450 m of continental coal- and gas-bearing strata of the upper Carboniferous-Permian Tunguska Series (Duzhikov et al., 1992); underlying lacustrine carbonates and sulfate evaporites (Cambrian to Ordovician), marine graptolitic shales and fossiliferous limestones (Silurian to Lower Devonian), argillaceous to conglomeratic strata with sulfate evaporites (Middle Devonian), evaporites (Upper Devonian) and shallow marine limestones (Carboniferous) (ibid.).	Basalts conformably to unconformably overlie the uppermost formations of the Neoproterozoic Shaler Supergroup (Table 3), a 4-5 km-thick weakly metamorphosed and gently folded, locally sulfidic and carbonaceous succession of platformal carbonate, sulfate evaporite, shale and quartzarenite which filled the shallow, intracratonic, Amundsen Basin (Christie et al., 1972; Young, 1981). Local steep dips and thrust faults in Brock Inlier are related to a number of deformational events culminating in the Cretaceous Laramide orogeny (Jones et al., 1992). The basalts and a complete section of the Shaler Supergroup are preserved only in Minto Inlier.
VOLCANIC STRATIGRAPHY AND PETROLOGY: Basalts are petrologically comparable, with kilometers of stratigraphy recording multiple phases of volcanism.	Lightfoot et al. (1990) and Naldrett et al. (1992) have reported four phases of volcanism representing an aggregate thickness of 2,200 m.: 1) alkalic to subalkalic, tholeiitic, and tholeiitic to picritic; 2) thick tuff; 3) tholeiites to picrites; 4) tholeiites. Olivine basalts are abundant in the Noril'sk region, and individual sheets of the lower three phases are thinner toward the flanks of the region (Naldrett, 1989). Isopach maps indicate close control on basalt thicknesses by regional faults, particularly the Noril'sk-Kharaelakh Fault (Naldrett et al. 1992). The fourth phase of volcanism is distributed widely across the Siberian Platform.	The Natkusiak Formation in Minto Inlier is the only extrusive representative of the Franklin event; it is 1100 m thick and has been subdivided by Jefferson et al. (1985) into seven regionally mapped volcanic members including a near-basal pyroclastic unit with significant lateral variations. Forty to fifty individual flows range in thickness from 0 to about 70 m and some have been traced laterally for up to 30 km. Minor mudstones and carbonates separate some flows. Pumpellyite grade burial metamorphism records pressures and temperatures suggesting that these flows were originally more than 2,000 m thick (ibid.). The compositions of the Natkusiak basalts are typical of continental tholeiites; however, their trace element characteristics imply some interaction with a crustal component (Dostal et al., 1986). Systematic petrology and detailed mapping have not yet been undertaken on these plagioclase-pyroxene-dominated basalts, although chemical variants include olivine rich phases (Dostal et al., 1976; Heaman et al., 1992).

Feature	Noril'sk - Talnakh Region (Permian Siberian Traps); NW Siberia	Amundsen Basin (723 Ma Franklin Event); NW Canada
DEFORMED DEEPER STRATIGRAPHY: below sill-bearing sequence, is also epicontinental; extent beneath basalts uncertain	Deformed Paleozoic epicontinental sequence: fluvial conglomerates and quartzarenites.	Open-folded and thrust-faulted 1270 Ma Coppermine basalts and conglomeratic sandstones (Baragar and Donaldson, 1973; Hildebrand and Baragar, 1991). Focus of 1270 Ma Mackenzie dyke swarm was north-central Victoria Island, same as the Franklin event.
TECTONIC SETTING Both cratonic margins.	Northwest part of the Siberian Platform (Fig. 1 of Naldrett, 1992)	NW corner Canadian Shield; bounded by marked break in aeromagnetic pattern (Fig. 13).
ASSOCIATED MAJOR FAULTS; PROXIMITY TO FOCUS OF MAGMATISM: Both areas are bounded by major associated faults which appear to have been near the focus of magmatism and also influenced the style and location of basalt eruption and sill emplacement. These faults appear to be the surface expressions of major crustal breaks.	Many of the mineralized intrusive centres of the Noril'sk-Talnakh mining camp are associated with the Noril'sk-Kharaelakh Fault (Naldrett, 1989). This fault is considered to be deep-seated, to have acted as a conduit for upwelling magma during the Early Triassic and to have been reactivated during subsequent rifting. The associated economic intrusions appear to be restricted to localities where the Noril'sk-Kharaelakh Fault impinges on the borders of depositional troughs in the pre-Permian country rock. These troughs are also coincident with thickening of the flood basalts (Genkin et al., 1981). At Noril'sk, the economic sulfide-bearing intrusions are inferred to represent volcanic conduits which radiated upward and outward from master magma chambers at depth.	Significant northeasterly trending piano-key-type faults from Glenelg Bay (Fig. 6) to Minto Inlet have offsets in the order of tens to hundreds of metres; NE faults with lesser offset cut the basalts in the axis of Minto Inlier (Jefferson et al., 1985) and some are differentially intruded by sills and dykes (Figs. 6, 9). The only ultramafic differentiates and some of the thickest sills found to date are also in Glenelg Bay area. A major northeast-trending crustal break from Mackenzie Delta to Lancaster Sound (an extension of the Kaltag-Porcupine Fault? cf. Jones, 1980) is inferred to transect the NW side of Minto Inlier, from Minto Inlet to Glenelg Bay, based on a significant break in regional aeromagnetic anomalies (Fig. 13) which is not manifested in Paleozoic cover. Also, Rainbird (1993) has described stratigraphic evidence for mantle plume uplift under NE Minto Inlier. Minor NW faults occupied by dykes may be more significant on flank of the uplift.
SYN- AND POST-VOLCANIC TECTONISM: Both areas record immediate pre- and syn- basalt tectonism. Post-basalt tectonism is documented in Siberia and possible in NW Canada.	Stable continental platform; deeper tectonic record not investigated for this comparison. Post-volcanic rifting and considerable subsidence are recorded by trough-filling alluvial conglomerates and sandstones of Late Triassic to mid-Tertiary age (Tamrazyan, 1971). The major Noril'sk-Kharaelakh Fault described above is related to pre-, syn- and post-basalt tectonism.	Stable continental platform. Local small faults, subtle pre- and syn-basalt uplift in NE Minto Inlier, interpreted as plume-related crustal doming (Rainbird, 1993); corroborated by a swarm of intrusive breccia pipes concentrated along NE Holman Island Syncline (see Figs. 7, 9, 10; further details in text). Post-basalt tectonism has no sedimentary record in Amundsen Basin, but syn-sedimentary rifting has been documented in correlative Mackenzie Mountains strata (see text).
ASSOCIATED LARGE INTRUSIONS: Both have associated gravity and magnetic anomalies which are inferred to represent large mafic-ultramafic intrusions	A pronounced 25 mGal regional gravity anomaly is located beside the Noril'sk-Talnakh Fault and is ascribed to a downward projecting conical distribution of denser igneous rocks. Naldrett (1992) inferred the presence of a buried large intrusion near Noril'sk for petrogenetic reasons (see text for further discussion).	The 130 mGal Darnley Bay gravity anomaly on the NW corner of Brock Inlier is coincident with an aeromagnetic anomaly. It is SW of a U-shaped array of five other 80-100 mGal gravity anomalies, some coincident with moderate aeromagnetic anomalies. All are inferred to be mafic intrusions based on interpreted densities in the order of 3.0 g/cc (McGrath et al., 1993). Relationships to Franklin Events are tenuous (see text).

Feature	Noril'sk - Talnakh Region (Permian Siberian Traps): NW Siberia	Amundsen Basin (723 Ma Franklin Event); NW Canada
MORPHOLOGIES OF GABBRO-DOLERITES: Both regions have chonoliths, climbing sills, dykes feeding sills, and a range of thin to thick tabular sills and dykes.	i) sheet-like bodies ranging from thin sills to huge masses of several hundred cubic kilometers, ii) thin dykes less than a few tens of meters in width and iii) chonoliths (Genkin et al., 1981) are defined as gabbro-dolerite intrusions of highly variable shape; in this region chonoliths assimilated wall rocks.	i) most are sills, ranging from a few metres to more than 120 metres in thickness, being most abundant and thickest in the Glenelg Bay area; ii) huge masses in Glenelg Bay (Fig. 6) with sharp margins bounded by syn-magmatic faults; thick masses also in Duke of York Inlier (Fig. 12A); iii) one chonolith mapped at Kilian Lake (Fig. 9) feeds several sills and has assimilated wall rocks.
CONTACT META-ORPHISM: Sills in both regions have contact magnetite-chalcopyrite-pyrite skarns with locally elevated PGEs.	i) and iii) above have wide (up to 100 m) contact metamorphic aureoles. Numerous small skarns with elevated PGE are characteristic of the mining camp.	i) & ii) above: in Minto Inlier, Duke of York Bay and Cape Lambton, large gossans record pervasive contact metamorphism and magnetite skarns. (iii) above and a skarn in an intrusive breccia complex yielded anomalous PGE (Figs. 4, 8, 9) .
SOURCES OF S, Se, As.	Abundant coal measures, petroleum-bearing strata and sulfate evaporites beneath Traps and intruded by sills.	Abundant carbonaceous shales with disseminated pyrite; pyrobituminous sands in Nelson Head Formation (Rainbird et al., 1992; 1994).
VARIED SULFUR ABUNDANCES AND HEAVY SULFUR ISOTOPES: Sulfur abundances range widely, and $\delta^{34}S$ ranges from negative values to +28 ‰.	Most uneconomic intrusions contain < 0.10 wt.% S, average $\delta^{34}S$ ranges from +0.1 to +4.6 ‰. Mineralized non-economic intrusions range from 0.17 to 0.34 wt.% S with average $\delta^{34}S$ of +5.5 to +8.4 ‰. Economic sulfide-bearing intrusions contain on average 0.95 to 2.2 wt.% S, with average $\delta^{34}S$ values from +8.9 to +11.4 (Grinenko, 1985).	S abundances range from <100 ppm to 10% (Fig. 16C); $\delta^{34}S$ ranges from -15 ‰ to + 18 ‰ (Fig. 18). Most high values and ranges of $\delta^{34}S$ (Fig. 22) are in sills of the upper Shaler Supergroup in Minto Inlier, particularly sills #4, 5 in the upper Wynniatt and Kilian formations. One exception, sill # 26 at Coppermine Townsite, ranges up to +28 ‰. Brock Inlier is nondescript (Fig. 18B); sills range from 0 to +8 ‰.
CUMULATES	Both magmatic suites contain plagioclase-olivine cumulates; Olivine is both early and late (Fig. 14).	
DIFFERENTIATION	Parts of both suites are strongly differentiated from picrites to granites. A synopsis of range of mineralogy and textures observed in Franklin sills is given in Fig. 14.	
SELENIUM & ARSENIC	Se and As are locally highly enriched in the sills and contact skarns in both Noril'sk camp and Franklin gabbro-dolerites, Amundsen Basin. Chondritic S/Se ratios are typically 4,000; highly contaminated gabbro-dolerites are typically 40,000; but contamination of Noril'sk and Franklin gabbro-dolerites with Se as well as S has led to high abundances of both, and depressed S/Se ratios in the order of 3,000. Se in both regions is thought to be from carbonaceous strata. Fig. 17D shows S/Se vs Mg # for Amundsen Basin; Fig. 20D shows S/Se vs Mg # by formation for northeastern Minto Inlier. Se exceeds 2% in massive pyrite skarn adjacent to breccia dyke at station 93JP13, northeastern Minto Inlier (Fig. 5) cwj940418	

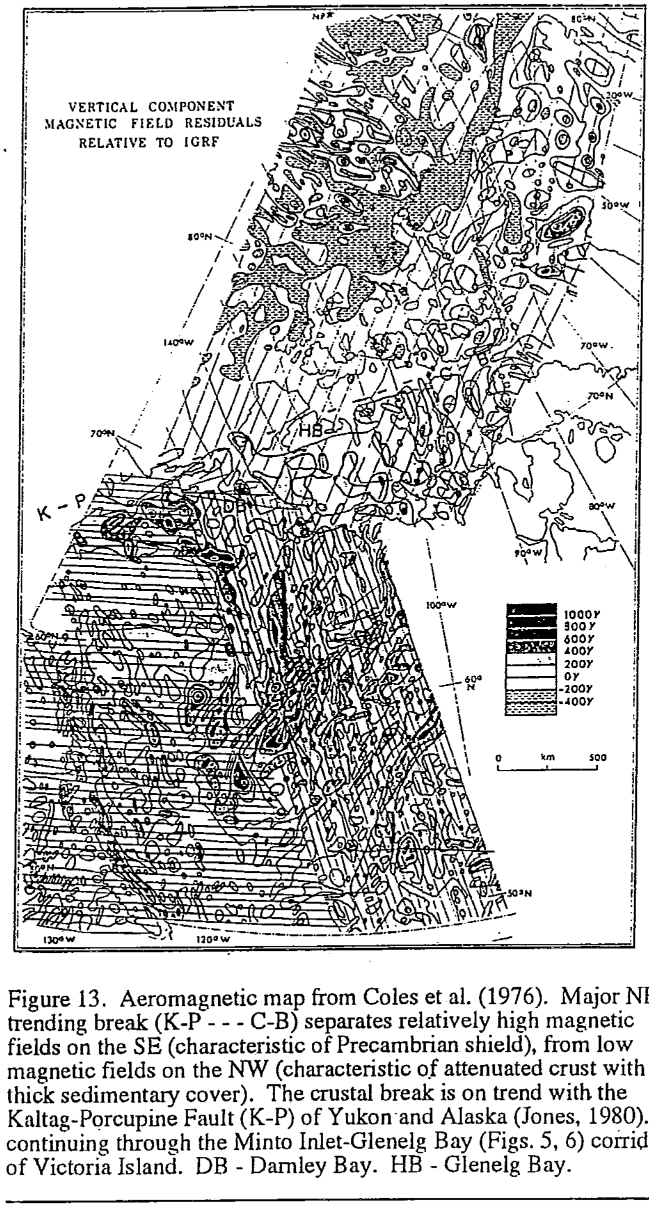


Figure 13. Aeromagnetic map from Coles et al. (1976). Major NE-trending break (K-P - - - C-B) separates relatively high magnetic fields on the SE (characteristic of Precambrian shield), from low magnetic fields on the NW (characteristic of attenuated crust with thick sedimentary cover). The crustal break is on trend with the Kaltag-Porcupine Fault (K-P) of Yukon and Alaska (Jones, 1980), continuing through the Minto Inlet-Glenelg Bay (Figs. 5, 6) corridor of Victoria Island. DB - Darnley Bay. HB - Glenelg Bay.

pyroclatic member is thicker and more continuous to the southwest; it is underlain by several flows in the southwest but not in the northeast; pillowed flows are present in the southwest but not in the northeast, and dykes cutting the basalts are much more numerous toward the northeast. Additional field data reported here (Figs. 4 - 12), including the breccias (see following), further support the concept of northeastern Minto Inlier being at or close to a focus of the Franklin basalt eruptions.

Intrusive Breccia Complexes comprise brecciated Shaler Supergroup strata and gabbro-dolerite sills, punctuated by olive-green-weathered conical mounds and keyhole dykes of brecciated and minor massive gabbro-dolerite (e.g. Fig. 7). These were mapped in northeastern Minto Inlier, only along the axis and northwest side of Holman Island Syncline (Fig. 5). Diameters of the complexes range from several hundred metres to several kilometers. The lake marked "volcanic centre?" west of Kilian Lake on Fig. 8 is the largest inferred to date, and station 93JP58 (Fig. 7) the second largest.

The circular breccia complexes are surrounded by upturned, faulted and complexely folded but unbrecciated Shaler Supergroup strata and Franklin sills. Internally, the complexes comprise large areas of poorly exposed, intensely brecciated and highly disrupted Shaler Supergroup strata, and brecciated gabbro-dolerite. The degree of brecciation and disruption decreases gradually toward the margins of the complexes. Marginal brecciation is manifested by in-situ shattered sills and sedimentary strata which preserve tilted and faulted geometries (e.g. stations 58 Q, W of Fig. 7). The broad areas of brecciated stata are punctuated by dark- to light-olive-weathering plugs of brecciated gabbro-dolerite and vesicular basalt. The plugs also include minor amounts of unbrecciated gabbro-dolerite and amygdaloidal basalt.

A deeper stratigraphic manifestation of the breccias is a northwest-striking keyhole-shaped dyke with intense marginal breccia and extensive linear gossan (stations 93-JP-10 to 13; Fig. 5) which cuts the Boot Inlet Formation, Reynolds Point Group. The dyke is 10-50 cm thick, gabbro-dolerite in composition, with mm-size spherical olivine and pyroxene crystal aggregates concentrated along the centre, suggesting flow-differentiation. The margins of the dyke are very fine-grained gabbro-dolerite to amygdaloidal basalt, grading through brecciated sedimentary rocks with basalt matrix, to brecciated and intensely altered and gossanous sedimentary rocks, mainly dolostone. Multiple intrusion is recorded by fragments of fragments. Pyrite is disseminated in the dyke and forms disseminated to massive pods in the adjacent brecciated dolostone. Grab samples of this pyrite contain up to 2,000 ppb selenium.

Although little of the third dimension is exposed, the stratigraphic distribution of the breccia bodies, the keyhole- to sub-circular shapes of entire complexes and internal gabbro-dolerite bodies, and the conical relief of the gabbro-dolerite bodies, strongly suggest that these are vertical pipes that were intruded at high velocities from considerable depth and expanded upward as confining pressures were released (Fig. 4).

The vent facies of the intrusive breccias is exposed south of Kilian Lake (just east of Station 93JP76; southwest corner of Fig. 8), where a circular breccia complex is coincident with the exposed unconformity between the Kilian Formation and overlying Natkusiak basalts. The circular breccia body is flanked by upturned and block-faulted dolostones of the Kilian Formation. Variable thicknesses (a few to 30 metres) of cross-bedded and massive-bedded, fine-grained to boulder breccia fills small fault grabens, mantles small horsts and pinches out within a few km to the east and southwest of the circular intrusive breccia body.

West of Fig. 8, at the type section of the Kilian Formation (Thorsteinsson and Tozer, 1962), another manifestation of the explosive breccias was previously observed by R.H.R.: low-angle breccia sheets feed upward into similar extrusive breccias which also fill small grabens at the faulted Kilian-Natkusiak contact. Low-angle gabbro-dolerite sheets here are highly amygdaloidal and chilled on both sides. These sheets were previously interpreted by Young (1981) as basalt flows in the Kilian Formation.

The faults at the Kilian-Natkusiak interface are interpreted as accommodating explosive uplift and collapse during breccia eruption (compare with Station 93-JP-58, Fig. 7). The lithology of intrusive breccias (Stations 93JP58 and 75) and extrusive breccias (Station 93-JP-76) is identical - both breccias include carbonate and scoriaceous basalt fragments. The intrusive breccias are thus interpreted as the sources of the extrusive heterolithic breccias.

The coarse extrusive breccias southwest of Kilian Lake are correlated to the southwest with the finer grained Lithic Pyroclastic Member of the Natkusiak Formation which was initially described by Jefferson et al. (1985) and referred to as the "red bed" member by Dostal et al. (1988). The term "red bed" is inappropriate for this member because it is used for hematitic sedimentary rocks, whereas the Lithic Pyroclastic Member is clearly volcanic, and its lower half is green in the southwestern part of Minto Inlier. Based on this lithostratigraphic correlation, further evidence of doming is provided by the several basalt flows which underlie the Lithic Pyroclastic Member in southwestern Minto Inlier but are absent (due to erosion or non-deposition?) in the northeast. In addition, strong thickness changes in the Lithic Pyroclastic Member shown by Jefferson et al. (1985) suggest local sources and therefore more pipes should be found in southwestern Minto Inlier.

Jefferson et al. (1985) and Dostal et al. (1988) interpreted the Lithic Pyroclastic Member as a result of phreatic explosions (hot basalt interacting with seawater and wet sediments to cause steam explosions). However, the intrusive breccias which are exposed cutting strata as low as the Boot Inlet Formation show that the magmas themselves were very high in volatiles and the explosions are easily explained as a result of pressure release during high-speed ascent of the magmas. The intrusive and extrusive breccias are thus interpreted as physical evidence of abundant SO_2 release during the Franklin magmatic Events. This is an important point regarding potential sources of sulfur for Ni-Cu-PGE deposits.

Major Faults Associated with the Franklin Events

The northeast-striking fault array mapped in the Glenelg Bay area of Minto Inlier (Figs. 5, 6) provides a crucial analogue to the Noril'sk-Kharaelakh Fault (Table 4) which is thought to be so critical to localization of the massive sulfide deposits at Noril'sk (Naldrett, 1989; 1992). The Glenelg Bay fault array extends to the Minto Inlet area (unpublished field data of R.H.R.), and has a weaker manifestation close to the basalts, although some northeasterly faults in the Kilian Lake area (Fig. 8) and those to the southwest shown by Jefferson et al. (1985) are also part of this array.

The Glenelg Bay fault zone is coincident with a pronounced regional break in the aeromagnetic pattern of northwestern Canada (Fig. 13), which we interpret as marking the edge of the contiguous Canadian Shield as basement to the Phanerozoic cover. This aeromagnetic break does not have any obvious expression as major Phanerozoic facies changes and thus must be Precambrian in origin, although local offsets of the Phanerozoic-Proterozoic contact may have resulted from reactivation of northeasterly Proterozoic faults.

The northeasterly faults are defined in the Glenelg Bay area by straight lineaments which outline piano-key-like offsets of a unique stratigraphic sequence (Nelson Head\prominent sill\Aok\Grassy Bay formations; Fig. 6). The map offsets are multi-kilometers in scale and are interpreted to record normal (extensional) offsets in the order of hundreds of metres for the following reasons. The fault traces must be near-vertical, because they are straight in plan despite rugged local topography. Northeasterly faults in the Kilian Lake area (Fig. 8) were observed to be vertical in cliff faces. There is little overall strike-slip component because of the back-and-forth map offsets of the unique stratigraphic sequence. The large map offsets result from the gentle dip of the faulted strata. A reverse component is unlikely because there is no compressional fabric present, and the dip of the faults is too steep for thrust orientations.

No other parts of the Amundsen Basin preserve a record of extensional faulting such as that in Glenelg Bay. The large faults in Brock Inlier are north-northwest trending and have compressional Phanerozoic offsets (Jones et al., 1992). Northeast-striking faults in Brock Inlier postdate the northerly trending faults and delimit horsts and grabens occupied by coal measures. The Darnley Bay anomalies are located southeast of the northeast-trending magnetic break, as are the other combined gravity and aeromagnetic anomalies (Figs. 3, 13).

Northwest-striking dykes, associated minor faults and fractures (Figures 5, 6, 8) are very numerous in northeastern Minto Inlier and are distinguished from faults elsewhere in Amundsen Basin by their straight, sharp surface traces, uniform strikes and distinctive lineaments visible on aerial photographs. The northwesterly faults and fractures are here interpreted in part as adjustments of the sedimentary and volcanic pile to the volume of gabbro injected into them at this focus of eruption. These adjustments were mapped in Glenelg Bay area as sharp northeast-striking boundaries of sills (Fig. 6) which are very thick in one fault panel but thinner or absent in the adjacent panel (e.g. stations 93JP73, 74). Sill offsets across northwest-striking fractures were previously observed by R.H.R. in southwestern Minto Inlier. The uniform northwesterly strike of the fault array also implies a regional stress field, interpreted by Rainbird (1993) as a result of mantle plume uplift to the north-northeast of Minto Inlier. This array could also have accomodated northeast-southwest extension after extrusion of the lavas. North-northwest-striking dykes and lineaments are uncommon in southwestern Minto Inlier and rare in Brock Inlier (e.g. 93JP109, Fig. 9) and Coppermine area (e.g. stations 93JP91, 95; Fig. 13B).

Faults associated with the unconformity between the Mikkelsen Islands and Nelson Head formations have a subtle surface expression but were active during sedimentation, as reflected in conglomerates developed at the unconformity (Rainbird et al., 1992a). These are also occupied by Franklin dykes (e.g. the northerly trending fault occupied by a dyke crossing Rae River at station 93JP91, Fig. 13B) was active during sedimentation of the Other more gradual facies and thickness changes in the basalts are more widespread and may be related to local extrusive architecture. A few local extrusive centres are also inferred for southwestern Minto Inlier, because there the pyroclastic unit varies from zero to more than 100 metres, and the basalts have local pillows and thickness changes suggesting local relief during eruption (Jefferson et al., 1985).

Pre-, Syn- and Post-Magmatic Tectonism

There is little direct record of faulting preceding or accompanying eruption of the Natkusiak basalts. Indirect evidence includes an angular unconformity at the base of the Natkusiak basalts in northeastern Minto Inlier (Jefferson et al., 1985), the southwest-northeast stratigraphic changes in the upper Shaler Supergroup and Natkusiak basalts, the northeasterly and northwesterly faults in the same area (see above), and the local faults associated with the intrusive breccia complexes. These were all better explained by Rainbird (1993; see **Foci** above) as the results of mantle plume-related crustal doming. The lack of extensional tectonism directly preceding the exposed flood basalts is more common than not in most flood basalt provinces. The most significant extensional faulting, commonly recorded by thick conglomeratic sequences with subordinate intercalated lavas, postdates the initial thick basalt eruption in the case of the Keeweenaw, Coppermine and Little Dal basalts (e.g. Jefferson and Parrish, 1989). Hooper (1990) corroborated this in other areas of the world, where pre-eruptive extension or doming is minor and in nearly all cases significant extension post-dates the main stages of volcanism.

The restricted areal preservation and the absence of any stratigraphy above the Natkusiak basalts precludes direct evidence of post-eruptive tectonism in Minto Arch. The prehnite-pumpellyite assemblage documented by Jefferson et al. (1985) was used to infer that present exposures of the Natkusiak basalts are only a remnant of a much thicker and more extensive volcanic pile. This could well have included a conglomeratic upper part. Many of the northwest-striking faults and the dykes that occupy them cut the flood basalts, with at least local small offsets. These prove post-eruptive tectonism in at least the preserved record of the Natkusiak basalts and are weakly comparable to the abundant dykes cutting the Columbia River and Deccan flood basalts (Hooper, 1990).

Other indirect evidence suggests faults which may have acted as feeders for gabbro-dolerite intrusions in Amundsen Basin. In eastern Minto Inlier (from 93JP79 to 80; Fig. 5), an unconformity has been documented by the presence of residual cherty breccias between paleokarsted Mikkelsen Islands Formation (former middle cherty dolostone) and Nelson Head Formation (former upper clastic member of Glenelg Formation) (Rainbird et al., 1992a). In the Coppermine area this unconformity is also marked by conglomerates and paleokarst topography associated with small northwesterly striking faults, one of which is occupied by a highly altered dyke (Station 93JP91; Fig. 13B) (Rainbird et al., 1992a).

Evidence elsewhere in the subsurface (Proterozoic faults interpreted in seismic profiles by MacLean and Cook, 1992), and thrust faults in the older Coppermine River Group (Hildebrand and Baragar, 1991), have clearly demonstrated that at least some northerly faults in the Amundsen Basin region, outside of Minto Inlier, were active during the Neoproterozoic.

Cook and Aitken (1969) inferred that some north-south block faulting took place on the western side of the Brock Inlier (Fig. 10), during sedimentation of the Shaler Supergroup. One fault thought to have initiated during the Proterozoic (Cook and Aitken, 1969) (thrust fault between stations 97 and 112, Fig. 9) is part of an array that offsets Paleozoic strata and could be a result of Laramide deformation, particularly on the western margin of the Brock Inlier, close to the gravity anomaly (Fig. 9). Proterozoic initiation of these faults was disputed by Jones et al. (1992) based on apparently uniform stratigraphic thicknesses of Proterozoic units across the faults. The uniform thicknesses were confirmed in 1993 by careful measurements of the Aok and Grassy Bay formations on each side of the putative Proterozoic faults.

Related Geophysical Anomalies and Inferred Large Intrusions

In the western Siberian Platform a 25 mGal regional gravity anomaly is located beside the Noril'sk-Talnakh Fault and is ascribed to a downward projecting wedge-shaped distribution of denser igneous rocks (unpublished Russian data presented to L.J.H. at Noril'sk). Naldrett (1992, p. 1955), in discussing the volume of magma required to derive the sulfide ore deposits by depletion of chalcophile elements in the Noril'sk gabbros, inferred that the ore in the northwest Talnakh intrusion must have been derived from a large volume of magma in a holding chamber at a deeper level than that of the exposed host intrusions. The 25 mGal gravity anomaly may represent this large volume of magma.

Naldrett also discussed an important corollary of the inferred deeper level of the Noril'sk-Talnakh holding chamber: magma therein could not have interacted with crustal sulfur in the Devonian evaporites which Godlevsky and Grinenko (1963) postulated to be the source of sulfur contamination. The sulfur must have come from sour gas (Grinenko, 1985) or other sedimentary units at deeper levels in the crust. The concept of deeper magma chambers is supported by the homogeneity of $\delta^{34}S$ within individual ore bodies (Eckstrand, pers. comm., 1994). These same corollaries may apply to the inferred parent magma chamber(s) for the Franklin Events.

One putative candidate for a Franklin magma chamber is the Darnley Bay combined gravity and magnetic anomaly, located on the west side of Brock Inlier (Fig. 10). This anomaly was discovered by a routine gravity survey of the Mackenzie District in 1969 (Hornal et al., 1973). A 1970 follow-up survey (Coles et al., 1976) revealed a large magnetic anomaly in the same location as the gravity anomaly. Stacey (1971) suggested that these anomalies are caused by a shallow, basic or ultrabasic intrusion. The direction of magnetization measured in the coincident magnetic anomaly was interpreted by Riddihough and Haines (1972) as compatible with that of the Franklin Events. Hornal et al. (1973) documented the feature as a 130 mGal circular gravity high, which is centred immediately south of Paulatuk on the west side of the Brock Inlier.

A 14 km seismic line over the western third of the Darnley Bay anomalies has been interpreted by Vye (1972) and Hole and Bradley-Isbell (1990) to indicate that the upper part of the intrusion is layered and the layering dips gently east (Fig. 10A). The layers in question are interpreted from a series of distinct reflectors at least 3 km below surface. The distinct reflectors indicated by the seismic line are less than 1 kilometre thick; material deeper than about 4 km caused no planar reflections. The above authors inferred that strata above the distinct reflectors are the Shaler Supergroup.

Magnetic and gravimetric modelling of the Darnley Bay anomalies by Chavez et al. (1987) suggested a steep-sided, basic to ultrabasic intrusion, at a depth of 1.5-3.3 km, that could be as thick as 15-20 km. Additional gravimetric data have been acquired and some problematic aeromagnetic data recalibrated (Geophysics Division, 1992). The gravimetric data have been modelled by McGrath et al. (1993), using two different methods. Both methods indicate a crustal scale (at least 15 km vertical extent), steep-sided, outward dipping, NE-SW elongated (50 x 37 km), cylindrical mass of basic composition, its density increasing from 2.995 to 3.095 toward the centre. The magnetic intensity also increases toward the centre. A secondary body which is 12 km in diameter and possibly connected, is located to the southeast. The plan outline of the two bodies (Figs. 1, 9) is interpreted from the maximum horizontal gradient of the aeromagnetic data (after Geophysics Division, 1992).

The cross-sectional shape of the body as modelled by McGrath et al. (1993) is summarized in Fig. 11. Assuming a velocity of 4.6 km/sec, the existing seismic data (Fig. 10) provide a depth estimate of 2.6 to 3.1 km for a near-horizontal reflector which was interpreted by Vye (1972) and McGrath et al. (1993) as the top of the intrusion.

D.G. Cook and B.C. MacLean (pers. comm., 1993) interpret the seismic line of Vye (1972) in the context of a regional seismic data base extending from Anderson and Horton Plains to Great Bear Lake (Fig. 1 of MacLean and Cook, 1992). They suggest that an unconformity (dash-dot line on Fig. 10) crosses the volume of rock considered by Vye (1972) and McGrath et al. (1993) to represent the basic intrusion. This interpretation holds that the variety of discontinuous distinct reflectors with varied orientations below the dash-dot line represent deformed Hornby Bay and Dismal Lakes groups. In contrast the gently east-dipping, very distinct reflectors show virtually no deformation and thus could represent the Shaler Supergroup. Cook and MacLean suggest that the igneous intrusion should have a massive character with little internal structure detectable by seismic techniques. If the igneous body is part of the Franklin suite, it should intrude the Shaler Supergroup, not be truncated by the flat-lying layers. Alternatively, the distinct reflectors may be Franklin sills in Mikkelsen Islands Formation of the Shaler Supergroup, unconformably overlain by Nelson Head Formation. In any case, the existence of an unconformity (dash-dot line), would require that the basic intrusion be much deeper in the section than the above models predict.

McGrath (pers. comm., 1994) has remodelled the gravity data assuming a depth of 7 km for the top of the body. With this assumption the shape is essentially the same, but density contrasts are greater (starting at 3.03 g/cc and increasing toward the centre. Remodelling of the aeromagnetic data has also been done with this depth assumption, and is also compatible. McGrath (pers. comm., 1994) points out that he favours the shallow interpretation because the distinctive seismic reflections at 2.6 to 3.1 km disappear to the west at the same place as the maximum gradient of the gravity data.

The potential economic significance of the Darnley Bay body and the possible genetic relationship of Franklin sills in Brock Inlier were further tested by careful documentation of exposed sill thicknesses and compositions. A lack of relationship is suggested by thinning and decrease in abundance of the sills toward the southwest in Amundsen Basin (Figs. 4, 9). In particular, only one sill is hosted by the Reynolds Point Group in the Brock Inlier area, and that single sill pinches out from about 10 meters to zero in the vicinity of station 93JP112 (Fig. 9). In contrast, several sills in the order of 50 to 100 metres thick are hosted by the same group in the Glenelg Bay area (Figs. 4, 6). The large area of gabbro mapped in the Hornaday River valley by Cook and Aitken (1969) was also investigated in 1993 and is typified by station 93JP97. The gabbro constitutes a single sill, no greater than 50 metres thick, which appears to be larger because it is flat-lying and dissected by fluvial erosion; thus being exposed for a considerable distance along each shoulder of the Hornaday River valley. A similar sill at the contact of the Reynolds Point Group and Minto Inlet Formation (stations 93JP103 and 105, Fig. 9) also has a very large outcrop area, north of the Little Hornaday River, which is also a function of erosional resistance and gentle dip.

All other aspects of exposed geology also give no hint of the Darnley Bay body, except possibly Darnley Bay itself and the Hornaday River which bisects the gravity anoomaly. These geographic features may result from increased crustal subsidence of the dense body. The Brock Inlier to the east is a structural uplift of Proterozoic strata surrounded by Paleozoic strata. The Inlier is transected by northwesterly striking steep faults which are prominent near its eastern and western margins, but the actual outlines of the Inlier are erosional exposures of the sub-Paleozoic unconformity. As noted earlier, movement on the northwesterly faults is inferred to be Devonian and later by Jones et al. (1992). There is no stratigraphic evidence that these faults are Proterozoic in origin, even though seismic profiling by MacLean and Cook (1992) convincingly documents Proterozoic faults in the subsurface of Anderson Plain, and one Proterozoic fault is inferred in our interpretation of seismic data of Vye (1972) on the west side of the Darnley Bay gravity anomaly (Figs. 10, 11). Furthermore, east-west faults which offset the western margin of Brock Inlier (Fig. 10) are post-Paleozoic, because the resultant grabens are filled by coal measures. There is no obvious stratigraphic or structural evidence of the inferred Darnley Bay body (but we are convinced it is there from the geophysical data!). This lack of evidence supports a Mackenzie age for the body, by comparison with the Coppermine area. There, a structurally repeated belt of Coppermine River Group basalts and conglomerates is bevelled and overlain by the Rae Group with no surface expression except possibly the syn-sedimentary fault and Franklin dyke at station 93JP91, which is on strike with a pre-Rae Group easterly directed thrust fault shown by Hildebrand and Baragar (1991).

Sills and Dykes of the Noril'sk Region

The gabbro-dolerite intrusions of Noril'sk and Amundsen Basin areas are compared briefly in Table 4. The majority of the Noril'sk intrusions are undifferentiated and barren. Only the differentiated intrusions (only 1-2 % of all intrusions), which are associated with the second phase of volcanism, contain ore bodies.

The differentiated ore-bearing intrusions are irregularly shaped and termed "chonolith", being typically less than 250 m thick, less than 1.5 km wide, and up to 12 km in length. In cross section most are lenticular and trough-shaped; fewer are tabular. Shapes of some intrusions vary substantially along strike and down dip, depending on the structure of the country rock. A characteristic that distinguishes the chonoliths from tabular sills of the Noril'sk region, is that there is no evidence that they pushed apart their wall rocks, but substantial evidence for wall-rock assimilation in their geochemistry (see below), even though xenoliths are not abundant. Some dykes and other sills pre- and post-date the chonoliths.

In the Noril'sk-Talnakh camp, the ore-bearing differentiated chonoliths are characterized by a regular lithological sequence. However, apart from the obvious olivine-rich cumulates (picrite, picrite gabbro-dolerite, troctolite and feldspathic peridotite and dunite) in the lower part of these bodies, many of the lithological units and transitions are subtle and their recognition requires special attention and petrological verification. The typical sequence from top downward at Noril'sk-Talnakh Camp is:

1) upper contact gabbro-dolerites,
2) upper taxitic gabbro-dolerites, quartz-bearing gabbro-dolerites, gabbro-diorites and diorites,
3) olivine-free and olivine-bearing gabbro dolerites,
4) olivine gabbro-dolerites,
5) picritic gabbro-dolerites,
6) taxitic gabbro-dolerites
7) lower contact gabbro dolerites.

For a more detailed description of these lithologic units the reader is referred to Hulbert et al., 1988 (p. 68).

The "taxitic" rocks of Noril'sk vary in grain size from medium to coarse and pegmatitic, with a pronounced ophitic to poikilophitic texture. Taxitic texture is found in patches and irregular zones in the Noril'sk intrusions, and is ubiquitous in the upper and lower contact zones of the mineralized chonoliths. It is considered to represent more slowly cooled volatile-rich magma pockets resulting from assimilation of country rock strata (ibid.).

Extensive metamorphism and metasomatism of country rocks forms wide aureoles at the upper and lower contacts of the Noril'sk chonoliths. Genkin (1981) stressed that the aureoles are much larger about the mineralized chonoliths than about others - far larger than can be explained by higher fluid contents of the magmas and the nature of country rocks (e.g. more pronounced aureoles in carbonate and evaporite hosts than in quartzarenite hosts). The extensive aureoles could be explained if the chonoliths were conduits for the overlying volcanics, and a much larger flux of magma was associated with them than their present size would suggest.

Morphologies of Franklin Gabbro-Dolerites, Amundsen Basin

In contrast to the Noril'sk region, much less is known about the shapes and structural settings of sills and dykes of the Franklin Events, although the information collected in this study indicates strong similarities (Table 4) and further investigations will likely strengthen the comparison. For descriptive purposes and slightly modifying the convention started by Dostal et al. (1986), the sills in Fig. 4 are numbered from the top down, starting in the Kuujjua Formation immediately below the Natkusiak basalts. The same sill numbers in the separate domains are based solely on stratigraphic position and do not necessarily (although they might) represent the same continuous sills. Descriptions by domain are as follows.

In Minto Inlier all formations are intruded by at least 29 major to minor gabbro sills (Fig. 4) and numerous smaller sheets that were not distinguished here. The sills are generally 5-70 m thick but locally attain thicknesses of 120 m or more. In much of Minto Inlier the sills are relatively uniform sheets intruded concordantly within the sedimentary strata. Christie (1964) mapped some sills as being laterally continuous for up to 50 km along strike. On a gross scale the sills are structurally conformable and appear to be evenly distributed throughout the stratigraphy. Most sills transect the stratigraphy to some degree, and preferentially intrude quartzite-shale and carbonate-shale transitions, carbonate members of the evaporitic formations, and are randomly distributed within carbonate formations. On the northwest limb of Holman Island Syncline, the transgressive tendencies of sills are amplified, as follows.

Sill number 4a-4b (Fig. 4), a part of which is mapped in Fig. 8, climbs stratigraphy in a northwest-to-southeast direction, from upper Wynniatt to mid-Kilian formation. Its upper component (4a), is much more differentiated and amygdaloidal than its lower component at the same distance from the base. For example, sill 4a is distinguished at its 63-70 m level (Station 93-JP-71) by granitic segregations and marked layers defined by liquid immiscibility features and concentrations of amygdules (see detailed descriptions of petrologic units below).

In the Glenelg Bay area (Fig. 6) and in the Duke of York Bay area (Fig. 12A) some sills form chonoliths to huge tabular masses, more than 100 metres thick. Rectilinear shapes of the thick sills in Glenelg Bay suggest that they preferentially invaded specific fault blocks. One of these thick masses was sampled at station 93-JP-73, where it is associated with angular float of layered uultramafic rocks which are of very local derivation. Station 93-JP-77 sampled a distinct gossan at the base of part of another irregular intrusive complex to the southwest, where partially melted footwall quartzarenites record high heat-flow.

A distinctive chonolith of gabbro-dolerite invades the Wynniatt Formation north of Kilian Lake at stations 93-JP-27 to 30 (Fig. 8). This chonolith emulates its Russian namesakes in being several hundred metres in vertical dimension, but only 200-1000 m in outcrop width. The ragged sub-vertical contact margins of this chonolith and the abundant xenoliths and disseminated sulphides around its margin indicate that it melted rather than pushed its way in. This chonolith feeds several tabular sills to the east, but terminates to the west. It is separated by a thin screen of Wynniatt Formation from overlying sill No. 6 which is continuous to the east and west. An extensive gossan at the top of the Kilian chonolith is a weathering product of abundant disseminated pyrite and pyrrhotite. Grab samples of the sulphidic material contain up to 48 ppb Au, 67 ppb Pt and 427 ppb Pd. Heaman et al. (1992) had noted the presence of such bodies, and R.H.R. guided our field studies to this area. Irregularly shaped, and apparently isolated sills of variable thickness in the Minto Inlet area are also suggested by Fig. 4b of Heaman et al. (1992), but limited logistics prevented access by this study, and this speculation still needs to be tested by detailed field studies.

The most numerous and obvious dykes in Minto Inlier trend northwesterly; a number of these feed laterally into sills (Baragar, 1976); others intrude and feed sills within the basalts; but none have been shown to feed basalt flows (Heaman et al., 1992), even though they show similar chemistry (Dostal et al., 1986). Heaman et al. (1992) documented sills feeding flows, and this is fortified by observations here that upper sills are highly vesicular. Some flows were probably fed directly by conduits through the breccia complexes, because several plugs cutting the breccias are essentially vesicular basalt. As noted above, the intrusive breccias (see **Foci of Franklin Magmatism**) are almost certainly the sources of the lithic pyroclastic member of the Natkusiak Formation.

The northwest-striking dykes tend to weather positively and are draped by Phanerozoic cover on both sides of Minto Inlier. The strikes of the dykes appear to be controlled by pre-existing northwesterly fractures which have minor fault offsets and form distinct lineaments transecting the entire Minto Inlier. The lineaments are most abundant in the northeast. Most of these lineaments are not occupied by dykes. In the Glenelg Bay area (Fig. 6) northwesterly lineaments form straight boundaries to tabular masses of gabbro-dolerite, and obviously accommodated differential intrusions during magmatism. For example, at station 93JP73 the sill is more than 100 m thick; immediately adjacent to this station but on the northeast side of a northwesterly lineament, two much thinner sills occupy the same stratigraphic position with very little fault offset of host strata except to accommodate the much thicker sill on the southwest side. The lower of the two thin sills was sampled as station 93JP74. Similar observations apply elsewhere in Minto Inlier; for example the recent map of NTS 78B/7 by Rainbird et al. (1994b) also illustrates rectilinear boundaries to sills.

In the Brock Inlier, all formations of the Shaler Supergroup are intruded by a series of prominent gabbro-dolerite dykes and sills whose thicknesses range from 1 - 50 metres, texture ranges from very fine- to-coarse ophitic to granular, and composition from olivine gabbro to quartz gabbro (Cook and Aitken, 1969). Chemical analyses of this study are very similar to those of Minto Inlier (see following chapters). The sills form subdued cuestas and bluffs, much more subdued than in Minto Inlier, which preserve exposures of softer Shaler Supergroup strata beneath.

Most sill exposures in Brock Inlier are limited in lateral extent to <20 km, although a sill is exposed for 50 km along the Hornaday River on the west side of the inlier at its contact with Paleozoic strata (Fig. 9). This sill was mapped along its strike-length, and sampled at station 93JP97 (Fig. 9) - it is only about 50 m thick and subhorizontal, located in structural conformity at the contact between the Mikkelsen Islands (NMI) and Nelson Head (NNH) formations. Paleozoic rocks unconformably overlie the Shaler Supergroup at this locality and there is no evidence of Proterozoic faulting. Elsewhere in Brock Inlier, mapped sill exposures are concentrated in certain stratigraphic zones and may be parts of single extensive sills in these zones. Six exposures are within basal mudrocks (Escape Rapids Formation, NE), five are at the NE\NMI contact, eight including the 50 km Hornaday River sill are at or near the NMI\NNH contact, one is a thin continuous sill in the base of Reynolds Point Group (NRP), and more than six exposures appear to be parts of two sills in Minto Inlet Formation (NMI). The sills are sheet-like in shape but arcuate in plan because of their dissection along river canyons, and the many separate exposures translate into only the nine stratigraphic sill occurrences shown in Fig. 4. For consistency, the numbers assigned to these sills are the same as those at the same stratigraphic positions in Minto Inlier (right-hand colummn). Is it possible that some of these are actually the same sills? Sill number 16 pinches out to the southwest at station 93JP112. The entire area of Minto Inlet Formation along Little Hornaday River is interpreted to be underlain by sill number 13, which was sampled at stations 93JP103 and 105. Sills (only one?) intruding Minto Inlet Formation along Amundsen Gulf are poorly and discontinuously exposed.

In the Duke of York - Coppermine region (Coronation Gulf; Figs. 13A, 13B) up to fifteen 50-100 m-thick sills have been noted by Robertson and Baragar (1972), and seven were examined for this study (stations 93JP 90-96). The sills around Coppermine (Fig. 12B) are about the same order of thickness as in Brock Inlier and are interpreted to be relatively peripheral to the magmatic centre. In Duke of York Inlier (Fig. 12A), however, very thick and extensive sills, with relatively intense contact metamorphism, suggest proximity to source of magmas. Chemistry is very similar to that in Brock and Minto Inliers, varying more with thickness of sills and stratigraphic position than with lateral position.

In the northern Slave Structural Province, south of Coronation Gulf, moderately dipping to sub-horizontal gabbro sheets transect Archean supracrustal and granitoid rocks, and range in thickness to several hundred 100 metres. Stations 89RJ120, 90RJ543 (courtesy of R. Johnstone, 1990) and 89JPS165 (courtesy of Schaan, 1991, 1993) represent these sheets, although they were not systematically sampled like those of the Amundsen Basin region.

The remaining areas of Franklin igneous rocks are characterized by dykes as described by Heaman et al. (1992), except in the region around Great Bear Lake, where northeasterly trending dykes are now known to be part of the 779 Ma event (LeCheminant and Heaman, in press) and are not shown in Fig. 2. In northern Baffin Island, the Franklin dykes radiate from a focus toward the northwest; on Somerset Island the Franklin dykes trend northeasterly.

Contact Metamorphic Effects of the Franklin Gabbro-Dolerites

Previous studies: Contact metamorphism has not been systematically documented prior to this project. Jefferson et al. (1985, 1988) stated that serpentinization of argillaceous dolostones in Minto Inlier generally is limited to 1 to 3 metres above and below sills, except where sills are closely spaced. In the case of sills spaced within 50 m of each other, and sills thicker than about 80 m, serpentinization extends up to 10 metres away. Metamorphic effects in siliciclastic rocks are not extensive. In the Mikkelsen Islands Formation in Hadley Bay area (e.g. sills around stations 93JP62, 63, 79, 80; Fig. 5), large euhedral magnetite crystals in serpentinized dolostone/marble are associated with sills (Jefferson et al., 1988). Unpublished field notes of R.W. Baragar suggest that there are contact aureoles on some of the Coronation sills, for example a 3 metre bleached zone against Mikkelsen Islands Formation dolostone for the sill dated by Heaman et al. (1992). Jones et al. (1992) specifically examined many dyke-sediment contacts in a search for carving stone (serpentinized dolostone) occurrences. They documented dozens of such contact aureoles in the Coppermine area and Brock Inlier; most are less than 1 metre thick. The largest alteration zones are associated with northwest-striking dykes, and one such locality on the south side of Rae River (opposite station 93JP91; Fig. 12B) has supplied carving stone to Coppermine residents for generations. The latter site is the same locality where paleokarst and conglomerate wedges attest to paleo-growth faulting along the fracture now occupied by the dyke (Rainbird et al., 1992a).

This study has confirmed the above observations, especially the regional differences which appear to be a result of size and abundance of sills, but even here the documentation has been incidental to examination of the sills. Thinner and less abundant sills in the Coppermine Area and Brock Inlier have relatively thin and inconspicuous aureoles of serpentinized dolostone or other evidence of magma-wall rock interaction. The greatest alteration appears to be laterally adjacent to dykes, probably due to fluid movement along bedding planes. The uppermost sill in the Little Hornaday River area (Station 93JP104; Fig. 9) is the most altered gabbro-dolerite observed in Brock Inlier. Its upper and lower thirds are intensely altered and vesiculated, and transected by aphanitic secondary dykelets; spheroidal and reticulate rubbly weathering patterns are developed here, and all phases contain disseminated pyrite (rare chalcopyrite). This sill clearly resulted from multiple magma injections, the early ones incorporating abundant volatile material from the country rocks.

In the Glenelg Bay and Kilian Lake areas of Minto Inlier (Figs. 5, 6 and 8), thick irregular intrusions have extensive alteration haloes, as well as internal evidence of magma-wallrock interaction (see Contact Gabbro-Dolerite below). Gossans related to magnetite- and pyrite-chalcopyrite skarns are widespread in the Hadley Bay area (Rainbird et al., 1992a, 1994b), along the Kuujjua River (I. Mason, pers. comm., 1993), on southern Banks Island (Jefferson et al., 1988), and in the explosive breccias of northeastern Minto Inlier (Fig. 7).

Based on field observations of contact relationships it appears that the magnitude of reaction between the intrusions and country rocks is governed mainly by the composition of the latter. In most cases intrusions in contact with argillaceous and siliceous strata display rather limited contact effects and have relatively thin thermal aureoles (~10-50 cm), whereas many carbonate footwall rocks (i.e. Minto Inlier, Sill #5) were observed to display thermal metamorphic effects over several to tens of meters from the intrusive contact. In some instances it was observed that carbonate country rocks also are associated with highly vesiculated and carbonatized fine-grained contact gabbro-dolerite zones with anomalous concentrations of barren pyrite both in the chills and the surrounding meta-carbonate.

Although carbonates generally were more reactive than non-carbonates, anomalous thermal metamorphic conditions are recorded by local rheomorphic melts (with abundant pyrite) in quartzarenites of the Grassy Bay Formation beneath Sill #20 in Glenelg Bay (station 93JP77, Figs. 5, 6). Coupled with the discovery of ultramafic blocks 10 km to the northeast (Sill #21; Station 93JP73), this suggests that an anomalous (prolongued?) heat source was associated with the Franklin sills located in the Glenelg Bay area. The presence of ultramafic-bearing differentiated intrusions in conjunction with intrusions demonstrating anomalous thermal metamorphic effects are two of the most important exploration guides for Noril'sk-type mineralization (Naldrett, 1992; Naldrett et al., 1992).

Petrologic Units of the Franklin Gabbro-Dolerite Sills

Mafic sills related to the Franklin Events appear to be rather unremarkable looking doleritic to gabbroic bodies (a feature also common to the Noril'sk intrusions) not unlike those from other continental flood basalt terranes. However, subtle differences in texture, mineralogy and weathering define exceptionally consistent and predictable lithological and textural horizons within Franklin sills throughout the Amundsen Basin. Local recognition of some of these features by Baragar (1976), Jefferson et al. (1985; 1988), Dostal et al. (1986), Heaman et al. (1992), and a number of exploration geologists (see ACKNOWLEDGMENTS) added incentive to this study. Field observations were corroborated by petrography of over 550 thin sections made from samples spanning the entire stratigraphic and geographic suite of Franklin intrusions in the Minto, Brock and Duke of York inliers, and the Coppermine area (Fig. 4).

Sills range in thickness from less than 2m to a maximum of at least 120m. Internal stratification has been noted only in those sills greater than 30m thick. Layering is visible from a distance in many of these sills. An idealized section of a Franklin gabbro-dolerite sill from the northeastern portion of the Minto Inlier is shown in Figure 14. Results of petrography, electron microprobe and chemical analyses are reported and discussed in the following sections.

Contact Gabbro-Dolerite units (see also **Contact Metamorphic Effects of Franklin Intrustions**, above) were observed in most fully exposed intrusions and have thicknesses that increase with thicknesses of the intrusions (Fig. 14). In sills, the upper and lower contact gabbro-dolerites consist of compact, massive, quenched (chilled) basaltic rocks. Gabbro-dolerites in contact with the immediate country rock are hypocrystalline, aphanitic and generally contain <10% phenocrysts consisting of plagioclase, clinopyroxene, olivine and coarser-grained glomerophyric plagioclase-clinopyroxene olivine aggregates. In some cases thin (<1cm) glassy chills mark the interface between the aphanitic unit and the country rock. Grain size increases away from the contacts, through very fine-grained felted groundmass with plagioclase and olivine phenocrysts, to fine-grained varieties with a distinctive ophitic to weakly poikilitic texture.

Abundant xenoliths and disseminated pyrite characterize the PGE-rich margins of the irregular intrusion (chonolith) southeast of Kilian Lake (station 93JP27; Fig. 8). These are clear evidence of crustal assimilation.

The sill at station 93JP64 on the west side of Kilian Lake (Fig. 8) is similar to and more intensely sulfidic than that at station 104 in

Brock Inlier; both are located relatively high in the stratigraphy, and both have 10-15 metre zones of amygdaloidal, aphanitic, silicified basalt (dacite) at top and bottom. The upper contact zone in the Kilian Lake sill is extensively gossanous, related to abundant pyrite, calcite and quartz filling the amygdules. Pyrite is minor in the Brock Inlier example. Spheroidal weathering patterns in both are reminiscent of pillows; breccias suggest hyaloclastic processes. These features and other features described by Rainbird (1993) suggest that the strata were wet sediments when the sills were intruded. A number of other sills located high in the stratigraphy in Minto Inlier are also abundantly amygdular, particularly in the contact zones. This indicates very shallow levels of emplacement.

Olivine-Bearing Gabbro-Dolerite units generally comprise the lower-half of most Franklin sills and directly overlie the basal contact gabbro-dolerite units. Thin equivalents of this lithology have also been observed in some intrusions immediately below the upper contact gabbro-dolerite units (Fig. 14). Detailed petrographic studies indicate that the olivine-bearing units are cumulates comprising varying proportions of plagioclase, clinopyroxene and olivine. The most characteristic features of these units are the olivine and the mottled poikilitic or oikocrystic texture of the outcrop due to the presence of large intercumulus clinopyroxene crystals. The oikocrysts contain chadacrysts of plagioclase and olivine. The rocks are generally fine to medium-grained and are typically grey-brown to brown in colour. Olivine imparts a pitted appearance to the weathered surface. Grain sizes within these units are characteristically uniform along strike in contrast to those from the overlying gabbro-dolerite-ferrogabbrodolerite unit.

The lowest abundance of olivine (2.6-3.2 % by volume) generally occurs in the basal, fine to medium grained, 2 to 10 m interval (Fig.14). Rock units within this interval are initially fine-grained plagioclase-clinopyroxene-olivine cumulates (PCOC) that coarsen upward. Olivine content increases to 6-7 vol.% in the overlying 10 to 35 m interval. The increased olivine content in the PCOC is accompanied by decreasing proportion of cumulus clinopyroxene and increasing, large (2-4 cm diameter) intercumulus clinopyroxene which imparts a pronounced mottled, poikilitic (oikocrystic) texture to the rock. The more oikocrystic varieties are plagioclase-olivine cumulates (POC). Olivine content diminishes through the remaining portion of these units (35 to 55 m) and magmatic evolution is recorded by plagioclase-clinopyroxene-olivine cumulates (PCOC) to plagioclase-clinopyroxene cumulates (PCC).

The most primitive olivine compositions encountered in the gabbro-dolerites from these units are associated with the early cumulates in the 0 to 10m interval (Mg # = 0.71-0.75). Olivine from the following units have core compositions that generally fall within the Mg # range 0.49-0.54.

Wehrlite, Feldspathic Wehrlite. Angular blocks of ultramafic rocks were discovered as glacial erratics in the Glenelg Bay area within a 1 km radius of Station 93-JP-73, at the level of Sill # 21, which is hosted by the uppermost Nelson Head Formation (Figs. 4-6). Glacial flutings in the Glenelg Bay area are very strongly oriented northeasterly. The train of ultramafic blocks could be traced for only about 1 km southwest from this station in a search for their origin. No ultramafic blocks were found past 1 km southwest, nor anywhere in a transect across the next peninsula southwest, at Station 93-JP-77 (Figs. 5, 6). Due to the presence of anomalous olivine concentrations (>10%) in the lower portion of Sill # 21, the limited geographic distribution, easily weathered character and angular nature[1] of these large ultramafic blocks (up to 1m x 1m), they are believed to be very locally derived. They are probably derived from an unexposed basal portion of Sill # 21 or other unexamined sills to the immediate southwest of Station 77.

The ultramafic rocks are medium to coarse-grained mottled poikilitic wehrlites and feldspathic wehrlites. They display a pronounced pocked appearance due to differential weathering of olivine. Mottling within these rocks is due to the presence of large chrome-diopside oikocrysts (1 to 2 cm) and irregular areas of plagioclase of an intercumulus origin. Macroscopic chadacrysts of olivine can be seen within the pyroxene oikocrysts. The colour of these ultramafics varies from green to dark green to black, with the darker colours indicating advanced degrees of serpentinization. Petrographic studies indicate that these ultramafics are classic cumulates similar in character to those from the Rhum Complex of Scotland (Wager and Brown, 1968) and the Noril'sk and Talnakh intrusions of Russia. The following ultramafic cumulate types have been identified: olivine-chromite (OCC) and olivine-clinopyroxene-chromite (OCxCC) cumulates. Due to the high proportion of intercumulus material, reflecting the original porosity of these cumulates, these rocks should appropriately be referred to as orthocumulates (Wadsworth, 1961; Wager and Brown, 1968). Whole-rock MgO contents for these rocks range from 18.30 to 25.10 % by weight; Cr is up to 2200 ppm (Appendix II).

Investigated olivine core compositions range from Mg # of 0.780 to 0.857. The latter more primitive compositions are associated with the more mafic whole rock compositions. Although the exact location of the ultramafic member within the stratigraphy of the olivine-bearing gabbro-dolerite unit is not known at present, it has been placed near the base of the latter (Fig. 14) due to the compatibility of wehrlite olivine compositions with those of early cumulates (Mg # =0.71-0.75) from the 2-10m interval, relative to those from elsewhere in these units.

Gabbro-Dolerite - Ferrogabbro-Dolerite. The disappearance of cumulus olivine at approximately the mid-level of sills (Fig. 14) marks the base of plagioclase-clinopyroxene cumulate units (PCC). These are characterized by coarser grain size, higher concentrations of Fe-Ti oxides in patches, more Fe-rich mafic silicates, crystallization of pigeonite and Fe-rich (fayalitic) olivine as intercumulus phases, highly variable mafic rock textures (taxitic) and increasing proportions of intercumulus quartz and granophyre (granophyric gabbro). Rare plagioclase cumulates are enclosed by oikocrysts of intercumulus clinopyroxene. The PCC locally contain amphibole-bearing, dioritic, late differentiates with immiscible granitic segregations (see Granite and Granophyre below).

The PCC that constitute the bulk of the gabbro-dolerite - ferrogabbro-dolerite are medium to coarse-grained with a distinctive greyish-black colour on fresh surfaces. Weathered surfaces are generally slightly rusty. The darker colour of PCC is due to the more Fe-rich nature of the mafic silicates and the increased abundance of Fe-Ti oxides, hence the name ferrogabbro-dolerite. The rocks generally have a hypidiomorphic, randomly oriented plagioclase and pyroxene fabric, however igneous lamination is locally well developed. In the field trace amounts of quartz and granophyre can generally be discerned in these PCC.

Pegmatitic (Taxitic) Gabbro-Dolerite has grain sizes up to 2cm, forms irregularly shaped bodies which range from a few centimeters to several meters across, and is randomly distributed throughout the medium-grained PCC. The bodies are generally irregular patches, and less commonly are poorly defined conformable lens-like segregations, within a finer grained PCC. This pegmatoidal association is analogous to what Russian petrologists refer to as "taxitic", but unlike the taxitic gabbro-dolerites from the Noril'sk mining camp which generally occur in the lower part of the intrusions, most Franklin sills examined here characteristically have the "taxitic" texture developed in the upper half of the intrusion. Pegmatoidal gabbro-dolerites from the Franklin sills appear to be more Fe-rich differentiates than their basal Noril'sk counterparts which are associated with the Ni-Cu ores. The Franklin pegmatoids generally contain 10-15% interstitial quartz and granophyric intergrowths. Elongated, bent to highly curved and in extreme cases coiled pigeonite growth morphologies are characteristic of many of these pegmatitic bodies. Anomalous interstitial pyrite, apatite and coarse skeletal Fe-Ti oxide patches occur in this lithology relative to the surrounding finer grained PCC. The shape, distribution and more evolved Fe-rich character of the mineralogy within these pegmatoids suggests that these bodies represent late crystallizing volatile-enriched pockets within the enclosing plagioclase-clinopyroxene cumulates (PCC). Local variably oriented veins of the same texture and mineralogy crosscut the PCC in the vicinity of taxitic zones (e.g. at station 93JP71), recording remobilization of this material after most of the sill had crystallized.

Granite and Granophyre form thin (2-15cm), conformable to semi-conformable oval segregations in the PCC, first appear at approximately the 63m level (Fig. 14), and are found in nearly all of the sills thicker than about 60 m. The best exposures seen in this study are at Station 93-JP-71 (Sill # 4a) in the Kilian Lake area.. They are also distributed randomly elsewhere in the overlying PCC, and are rare in other units. The segregations are generally medium-grained, pink- to cream-coloured granophyres with diffuse

[1] It is understood that angularity alone is not definitive of short transport in glaciated terrains, because blocks can be plucked and passively carried a long distance by ice.

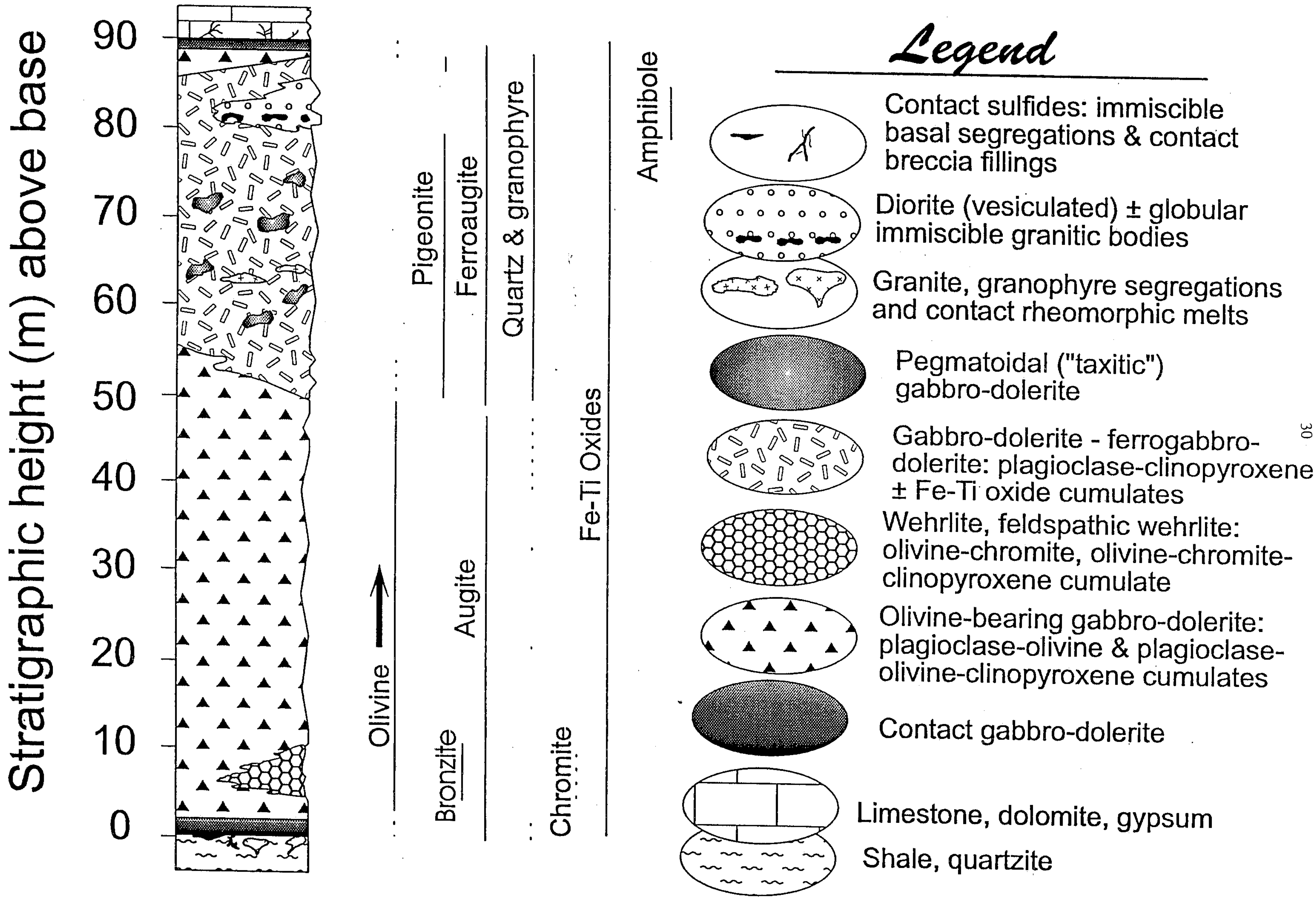


Figure 14. Idealized Franklin gabbro-dolerite sill showing complete range of mineralogy and textures encountered in northeast Minto Inlier.

boundaries and a friable and porous weathered surface due to leaching of primary interstitial epidote, carbonate, chalcopyrite and pyrite. Equant and elongated (up to 16 mm) light-green amphibole blades after clinopyroxene (hedenbergite) are the main mafic assemblage within the segregations. They also contain anomalous concentrations of disseminated sulfide (up to 6 %)

Diorite +/- Globular Immiscible Granitic Segregations are similar in composition to the granite and granophyre, and have been identified only within Sill # 4a at Station 93-JP-71. The dioritic member at this locality is relatively fine grained, contains locally abundant amygdules concentrated in layers, and is more altered than the surrounding PCC. The diorite has a distinctive salt-and-pepper appearance and is highly altered; all plagioclase is saussuritized, pyroxenes are pseudomorphed by actinolite and epidote is common. Ovoid, spherical and amoeboid (like oil droplets in water, just starting to coalesce) granitic lenses up to 6cm in length are concentrated together with the amydgules in several layers at the base of the diorite unit. Their long axes are parallel to the layering, and the layers have parted along the segregations during weathering so as to reveal the distinct immiscible structure. In cross-section, the globules have subtle but sharp boundaries defined by radial feldspar and magnetite crystals. The similar composition of these globular granitic bodies (including sulfide content) with that of the granitic segregations 20 m below this level suggests that the globules may represent portions of the less dense, buoyant granitic segregations that rose through the surrounding more dense PCC magma and ponded near the base of the diorite member.

Distribution of Sulfides in Franklin Gabbro-Dolerites

Pyrite is consistently present in altered sedimentary rocks adjacent to sills and dykes (see **Contact Metamorphic Effects** above) and in the Contact Gabbro-Dolerite Units (see above) of dykes and sills. Pyrite is disseminated in the glassy and felted groundmass, concentrated in alteration veinlets and abundant in vesiculated parts of the contact zones, where it coats the inside of amygdules (e.g. 93JP64 and 104; described above). The contact zone at station 93JP27, which yielded up to 64 ppm Pt and 224 ppm Pd, contains abundant pyrite disseminated in the silicate matrix as well as in parially assimilated tabular sedimentary xenoliths.

In the upper, Gabbro-Dolerite - Ferrogabbro-Dolerite Units of sills, pyrite is noticable especially in the Pegmatitic (Taxitic) Zones, in granitic pegmatite veinlets, in the layered amygdaloidal zones and in the associated liquid immiscibility zones. Fe-Ti-oxides are also abundant with the pyrite. Pyrrhotite and chalcopyrite are minor. Iron sulfides are sparse to absent in other phases of the gabbro-dolerites, including the ultramafic cumulate rocks (Wehrlite) seen to date. The geochemical distribution of sulfur and sulfur isotopes, and their interpretations are presented later in this report.

Olivine Compositions of Two Sills in Northeastern Minto Inlier

Olivine compositions with respect to the Mg # and Ni content (Fig. 15) have been determined in samples from sills # 4 and # 21. Sill # 4 is strongly differentiated and # 21 is believed to be the host sill, or in close proximity to the host, of the ultramafic erratics found in its vicinity. Fig. 15 demonstrates the extreme range in differentiation of these Franklin sills with respect to olivine composition. The core composition of olivine from these two sills was found to range from a Mg # of 0.366 to 0.857 which is appreciably greater than the 0.430 to 0.820 range established for the Noril'sk-Talnakh intrusions (Genkin et al., 1981). The most magnesian (primitive) olivine occurs within the wehrlite and feldspathic wehrlite rock types whereas the most ferruginous (fractionated) olivine occurs in the PCC from the lower portion of the gabbro-dolerite - ferrogabbro-dolerite unit.

This extreme compositional range of olivine is characteristic of ultramafic rocks associated with the mineralized Noril'sk intrusions. Clarification of the degree of differentiation of the Franklin sills based on olivine compositions corroborates the authors' earlier premise based on detailed field and lithological studies that these sills are in fact extremely fractionated, although this is not readily apparent on cursory field examination. The significance of the degree of differentiation becomes even clearer with the realization that of the five different groups of sills in the Noril'sk region it is only the strongly differentiated group that hosts economically significant Ni-Cu-PGE mineralization (Naldrett, 1992). Nickel content of olivine relative to its Mg # (Fig. 15) demonstrates that no significant Ni-depletion is associated with olivine from sills # 4 and 21. This does not imply that these intrusions, or others with similar trends from the Amundsen Basin, are not favourable intrusions because the most pronounced Ni-depletions in the Noril'sk-Talnakh camp are in sills associated with the sub-economic lower Talnakh type rather than the economic Talnakh type intrusions.

Sulfur and Sulfur Isotopes of Gabbro-Dolerites

Because the chemical composition of the basaltic parental magma(s) that gave rise to the Noril'sk-Talnakh ore-bearing intrusions compares with those of other continental flood basalts (Naldrett et al., 1992), it follows that the nature of the contaminant and the mechanics of assimilation are some of the most important factors governing the formation of Ni-Cu-PGE sulfide ore deposits. Although the Ni, Cu, Co, Pb, Zn contents of continental tholeiites are similar to those of basalts from other tectonic environments, they generally are regarded as sulfur-poor basaltic systems, even though they have elevated PGE contents (Hamlyn et al., 1985). If this is so, in order to initiate sulfide immiscibility, an external source of sulfur must be incorporated into and react with the magma. It follows that the most important external parameter in metallogenesis and exploration is to identify suitable external sources of sulfur and other elements such as arsenic and selenium to contaminate the mafic magmas and thus enhance the transfer of ore elements (nickel, copper and platinum group) from the silicate phase to an immiscible sulfide phase which can segregate to form ore bodies.

As noted in the above descriptions of the intrusive breccia complexes, at least some of the Franklin magmas had incorporated abundant external sulfur before intruding the Shaler Supergroup. Their gas pressure was so great that intrusive breccias, folds and faults were generated in the surrounding strata at stratigraphic depths of 3 km below the basalts, during rapid ascent and explosive degassing of the magmas in pipes. The correlation of pyrite content with abundance of vesicles in these pipes (e.g. stations 93JP11-13) suggests that sulfur degassing was operative. These volatile-rich magmas were generated after the intrusion of many sills, because they puncture and disrupt sills at all stratigraphic levels; but the breccias represent an early stage of basalt extrusion because they are situated just above the base of the volcanic pile.

Magmas within some sills (e.g. #5 at station 93JP64, Fig. 8; see Contact Gabbro-Dolerite Units above) had intermediate volatile contents and became vesiculated and pyritic at about 1 km stratigraphic depth below the basalts. Other non-vesiculated magmas eventually reached degassing conditions when they intruded to shallow levels. For example sill # 4, where it is hosted in the Wynniatt Formation at about 1 km stratigraphic depth (labelled 4b in Fig. 8), displays virtually no vesiculation at station 93JP65 even though sill # 5 about 10 metres below it is highly vesiculated. The same sheet, having climbed to a stratigraphic depth of 500 metres or less in the Kilian Formation (now labelled 4a), there contains abundant vesicular zones, noticeable pyrite, unusual liquid immiscibility structures and granitic segregations. Sill # 3 located just above this contains no vesicles and thus either had very little volatile content, or was intruded later, after some thickness of basalt had accumulated to increase its confining pressure.

It is uncertain how much the above changes represent:

(1) different original contents of sulfur and other volatile components of different original magma sources,
(2) progressive incorporation of volatiles and other trace elements as magmas rose through the strata, and/or
(3) timing of intrusion of particular sills with respect to basalt stratigraphy and confining pressures.

Petrochemical data reported in the following sections provide some insight into these questions, and help to interpret mineral potential of the sills. However more detailed, stratigraphically based petrochemical studies linking basalt and sill chemistries will be required to provide full answers.

Grinenko (1967, 1985), Godlevski and Grinenko (1963) and Gorbachev and Grinenko (1973) have measured the amount and isotopic composition of sulfur in unmineralized and mineralized intrusions from the northwestern Siberian platform, most of which carry only sparse disseminated sulfides and are uneconomic. However, by comparative studies Grinenko (1985) was able to distinguish between intrusions that contain economic Ni-Cu-sulfides and those that do not. Most uneconomic intrusions contain less than 0.10 wt.% S with average $\delta^{34}S$ values ranging from +0.1 to +4.6‰. Mineralized non-economic intrusions range from 0.17 to 0.34 wt.% S with average $\delta^{34}S$ values of +5.5 to +8.4‰. Economic sulfide-

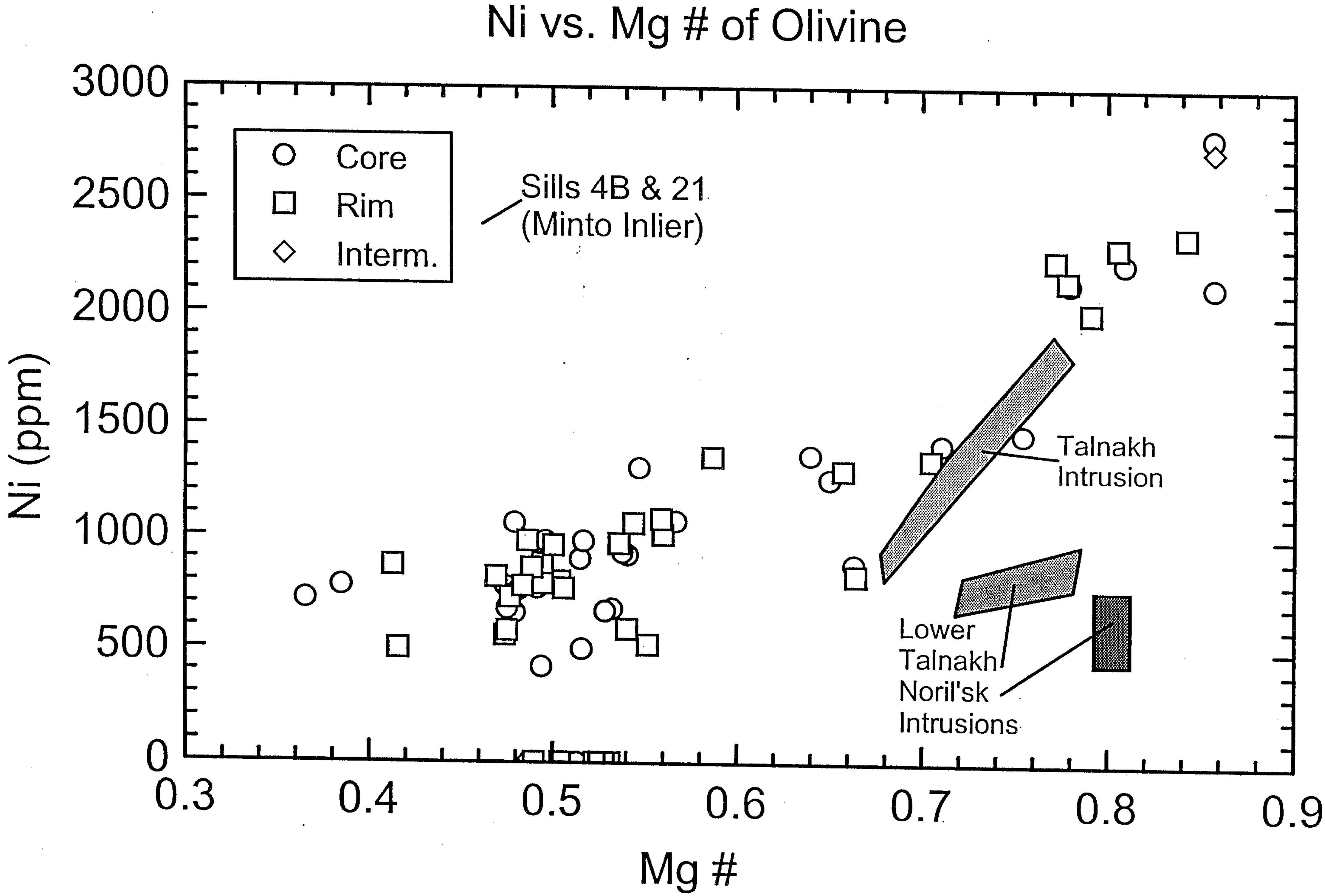


Figure 15. Ni vs. Mg # of olivine (microprobe analyses by B. Williamson) illustrates extreme range in olivine compositions with differentiation in northeast Minto Inlier, and similar values to those documented in the Russian Talnakh intrusion which contains economic Ni-Cu-PGE. Russian data from Naldrett (1992).

bearing intrusions contain on average 0.95 to 2.2 wt.% S, with average $\delta^{34}S$ values from +8.9 to +11.4‰. Grinenko also observed that there is considerably less spread in the $\delta^{34}S$ values from economic intrusions than in the less mineralized intrusions. The material used in Grinenko's studies was selected from drill core and analyzed for whole-rock sulfur and sulfur isotopes in Moscow. Analyses using near-identical procedures were purchased from a laboratory which was established by Dr. Grinenko at the University of Calgary in 1988. Dr. Grinenko personally conducted most of the sulfur and carbon analyses reported here.

A preliminary suite of sulfur isotope data was compiled and enhanced with new results to help infer the economic potential of gabbroic intrusions within the Amundsen Basin region (Fig. 3). Representative sulfur isotope analyses of the Shaler Supergroup here include sulfides in carbonates and shales as well as sulfates from gypsum-anhydrite evaporites. These external, sedimentary sources of sulfur are analogous to those in the Siberian Platform and are interpreted in the following to have generated sulfur compositions and isotope relationships in Franklin gabbros, similar to those discovered by Grinenko (1967) in the Noril'sk-Talnakh gabbros. A similar relationship between the sulfur isotope composition of host sedimentary rocks and the grade of the Ni-Cu-PGE Sulfides from the eastern and western marginal zones of the 1.27 Ga Muskox intrusion was established by Hulbert (1992).

Previous Geochemical Studies of Franklin Gabbro-Dolerite Intrusions in Amundsen Basin

The chemical compositions of the Franklin sills, dykes and lavas are typical of mantle-derived mafic magmas which have been contaminated by crustal material. They were termed continental tholeiites by Dostal et al. (1986), who compared the Natkusiak basalts with other continental tholeiites and found the following similarities:
1) positive interelement correlations within two groups of incompatible elements [K, Li, Rb, Sr, Th, Ba, La and Ce; and Nb, Sm, Eu, Tb, Yb, Lu, P, Zr, Hf and Y],
2) variable values of compatible elements, Th/La and Ba/La which are higher than mid-ocean ridge basalts (MORB),
3) lack of enrichment of some incompatible elements (e.g. K and Rb) from bottom to top of the volcanic pile,
4) a distinct depletion in Nb,
5) positive correlation between upward-decreasing radiogenic Sr and upward-decreasing K enrichment in the basalts, a measure of upward-decreasing contamination,
6) negative slopes of heavy rare-earth element plots.

Dostal et al. (1986) presented a model in which the lower Natkusiak flows were derived from magma reservoirs in differentiated sills such as 6a on the east side of Kilian Lake (Fig. 8); the upper flows are less differentiated and were thus derived more directly from mantle magma chambers. Their study was designed to classify the Natkusiak basalts, to estimate the source composition for the tholeiites and the role of crustal contamination in their generation. They did so with only 18 published whole-rock, trace element and rare-earth analyses and an un-referenced set of earlier, less precise analyses on samples collected by Baragar (1976). Their recognition of crustal contamination, sill differentiation, and taxitic texture (conspicuous patches of micropegmatite close to the base of a highly contaminated sill) are important components of the Noril'sk model, but their local studies were not designed to systematically survey the Franklin sills as required for assessing the Noril'sk model.

Similarly, studies by Jefferson et al. (1988) recognized compositional layering in the sills, but they presented whole rock and trace element data only for one sill and several basalts in Minto Inlier, and did not pursue petrochemical studies - their focus was on volcanic-red bed copper. Trace element analyses by ICP of 11 diabase sills and 2 dykes were reported by Jones et al. (1992), but no whole rock analyses were done. These represent 5 localities scattered along northern and eastern parts of the Brock Inlier and in the Coppermine River area. The above studies included only a few analyses of platinum group elements, and no low-level precise analyses of sulfur, sulfur isotopes, selenium, carbon, or the hydride elements. No samples were taken of sills cutting the sulphate evaporites in Amundsen Basin, nor of the apparently large sill along the western side of Brock Inlier (station 93JP97, Fig. 9) which was considered a possible link to the Darnley Bay gravity-magnetic anomaly and thus an important research target for this study (it has now been shown to be less than 50 metres thick, weakly differentiated and unlikely to be related to the Darnley Bay anomaly).

Nickel values reported by Jones et al. (1992) are 18-58 ppm, compared to a range of 54-140 ppm reported by Jefferson et al. (1988) for basalts and sills in Minto Inlier, and averages of 51, 70 and 129 ppm for suites of the Coronation sills, Coppermine basalts and Keeweenaw basalts reported by Baragar (1977). None of these results were interpretable in a petrogenetic sense because their relationships to other elements in the same and other sills were unknown. Without a systematic geochemical survey calibrated against standards, and normalized against magnesium number, the low nickel values could be interpreted as a result of incomplete digestion in aqua regia prior to ICP analysis, or to result from precipitation as nickel sulfides according to the Noril'sk model, or to be a normal abundance for the Franklin suite. Platinum (about 10 ppb) and palladium (14-25 ppb) reported by the above are not exceptional and also not interpretable without a regional perspective. Therefore, until this study was initiated, the various types of data required to make rigorous petrochemical comparisons with the Noril'sk model were sparse or lacking in the Amundsen Basin region.

New Geochemistry of Franklin Gabbro-Dolerites

This geochemical investigation of Franklin intrusions within the Amundsen Basin was undertaken in order to determine if geochemistry is a useful exploration tool to delimit areas of the northwestern Arctic which have favourable signatures, similar to those of economic intrusions in the Noril'sk-Talnak district (Naldrett, 1992; Naldrett et al., 1992; Lightfoot et al., 1990, 1993).

Because this is the first study of its kind in such an immense area, few guidelines existed by which we could model our program, other than studies of the Noril'sk camp. Therefore, a two-scale approach was used: local detailed studies were done to orient the sampling procedures and provide examples of the variations one might expect; and regional sampling extended the results of the detailed studies. Because sills are the most abundant type of intrusion and the most likely potential host for Ni-Cu-PGE ores, they were examined and analysed in the most detail. The geochemistry of the sills therefore is presented here on two scales. In Figs. 16 to 18 are results from the regional survey of the Amundsen Basin (Figs. 3, 4). Data from a detailed study across the northeast portion of the Minto Inlier, from Wynniatt Bay to Hadley Bay (Fig. 5) is presented in figures 19 to 23.

Due to the wide range of differentiation encountered in these sills, the geochemistry is discussed relative to the Mg # of the rock. In order to facilitate further comparisons with the geochemical data of the Noril'sk-Talnakh camp the Mg # is calculated in the same manner as that of Naldrett et al., 1992:

$$\text{Mg \#} = \frac{\text{atomic \% MgO}}{\text{MgO} + 0.9 \times \text{FeO(total)}}$$

Many of the same elemental and ratio plots established (Naldrett 1992, Naldrett et al., 1992, Lightfoot et al., 1990 & 1993) are also used. The plots are based on a total 452 samples analysed for major and trace elements and Pt, Pd, Au; 164 whole rock trace sulfur-isotope determinations; and 77 unpublished sulphate S-isotope analyses from the Minto Inlier (all listed in Appendix II).

Sample Acquisition and Analytical Methods:

A representative stratigraphic and geographic selection of gabbro-dolerite sills (Fig. 4) were each systematically investigated and described in the field (Appendix I). Samples were collected from the chilled margins (base and roof), 2 m in from the chilled contacts, and at 10 m stratigraphic intervals above the base, throughout the entire exposure of each sill. Closely spaced samples were obtained from particular intervals showing diverse textural and lithological variations; generally in the more differentiated portions of the intrusions. Considerable care was taken to obtain fresh material in order to determine original compositions and avoid hydrothermal alteration and weathering, because magmatic processes are the best link to mineral potential in the gabbro-dolerite - hosted Ni-Cu-PGE deposit type. In the laboratory, only the freshest portions of the samples were cut for detailed petrological studies and sandblasted prior to pulverization for geochemical analyses. Selected mafic dykes and gabbro-dolerite breccia pipe complexes related to the Franklin Events were also sampled in similar detail.

All elemental groups of interest were analyzed in the same laboratory, at the same time (as one continuous batch), and under strict quality control conditions. Major-element oxides and Zr, Sr, Rb, Nb and Ba were determined by XRF whereas the traces Co, Cr, Cu, La, Ni, Sc, V, Y, Yb, and Zn were done by ICP-ES at the Geological Survey of Canada laboratories following the proceedure of Rousseau (1989a,b) and Thompson and Walsh (1983), respectively. FeO, H20(t), CO2(t), S(t) and loss-on -ignition were determined by standard chemical methods. Trace element data are accurate to within +/-5% of the given concentration. The metalloids As, Bi, Sb, Se, and Te were analyzed by hydride generation / quartz-tube atomic absorption spectrophotometry (AAS) following digestion in aqua regia and separation from potentially interfering base metals by co-precipitation with $La(OH)_3$. This method has a limit of detection of 0.02 ppm. The rare earth elements (REE) were determined by ICP-MS and have detection limits of 0.02 ppm. Trace sulfur-isotope analyses relative to CDT were performed by L.I.G. at the University of Calgary employing a method similar to that used to distinguish nickeliferous and barren gabbro-dolerite intrusions from the Noril'sk region (Grinenko, 1985). The $\delta^{34}S$ values are accurate to better than +/-0.5 ‰. Pt, Pd and Au were analyzed by ultrasonic nebulizer/ICP-ES on 30 gram rock pulps after preconcentration in a Pb bead by fire-assay at Acme Laboratories Ltd., Vancouver. This method has a detection limit of 1 ppb for each of the precious metals. The CANMET Pt-Pd-Au standard TDB-1 (of similar composition to the unknowns) was used for internal quality control.

Regional Geochemical Results, Amundsen Basin

Ni: One of the key metallogenic features of the Noril'sk region is chalcophile element depletion of the contaminated magma. This is most easily recognised with respect to Ni because low Ni values showing no relationship to the associated Mg # are not related to magmatic differentiation and are therefore probably related to the segregation of Ni-sulfides (Naldrett, 1992). Figure 16A illustrates the extreme differentiation (Mg # = 0.20 to 0.85) associated with Franklin sills and the general trend of Ni depletion associated with magmatic differentiation. However, from Figure 16A it is also apparent that the most Ni-depleted Franklin sills are from Minto Inlier. The depletion is based on the fact that the bulk of the Minto Inlier samples define a Ni:Mg # trend below that of the other comagmatic sill suites, and not by the three low Ni (<60 ppm) samples with Mg #'s in the range 0.75 to 0.85. These latter three are chilled margin samples that have been moderately contaminated by carbonates. The same samples are plotted in subsequent figures, to illustrate how easily unrepresentative samples can lead to erroneous chlacophile element depletions and therefore how crucial representative samples are to the interpretation and the success of such a study. Although the Brock Inlier samples generally show no Ni depletion the three co-linear samples with a low Ni:Mg # trend warrant further attention.

Cu: This chalcophile element demonstrates an overall increase in concentration with differentiation due to its incompatible nature (Fig. 16B). Although there is more scatter associated with this element it is apparent that part of the Minto Inlier suite is depleted in Cu relative to the others.

S: Although the Minto Inlier suite is relatively depleted in the other chalcophile elements Ni and Cu, this suite clearly contains the highest background S concentrations (Fig. 16C), thus strengthening the case for the role of sulfides in chalcophile element depletion. Furthermore, Grinenko (1985) found that the average S content of normal unmineralized samples from economic sills in the Noril'sk region is 5-10 times that of both weakly mineralized and barren sills.

TiO_2, like Cu, demonstrates incompatible behavior with differentiation, giving rise to a well constrained Mg # : TiO_2 trend (Fig. 16 D). This illustrates the well defined trends expected from magmas if only differentiation processes (in the absence of sulfide) control the trends. Similar trends are observed for P_2O_5, Zr and other incompatible elements. With the exception of the late differentiates, i.e. Mg # <0.40, all of the Franklin sills have TiO2 contents <2.0 wt.% which characterises them as belonging to the low-Ti continental basalt association (Petrini et al., 1987). The low-Ti character is also confirmed by the chilled margin samples which generally range from 1.40 to 1.80 wt.% TiO_2 and some as low as 1.00 wt.% TiO_2. In the Noril'sk region it is only the low-TiO_2 sills that are of economic significance (Naldrett, 1992). It is also interesting to note that the 1267 Ma Mackenzie diabase suite, part of which is geographically close to the study area, belongs to the high-Ti continental basalt association (Hulbert et al., 1993) and contains no known economic deposits.

Cr is geochemically similar to Ni with differentiation, in the absence of sulfides (Fig. 17A). However, the the relatively high Cr content of the sill samples from Minto Inlier is singled out because only sills with a relatively high Cr content are of economic importance in the Noril'sk region (Naldrett, 1992).

Pt+Pd, being chalcophile elements, should also be depleted, had they been scavenged by sulfides. The greatest spread and depletion with respect to Pt+Pd combined appears to be associated with the Minto Inlier suite (Fig. 17B). Sulfide-rich patches from within Sill# 4 in Minto Inlier were found to contain up to 279 ppb combined Pt+Pd. The absence of any obvious differentiation trend in Figure 17B is probably due to the incompatible nature of Pd relative to Pt with differentiation (in the absence of sulfide). Continuing studies should examine the individual plots of Pt and Pd vs Mg#.

NiO/MgO x 10^4 vs. Mg # (Fig. 17C) shows Ni depletion associated with the Minto Inlier sill suite, better than Ni vs. Mg# (Fig. 16A). Figure 17C is a more reliable index of chalcophile depletion because Ni decreases more rapidly with differentiation than MgO as a result of removal from the magma of early Ni-bearing mafic phases like olivine and to a lesser extent pyroxenes. The sharpness of the decrease in Ni with decrease in Mg # is somewhat reduced by using this ratio.

The S/Se ratio is another useful index of the degree of crustal contamination in the various sill suites on a regional scale (Fig. 17D). Chondritic or mantle-derived sulfides have S/Se ratios of 2500-3000 based on measured concentrations in sulfide, but most sulfide-bearing sedimentary rocks (some black shales excluded) have lower Se relative to the amount of S, therefore assimilation of such sulfide should be recorded in the S/Se ratio (Eckstrand and Hulbert, 1987).

The Minto Inlier suite has a greater population of samples with high S/Se ratios and thus has inherited considerably more crustal S than the other suites (Fig. 17D). Suites of gabbro-dolerites with low concentrations of sulfide, generally have S/Se <1000; this is attributed to S-loss due to alteration or weathering (ibid.); nevertheless, because all analyzed sample suites in this basin-side study are relatively fresh, and have been subjected to the same procedures, the S/Se index should be applicable in a relative manner.

Trace S-isotope compositions have been determined on Franklin sills from Minto Inlier, Brock Inlier and Coppermine Area (Figures 18A-C) with respect to the host sill # (Fig. 4). The S-isotope composition of strata from the Shaler Supergroup (Fig. 18D) helps constrain the source of the S within the various sills. Although mantle derived S-isotope compositions are generally believed to be close to the chondritic, i.e. $\delta^{34}S = 0$ ‰, experience has shown that the mantle signature usually ranges from -1 to +2 ‰ in gabbroic rocks. If this is so, then sills from all Amundsen Basin areas have been contaminated to some degree by crustal S (Figs. 18A-C). The Minto Inlier suite shows the greatest deviation of $\delta^{34}S$ values from the mantle signature, indicating the greatest assimilation of both ^{32}S and ^{34}S-enriched strata. The ^{32}S-enriched signatures are clearly due to assimilation of organic-rich black shales such as those in the Wynniatt Formation[1] (Fig. 18D) whereas the ^{34}S-enriched signatures have been inherited from strata other than black shales. Because sills 13 to 36 below the Minto Inlet Formation could not have intruded evaporites of the Minto Inlet or Kilian formations, these can be eliminated as external sources for ^{34}S in these sills. The wide range in S-isotope signatures associated with sills 4 to 8 relative to sills 9 to 29 in the Minto Inlier suggests that they incorporated a wider range of contaminants, and thus should be targeted for further investigation. One exception with heavy sulfur, sill #19, is disregarded because it is only 4 m thick and is fed by a thin anastamosing dyke which cuts pyritic carbonaceous shales in Boot Inlet Formation.

S-isotope profiles through the sills investigated in this pilot study did not reveal any sills that had pronounced crustal S-isotope signatures through the entire intrusion as is the case for the economic intrusions in the Noril'sk region. In most cases, the S contamination is only evident near the contacts and in rare cases it extends for a few tens of meters into the intrusion. Nevertheless, this does not rule out the possibility of more extensive intrusion-wide contamination in some of the many unsampled sills in Amundsen Basin.

[1] Other organic-rich black shales in the Shaler Supergroup, e.g. Burns Lake, Escape Rapids and Grassy Bay formations may have the same potential for sulfur contamination.

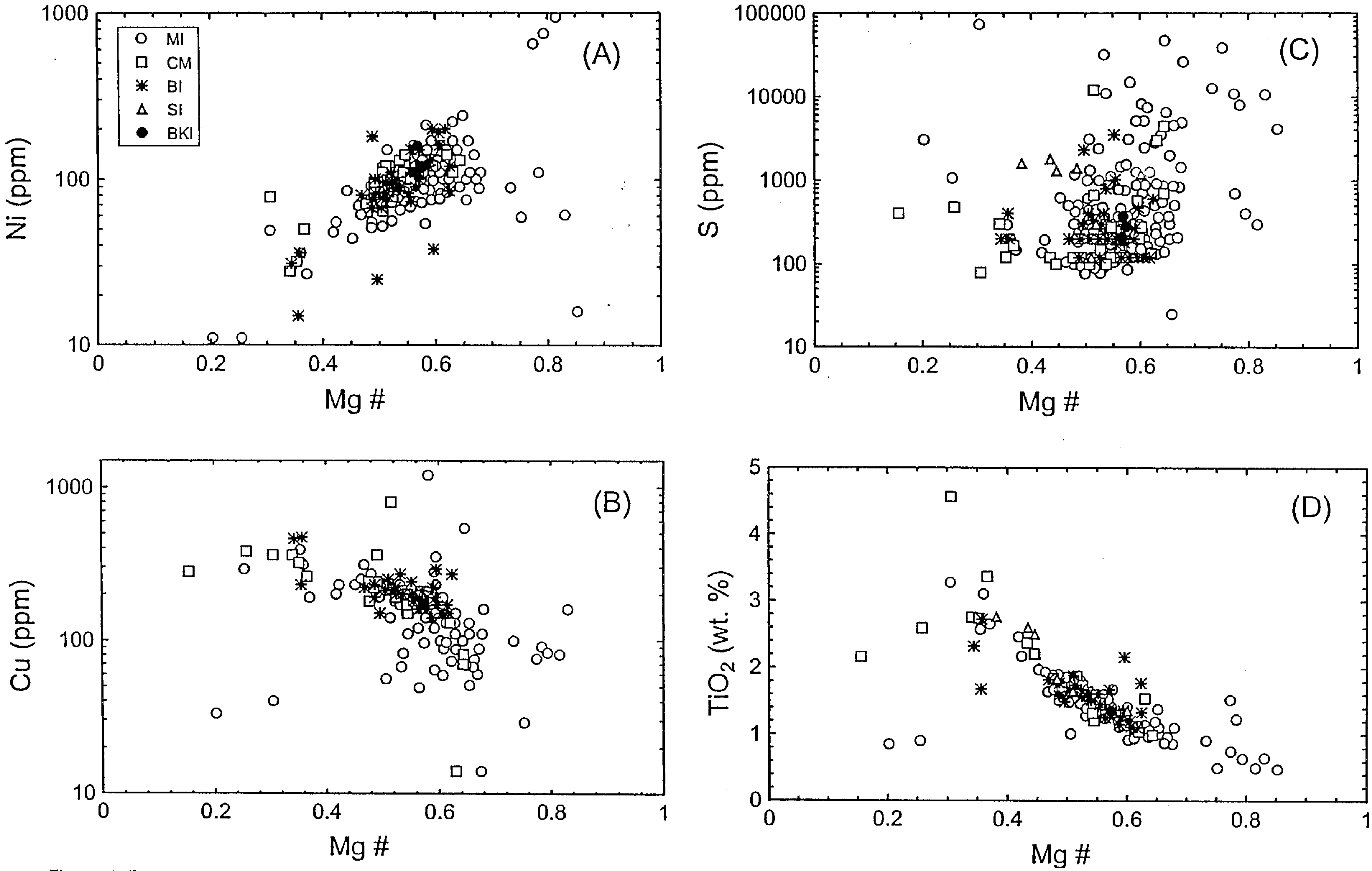


Figure 16. Evolution and depletion of chalcophile elements in northeastern Minto Inlier (MI) relative to the rest of Amundsen Basin. Other localities are Coppermine area (CM), Brock Inlier (BI), Banks Island (BKI) and Somerset Island (SI). A: Ni vs Mg #: overall linear trend with depletion in MI samples; B: Cu vs Mg #: overall linear trend with depletion and also much more scatter in MI samples; C: S vs Mg #: no clear trends overall, but relative enrichment of MI samples in S; D: TiO2 vs Mg #: complete range of differentiation from primitive to very evolved magmas; the kind of trend expected from differentiation as opposed to the contamination recorded by A, B, C.

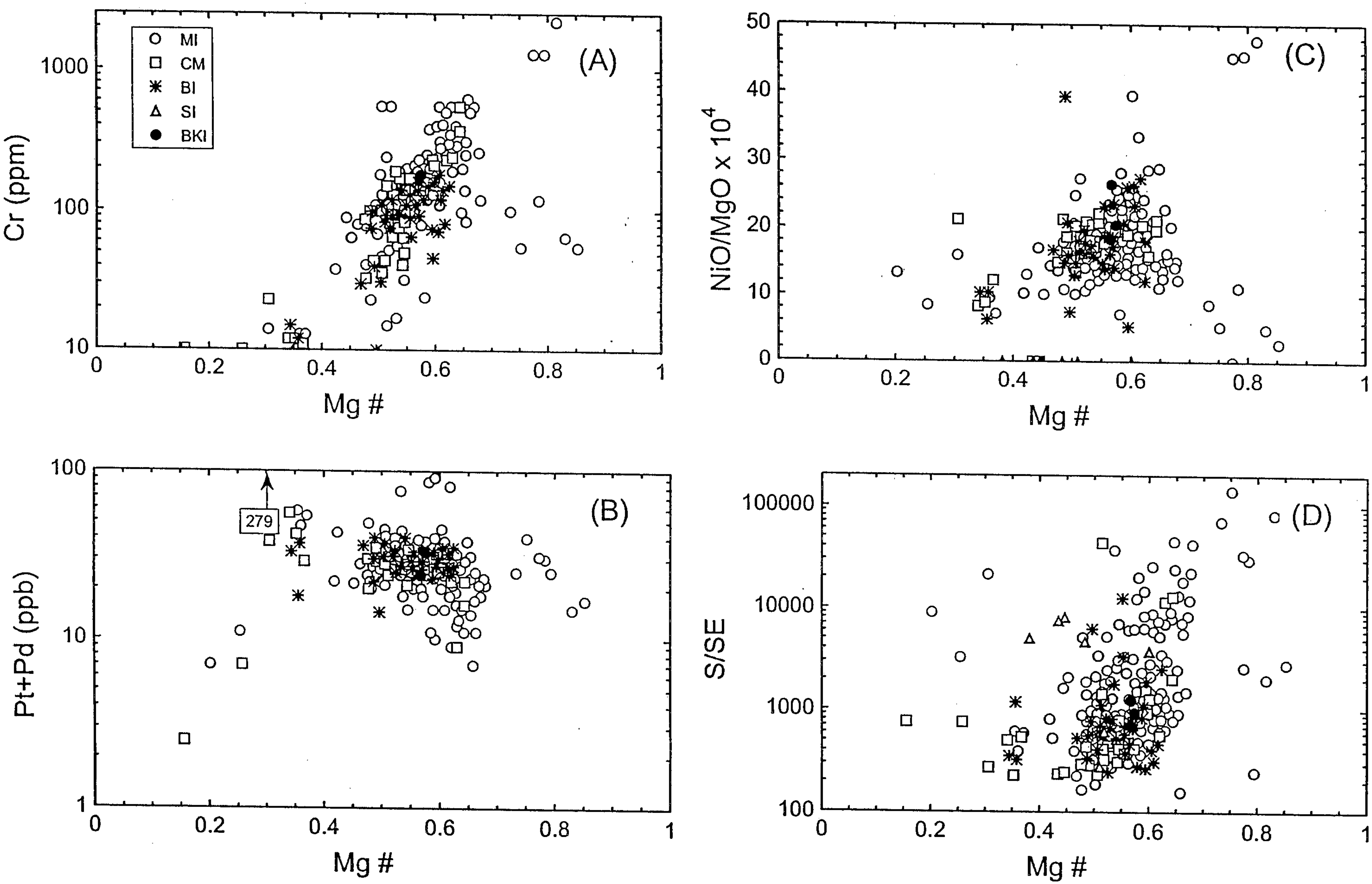


Figure 17. Variations in Cr, Pt+Pd, Ni and S/Se for the Franklin gabbro-dolerites, by area in Amundsen Basin. The greatest variations, hence contamination (+/- precipitation as possible ore), are in northeast Minto Inlier with a few in Coppermine area. See text for further discussion. A: Cr vs Mg #; B: Pt + Pd vs Mg #; C: NiO/MgOx104 vs Mg #; D: S/Se vs Mg #.

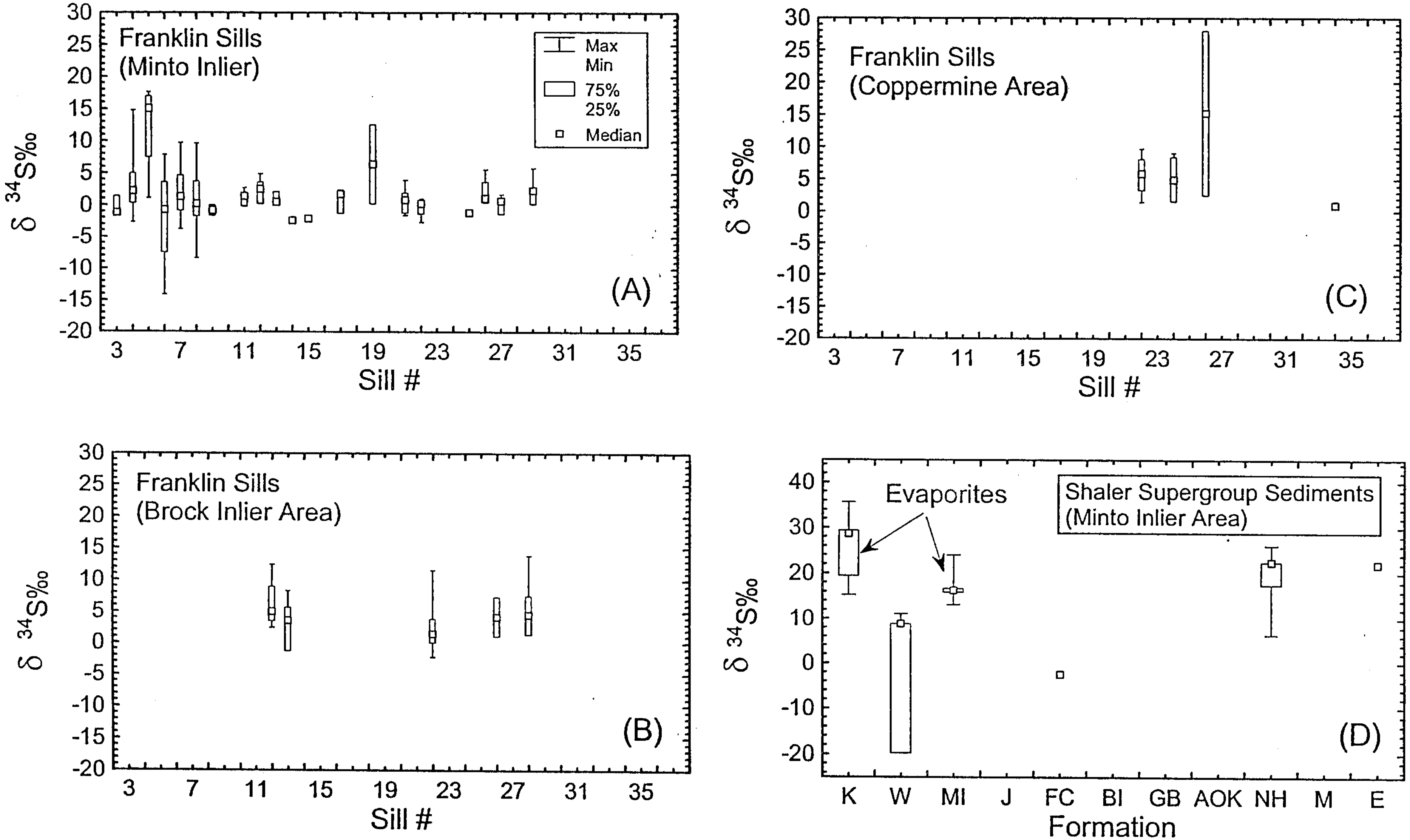


Figure 18. Box and whisker plots of sulfur isotopes in Franklin sills and various formations of Shaler Supergroup in Amundsen Basin. Isotopes are relatively heavy or range into heavy values for most sills. Isotopes are very heavy for sulfate evaporites of the Kilian (K) Formation and moderately heavy for the Minto Inlet (MI) (sulphate evaporites), Nelson Head (NH) and Escape Rapids (E) (carbonaceous sulfidic shales and sandstones) formations. They range from moderately heavy to relatively light for sulfidic black shales of the Wynniatt (W; samples 93JP 22a,b,c) and Fort Collinson (FC) formations . Sill numbers are shown graphically in Figure 4. Letter codes for D (sedimentary formations in Minto Inlier) are explained in Figure 19. Data for evaporites of the Kilian and Minto Inlet formations are from an unpublished manuscript by G.M. Young (U. of Western Ontario), Shin Shen and E.C. Parry (Northern Illinois U. at DeKalb) and K. Hattori (U. of Ottawa), and from unpublished files of J. Kaufman and J. Hayes (Indiana U.). Other analyses are from this study, by L.I.G. (with F. Krouse at U of Calgary) and by K. Telmer (Stable Isotope Facility of Ottawa-Carleton Geoscience Centre). See text for further discussion.

Detailed Geochemistry of Northeast Minto Inlier

From the above, the northeast Minto Inlier sills are the most depleted in chalcophile elements, have the highest Cr, S and S/Se, and generally the greatest range in S-isotope compositions (see above). These are the same favourable geochemical indicators summarized above for the Noril'sk region of Russia. The following chapter focusses on the Minto Inlier in order to discriminate favourable sills on the basis of geochemistry. The results are plotted with respect to the stratigraphic and sedimentary context of the sills (Figs. 19 to 23), and interpreted using the above-explained concepts such as chalcophile depletion, differentiation parameters, and sulfur isotope behaviour.

Ni, Cu, S, Pt+Pd: Sills hosted by the Wynniatt Formation demonstrate a rather marked chalcophile element depletion with respect to Ni, Cu and Pt+Pd (Fig. 19A, B, D). All of the other sillss display relatively coherent Ni and Cu trends with differentiation (Fig. 19A, B). This becomes particularly clear if samples hosted by the Wynniatt Formation are removed from the plots. Excluding the three contaminated chilled margin samples mentioned earlier, a distinctive Ni:Mg # depletion trend is associated with the sills hosted by the Wynniatt Formation and falls below the trend established by the other suites (Fig. 19A). Wynniatt-hosted sills are noticeably depleted in Cu but the scatter associated with this element is much greater than for Ni. The Wynniatt-hosted sills also contain much higher background S, the highest individual S (Fig. 19C), some of the highest S-isotope values (Fig. 21A) and a relatively depleted Pt+Pd population (Fig. 19D).

TiO_2, Cr, Ni/Co, P_2O_5: Plots of these oxides, element and ratio against Mg # of the associated rocks in Figures 20A-D serve to illustrate the coherent differentiation patterns of the incompatible (TiO_2, P_2O_5) and compatible (Cr) elements which are not influenced by the presence of sulfides. The Ni/Co ratio (Fig. 20C) also appears to be an indicator of differentiation. The lower Cr and Ni/Co ratios in the Wynniatt-hosted sills may be a consequence of scavenging by sulfide, but differences in partition coefficients for Ni (275) and Co (60) may actually reduce the scale of the depletion associated with this ratio.

From the above it is inferred that some factor in addition to magmatic differentiation has influenced the concentrations of Ni, Cr, Cu and PGE in these sills.

$\delta^{34}S$, S/Se, NiO/MgO x 10^4, La/Sm: $\delta^{34}S$, S/Se and La/Sm are good indicators of crustal contamination. The greatest degree of crustal contamination with respect to these three indicators is once again clearly associated with the Wynniatt Formation hosted sills (Fig. 21A, B, D). The La/Sm : SiO_2 plot demonstrates that some sills in the Wynniatt, Boot Inlet and Aok formations have higher La/Sm than other sills with comparable SiO_2; a plausible explanation for this aberrant geochemical signature is crustal contamination by material with elevated La/Sm (shales?). Naldrett (1992) used this plot as an indicator of crustal contamination because both SiO_2 and the La/Sm ratio "should increase with increasing contamination by continental crust". Naldrett demonstrated that the volcanic sequence believed to be associated with the mineralized sub-volcanic intrusions at Noril'sk have elevated La/Sm ratios and SiO_2 contents relative to the others within the sequence. Wynniatt-hosted sills show probable S-contamination (Fig. 21B: S/Se vs Mg #) and Ni depletion (Fig. 21C: Ni/MgO x 10^4 vs Mg#).

Ni : S and Pt+Pd : S (Figs. 22A, B). In the Wynniatt-hosted sills, sulfur attains concentrations at least two orders of magnitude greater than in any of the other sills. However, apart from the one sample with 279 ppb Pt+Pd, most of the contained sulfides are poor in both Ni and PGE. This is not surprising because all of the sulfide-enriched samples are products of interaction of the intrusion and the country-rock at the contacts. As a consequence of this rather limited interaction between the magma and the sulfidic country rock any sulfides generated within the sill had limited contact with the magma and thus could not have equilibrated with a significant volume of magma from which to sequester Ni, Cu and PGE. This ratio of silicate melt to sulfide melt is commonly referred to as the "R-factor" (Campbell and Naldrett, 1979).

The apparently restricted sulfide-forming potential inferred from these data should not be interpreted as a negative. On the contrary, the presence of the sulphide-forming process at any degree should be taken as positive evidence that the magma(s) are capable of reacting with the country rock and generating sulfides! Exploration should target intrusions where the sulfides have interacted with a larger volume of magma (larger R-factors). Target intrusions would not necessarily have to be abnormally thick sills, because irregular bodies (chonoliths) and thinner sills with ultramafic zones may have been conduits for larger magma chambers.

The above assumes that ultramafic cumulates constitute not only extensive layers at specific levels in large intrusions, but can also be local segregations resulting from the settling of olivine crystals from magma streams in smaller intrusions. Magmas could have streamed through a series of upward-propagating intrusions, and deposited cumulates and sulfide droplets where flow velocities changed because of shape changes in intrusion walls. Such deposits might be found at a variety of positions in laterally and vertically connected deeper sills that are continuous for distances of at least 50 km along strike, up through thin sub-volcanic intrusions which fed the overlying Natkusiak basalts. The concept of magma conduits was mentioned in Naldrett et al. (1992) and re-emphasized by Naldrett (1994). This process is somewhat analogous to the formation of olivine adcumulates (dunites, peridotites) in komatiitic volcanic terranes (Barnes et al., 1988).

Ce/Yb:Ce and Gd/Yb:La/Sm: It is evident from the above that most of the Franklin intrusions, notably the sills in the Wynniatt Formation, have been contaminated by supracrustal rocks. However, it has yet to be shown convincingly which strata are the most favourable contaminants. Although the evaporites are appealing candidates for the source of the sulfur in the Noril'sk orebodies, other sources such as hydrocarbons are suspected there (Grinenko, 1985; Naldrett, 1992). Other sources are also demonstrated for Minto Inlier as follows.

Sills hosted by the Wynniatt Formation are the most contaminated of the Franklin suite with respect to Ce/Yb:Ce compositions (Fig. 23A). Vectors illustrating the paths along which these magmas would evolve with increasing partial melting, fractional crystallization (solid arrows), or by crustal contamination (dashed arrow), are shown relative to a pristine chondritic composition in Fig. 23A. Unreasonably large degrees of partial melting and fractional crystallization would be required to raise the chondritic ratios to those associated with the Wynniatt sills. Furthermore, the evolutionary path of the Franklin magmas is incompatible with pure fractional crystallization, therefore crustal contamination is an essential component for the observed trend.

Only the Wynniatt Formation sulfidic strata have Ce/Yb:Ce compositions compatible with the most contaminated Franklin sills[1]. Ce/Yb:Ce of the Minto Inlet evaporites (gypsum/anhydrite like the Kilian evaporites) is totally incompatible with that of the most contaminated Franklin sills. This conclusion is also corroborated by the enormous S/Se ratios (3.3 x 10^6) of the evaporites which would have been inherited by the intrusions, if evaporites were the main source of the sulfur. Field observations provide further support in that the sills are only locally in direct contact with the evaporites - most have intruded along shaly dolostone members of the evaporitic formations.

Noril'sk ores have low S/Se ratios of 1900 to 3000 (Kovalenker et al., 1975) which are also incompatible with a sulphate sulfur source. Unfortunately, the chemistry of the potential sedimentary contaminants at Noril'sk has not been investigated in a manner similar to this study. Such a study might eliminate the Devonian evaporites as a credible source of the sulfur within the Noril'sk ores.

Although sulfidic strata of the Wynniatt Formation have the required compositions for the models used in Figures 23A & B, the possibility of other Shaler Supergroup sulfidic strata with similar geochemical characteristics cannot be ruled out. Also, the Intrusive Breccia Complexes (see descriptions above and petrology below) with their abundant sulfides, vesiculation of chilled gabbro-dolerite pipes and dykes, and physical evidence of explosive eruption (probable SO_2 release), are strong evidence that a significant proportion of sulfur (of deep crustal origin?) was already present in some Franklin magmas before they invaded the Shaler Supergroup.

Figure 23B illustrates the composition of the various Franklin suites from the Minto Inlier, the Noril'sk-Talnakh camp and the Mackenzie diabase sills from northern Saskatchewan, together with potential contaminant strata of the Wynniatt and Minto Inlet formations. This diagram is less informative than the Ce/Yb : Ce plot with respect to the plausible contaminant; however, it does demonstrate that the Franklin sills are more similar to those from the Noril'sk region than to the Mackenzie diabase suite.

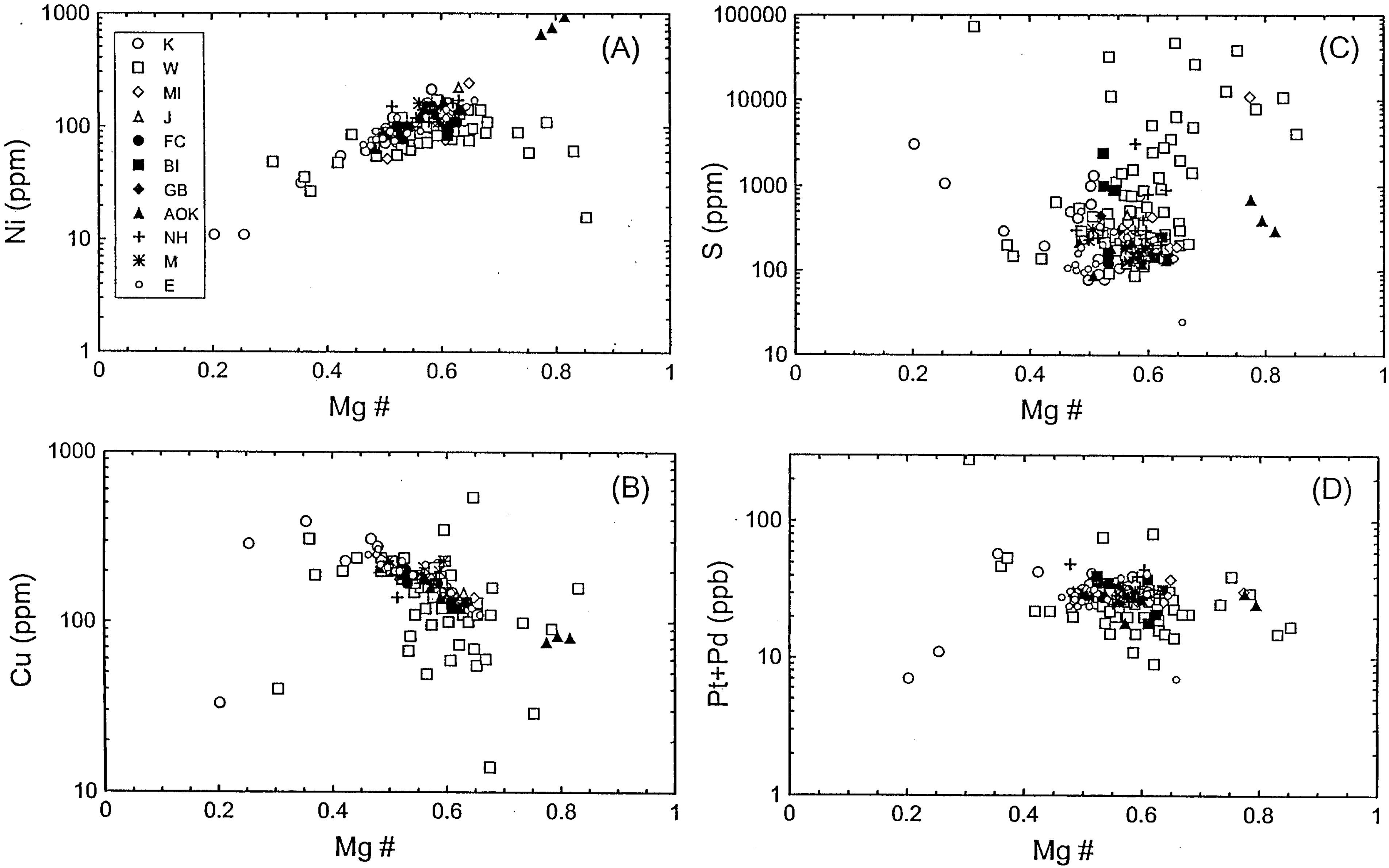


Figure 19. Evolution and depletion of chalcophile elements in sills from northeastern Minto Inlier
(A) Ni vs Mg # (depleted in Wynniatt Fm.).
(B) Cu vs Mg # (scattered in Wynniatt Fm.).
(C) S vs Mg # (enriched in Wynniatt Fm.).
(D) Pt+Pd vs Mg # (differentiation trend).

Key (for Figs. 18-23) to symbols for host Formation (lithology in Table 3), in stratigraphic sequence

NK	Natkusiak Formation	JB	Jago Bay Formation	AOK	Aok Formation
K	Kilian Formation	FC	Fort Collinson Fm	NH	Nelson Head Formation
W	Wynniatt Formation	BI	Boot Inlet Formation	M	Mikkelsen Islands Formation
MI	Minto Inlet Formation	GB	Grassy Bay Formation	E	Escape Rapids Formation

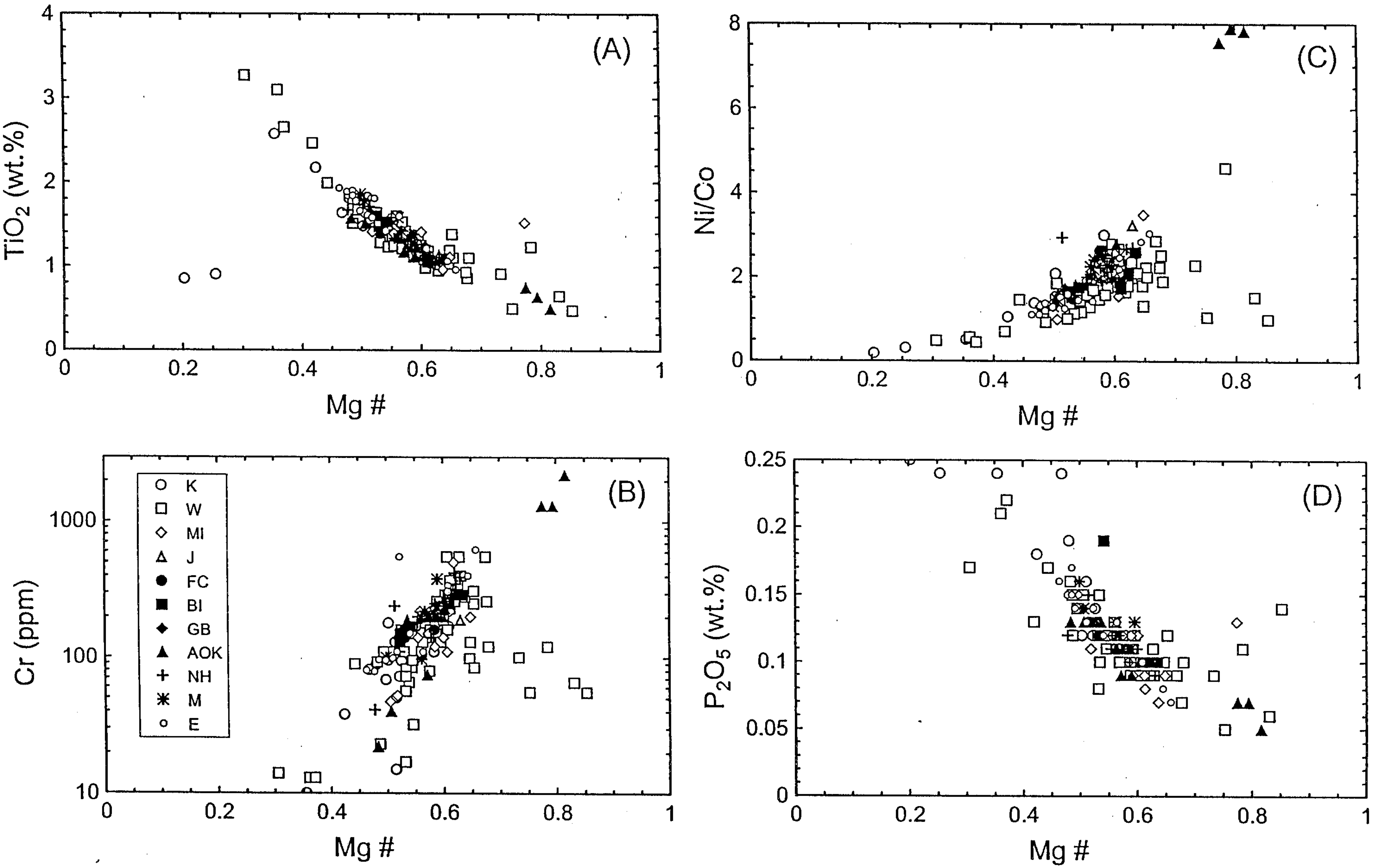


Figure 20. Elements which show expected coherent trends with differentiation. Sills of northeastern Minto Inlier; key to formations is in caption to Figure 19. See text for further discussion. (A) TiO_2 vs Mg #; (B) Cr vs Mg #; (C) NiO/Co vs Mg #; (D) P_2O_5 vs Mg #.

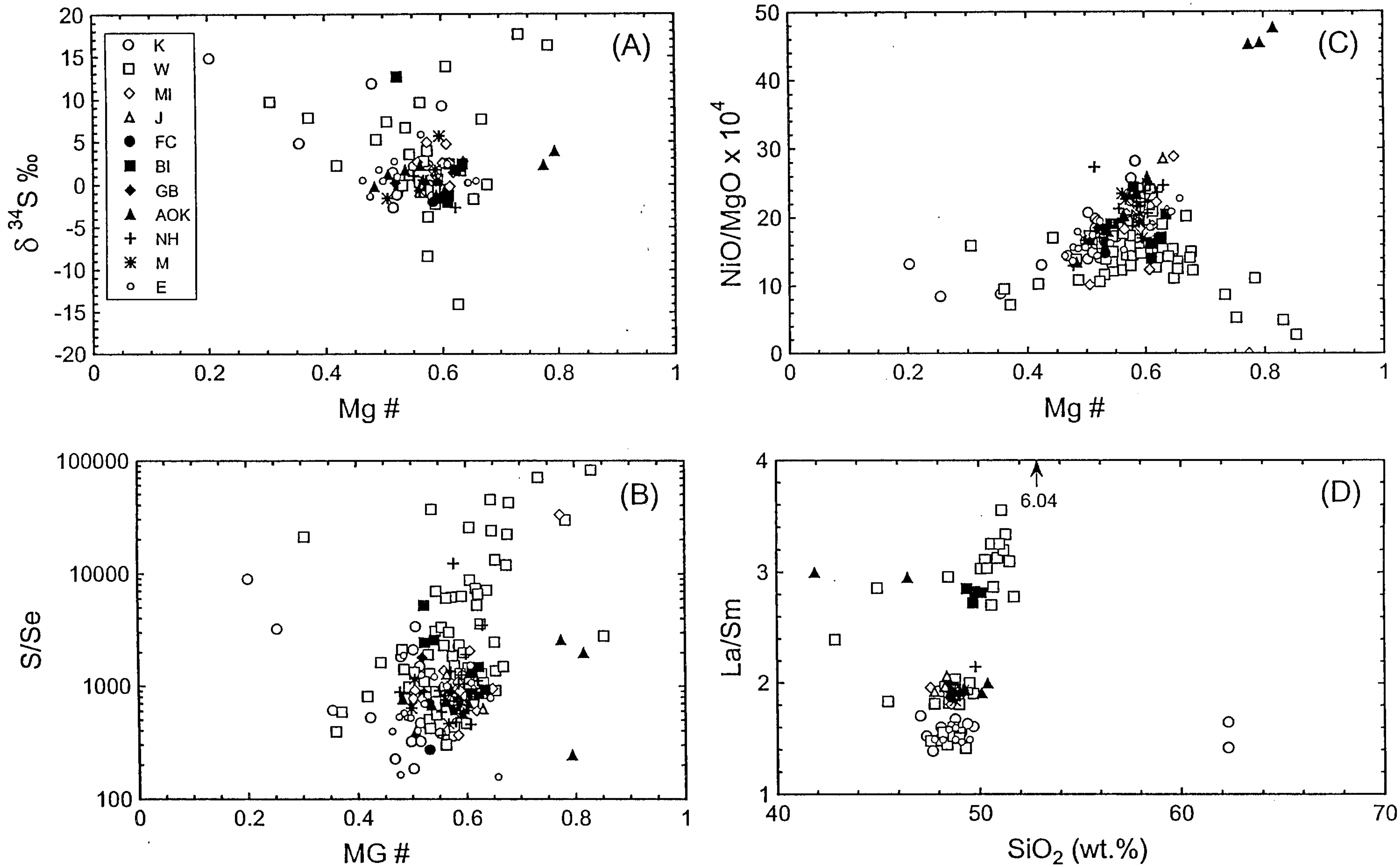


Figure 21. Elements which are good indicators of crustal contamination. Sills of northeast Minto Inlier; key to formations is in caption to Fig. 19. See text for further discussion.
(A) $\delta^{34}S$‰ vs Mg #; (B) S/Se vs Mg #; (C) NiO/MgO x 10^4 vs Mg #; (D) La/Sm vs SiO_2.

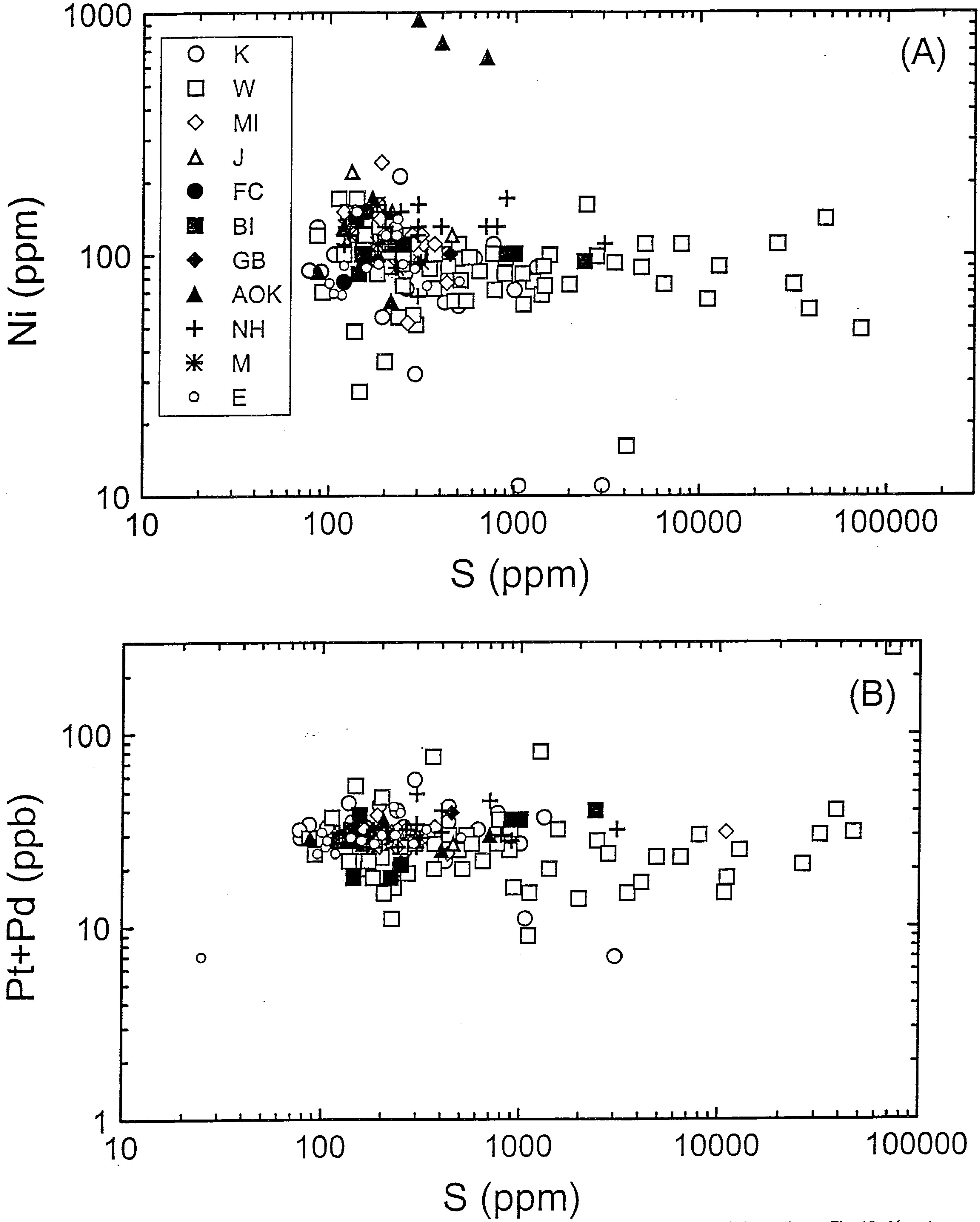


Figure 22. Ni and PGE relative to S content of host. Sills of northeast Minto Inlier; key to formations is in caption to Fig. 19. Note the high level of S associated with sills hosted by the Wynniatt Formation in northeast Minto Inlier. See text for discussion. (A) Ni vs S; (B) Pt+Pd vs S. The 279 ppb Pt+Pd is from the plug in the Wynniatt Formation (93-JP-27).

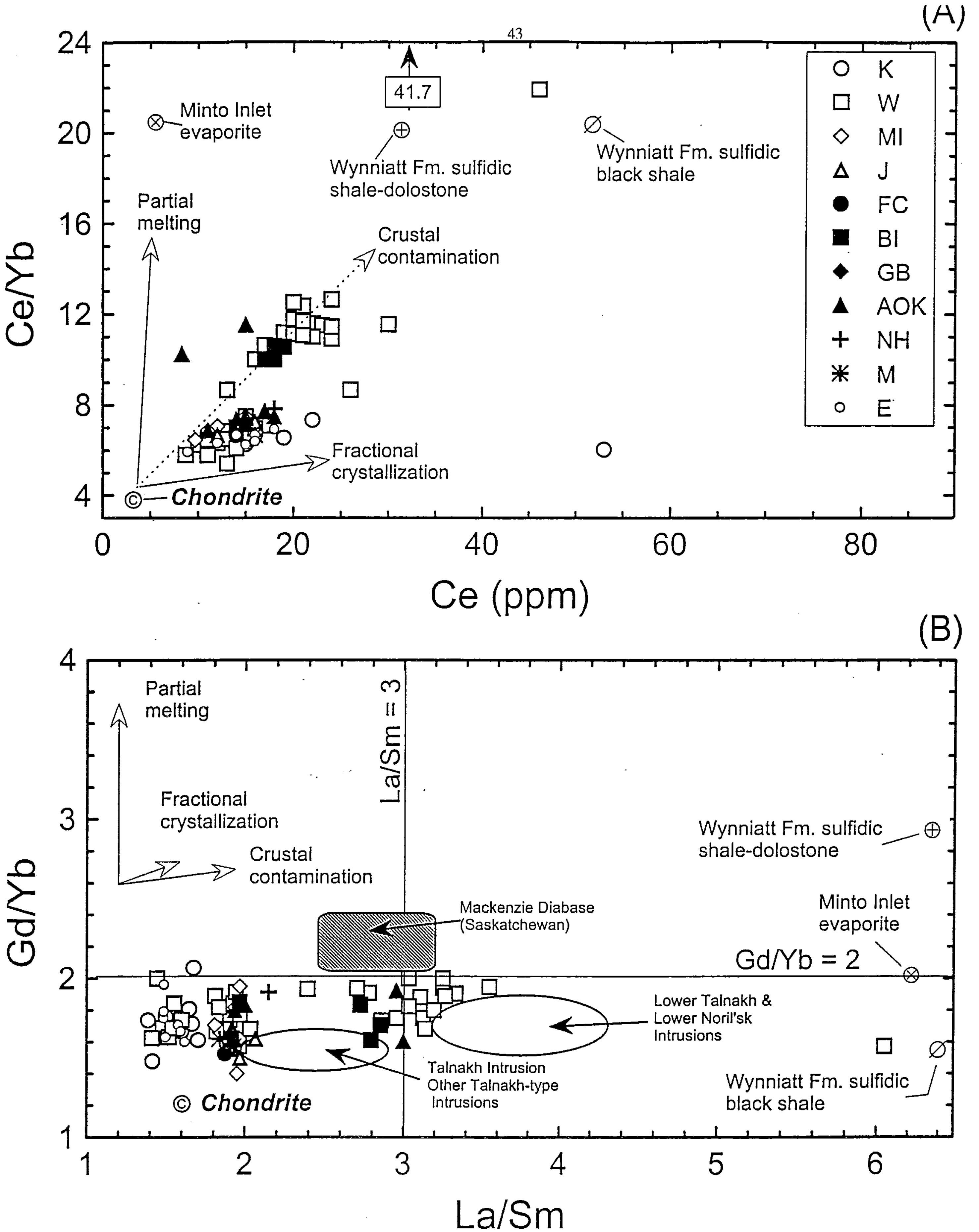


Figure 23A. Ce/Yb versus Ce in Minto Inlier. Arrows show how various ratios can be obtained by partial melting, fractional crystallization and crustal contamination of a primitive magma (cf. Lightfoot et al., 1991). Crustal contamination by incorporation of sulfidic shales and dolostones rather than evaporites appears to be the most likely cause of the observed ratios. Sills hosted by the Wynniatt Formation show the greatest degree of contamination by this process. See text for further discussion.

Figure 23B. Gd/Yb vs. La/Sm for sills in northeastern Minto Inlier. Data for comparison are Mackenzie Diabase (from Hulbert ,1993); Russian intrusions (modified from Naldrett et al,1992); and typical strata in Shaler Supergroup (this study). See text for further discussion.

Petrology and Geochemistry of Gabbro-Dolerites in the Intrusive Breccia Complexes

Doleritic to gabbroic breccia bodies consisting entirely of dolerite and quartz dolerite fragments in a highly granulated doleritic groundmass form striking intrusive units in northeastern Minto Inlier, particularly west of 110° on the northwest side of the Holman Island Syncline (Figs. 7, 8). The architecture and physical genesis of these breccias are discussed above (see **Foci of Franklin Magmatism**).

Fragments constitute 40-50% of the outcrop in the central portion of some of the breccia bodies. The matrix is a seriate mixture grading from friable, fine- to medium-grained dolerite to highly altered rock flour. Angular dolerite fragments range up to 10-18 cm in diameter; many are in the 1-2 mm size range. Cores of the breccia bodies appear to be sites of greatest brecciation, whereas dolerite closer to the margins of the intrusion demonstrate chilled contact features.

The distinctive pale olive green colour and granular appearance of the dolerites in the breccia complexes is due to the pervasive saussuritization of plagioclase and the uralitization of pyroxenes. Fresh, fine- to very fine-grained intrusive material is brown-sugar-coloured and has a sucrosic appearance in hand specimen.

Coarser grained fragments and matrix have a pronounced ophitic texture and are characteristically devoid of olivine, but contain anomalous concentrations of interstitial quartz (up to 12%), Fe-Ti-oxides (10%) and pyrite (2-3%). The Fe-Ti-oxide content of these rocks is approximately twice that of other Franklin dykes and sills of comparable grain size. Also, some of the finer grained unbrecciated material is highly vesiculated. The degree of vesiculation and alteration appears to be positively correlated with pyrite content. Vesicles in many cases are lined with epidote and pyrite. Some joints are also lined with epidote crystals.

Calc-silicate and magnetite-sulfide skarns are locally well developed in dolostones adjacent to the intrusive contacts of the dolerite dykes and pipes. One of the magnetite-sulfide skarn samples assayed 427, 67, and 7 ppb Pd, Pt and Au respectively. Other samples from this same locality returned anomalous values relative to the regional background signature (<30 ppb Pt+Pd). The discovery of these high values is encouraging because it demonstrates that PGE are associated with mineralized products of Franklin intrusive Eventss.

MINERAL RESOURCE ASSESSMENTS

Noril'sk Model in Amundsen Basin

The preceding results have demonstrated that the Noril'sk exploration model is applicable by almost every criterion to Minto Inlier (Table 5), therefore the potential for the Noril'sk Ni-Cu-PGE deposit type is rated as high (2) in Minto Inlier. Detailed field and laboratory studies reported here cover only the northeastern part of Minto Inlier, but the continuity of most, if not all of the criteria along Minto Inlier is indicated by stratigraphic data and previous observations of C.W.J. and R.H.R. in southwestern Minto Inlier. Nevertheless considerable further mapping and petrochemistry is highly warranted to complete the coverage of Minto Inlier.

The absence of many essential criteria (# 9 to 21) in Table 5 downgrades the Ni-Cu-PGE potential to low to moderate (5) in the Brock Inlier and Coppermine Area domains. This is the same assessment as given by Jones et al. (1992), but with a much higher degree of confidence because of our ability to compare high quality and detailed field and analytical data in both these domains and the Minto Inlier domain.

Moderate-to-high potential (3) is assigned to Duke of York Bay area where gabbro-dolerites are particularly thick, abundant and differentiated, chemistry is favourable, and a gravity high is coincident (Fig. 3). Moderate uncertainty accompanies this rating because only limited stratigraphy is preserved (only Rae Group), and no significant faults were mapped during a brief reconnaissance of this domain. The Mackenzie vs. Franklin affiliation of the gravity anomaly is highly uncertain.

The Cape Lambton Inlier is rated moderate-to-low for Ni-Cu-PGE potential, with a moderate-to-low degree of confidence because it was not included in the detailed studies. The Franklin sills here are tabular, uniform and only moderately thick (visually estimated to be about 60 m thick); only the lower stratigraphy of the Shaler Supergroup (Mikkelsen Islands and Nelson Head formations) is preserved; and there is no associated gravity anomaly. Extensive gossanous pyritic skarns associated with the sills in Mikkelsen Islands Formation have background base metal content (Jefferson et al., 1988). However, igneous layering in the sills at Cape Lambton is well exposed in cliffs and sea-shore exposures (ibid.) which would facilitate geochemical studies there.

A relatively low degree of confidence accompanies assessments of other domains of the Franklin suite, because they also were not included in the detailed field and laboratory studies reported here. Moderate-to-low potential is assigned to Noril'sk type Ni-Cu-PGE in the Somerset Island, northern Slave Province and Baffin Island-Melville Peninsula domains. Reasons include the predominant dyke rather than sill architecture and, in areas of subhorizontal sheets (e.g. northern Slave Structural Province), the lack of sulphidic supracrustal strata to contaminate the magmas.

One possible but anomalous representative of the Franklin sheets which cut the northern Slave Province is an isolated olivine

ATTRIBUTE	NEMI[1]	BI[2]
01. Host strata include shales with high C, Se & As which, if absorbed by magmas, would enhance Cu-Ni-PGE scavenging by magmatic sulfides	yes	yes
02. Many of the "diabases" are in fact cumulates	yes	yes
03. Plagioclase and olivine cumulates in Franklin sills are very similar to those at Noril'sk	yes	yes
04. Olivine present in both early & late differentiates	yes	yes
05. $\delta^{34}S$ +18-28 ‰ record crustal contamination	yes	yes
06. Sulfur-rich country rocks are host to sills	yes	yes
07. Upper sills contain elevated sulfur (.95-2%)	yes	yes
08. Sedimentary and volcanic evidence of mantle plume and corollary large magma chamber	yes	no
09. A number of sills are strongly differentiated; rock types range from peridotite to granophyre	yes	no
10. Some gabbro-dolerites form chonoliths	yes	no
11. Taxitic (pegmatitic) patches high & low in sills	yes	no
12. High Pt and Pd values up to 500 ppb indicate anomalous PGE in the system	yes	no
13. Major sills as magma chambers for basalts	yes	no
14. Se and As locally elevated in gabbro-dolerites	yes	no
15. Major faults located at edge of regional magnetic high indicate major crustal break	yes	no
16. Ultramafic rocks associated with large masses of gabbro-dolerite and syn-magmatic faults	yes	no
17. Structure & stratigraphy record syn-volcanic faults	yes	no
18. Thick flood basalts	yes	no
19. Extensive magnetite - sulfide contact skarns	yes	no
20. Exposed massive Cu-Ni-PGE sulfides	no	no
21. Gravity & magnetic evidence of large deep mafic bodies (highly uncertain)	no	no
22. Proximity to tidewater	yes	yes

Table 5. Status of criteria for the Noril'sk model in [1] northeast Minto Inlier and [2]Brock Inlier and Coppermine area.

[1] Analyses of other sulphidic strata in the Shaler Supergroup (e.g. Burns Lake, Escape Rapids and Grassy Bay formations) are required to test their potential to be contaminants.

gabbro pod which is about 50 m wide and 160 m long, and has been informally called Nickel Knob (Staargaard, 1987). Nickel Knob rests with uncertain, inferred intrusive contact, on Archean greywackes at Turner Lake, west of Bathurst Inlet (NTS 76N; approximately 69°12'N, 108°57'30"W). It appears to be the remnant of an eroded Franklin sheet. Nickel Knob is the southern of two nickel showings in Figure 5 of Roscoe (1984), but was not described in his text.

Samples taken by Staargaard (1987) reported up to 2.5% Cu, 1.2% Ni, 0.4% Co and 0.02 oz/t Au from disseminated chalcopyrite, pyrrhotite and pentlandite at the lower margin of Nickel Knob. Schaan (1993) recognized no plagioclase in thin section (her sample 89-018) but observed relict olivine which has been largely altered to tremolite-actinolite and chlorite. A few larger grains, up to 2.5 mm, of amphibole completely replace the olivine (ibid.). This degree of alteration was not observed in any definitive Franklin gabbro-dolerites; moreover no mineralization has yet been found in one thick, continuous sheet of probable (but undated) Franklin affinity, which is located several km to the east and dips about 30° E. The continuous sheet of gabbro-dolerite is of the same orientation and general appearance as the Quadyuk Island Gabbro (in Bathurst Inlet to the east) which was dated by Heaman et al. (1992) at 723 Ma.

Nickel Knob was examined in the field by CWJ and is too small to have economic potential in itself, but demonstrates that the nickel sulfide mineralization process took place in a younger ultramafic rock in the northern Slave Province. The Nickel Knob gabbro and the very extensive Franklin gabbro-dolerites located to the north and east of it (Johnstone, 1990; Henderson et al., 1991; Heaman et al., 1992) should be further documented by petrochemistry and geochronology.

Sudbury Model in Amundsen Basin

The Sudbury Model can only be applied to this study in a conceptual way - the concept of a very large mafic to ultramafic intrusion with associated magmatic sulphides, such as the Sudbury irruptive which is the host of numerous Ni-Cu orebodies. Mining of these orebodies has supported two major mining companies and their thousands of employees for decades. The concept of such a body being buried beneath Paulatuk and Darnley Bay is supported only by the remotely detected data obtained by modern geophysical techniques - seismic, gravity and magnetic measurements.

The age, magmatic association, petrochemistry and depth of the Darnley Bay body (Figs. 9, 10, 11) are thus not clear and can only be resolved by acquiring additional geophysical data followed by drilling. Darnley Bay Resources Limited (press release, February 8, 1994) has proposed to do so. The shape of this body as modelled from gravity and seismic data (Figs. 9, 11), and the seismic record of its apparent unconformity beneath the basal Shaler Supergroup strata suggest that it predated the Franklin Events which appears to have a magmatic focus at the northeast end of Minto Inlier (see above chapter on **Foci of Franklin Magmatism**). Neverthless, our present data have not ruled out a younger age for the body, and therefore three general possibilities with individual variants are considered as follows:

(1) The Darnley Bay body may predate deposition of the Shaler Supergroup, and be associated with the 1.27 Ga Mackenzie event. The layered rocks may be an upper layered portion of the mafic body. It is unlikely that the layering represents the Coppermine basalts because the Brock Inlier overall has a subdued aeromagnetic expression. In the Coppermine area and to the south of Brock Inlier the exposed and buried basalts are characterized by a significant broad aeromagnetic anomaly (200-600 gammas; Fig. 13; from Coles et al., 1976), which is big enough that overlying Proterozoic and Paleozoic strata are translucent to it. In the Darnley Bay area the aeromagnetic anomaly is a bulls eye surrounded by 0 to 200 gamma magnetic field residuals (ibid.). Figure 3 of Hildebrand and Baragar (1991) in the Coppermine River area shows an abrupt cutoff of the 200-699 gamma anomaly to the north, at about 67°45'N. They noted that this is compatible with the area north of 67°45'N being underlain by strata such as the Dismal Lakes or Hornby Bay groups. They did not decide whether this was due to complete erosion of the lavas in that area prior to folding or was the result of folding and later faulting. They were very clear that the deformation preceded deposition of the Rae Group.

(2) The Darnley Bay body might be a layered intrusion cutting Coppermine basalt equivalents and might be associated with the 779 Ma mafic event to the west (Tsezotene sills and dykes). The 779 Ma event was dated by Armstrong et al. (1982), Jefferson and Parrish (1989); and dated and correlated with gabbro sheets in the Great Bear Lake region by LeCheminant and Heaman (1994). On the other hand, magmas of this event intrude the Mackenzie Mountains Supergroup which is correlated with Shaler Supergroup (Fig. 3), and if the Darnley Bay body is related, there should be a surface expression of the 779 Ma event in Brock Inlier. This is not the case; the sills and dykes in Brock Inlier are petrochemically an integral part of the Franklin magmatic suite and distinct from the iron-rich 779 Ma gabbro-dolerites (cf. geochemical analyses of Jefferson, 1983; Lustwerk, 1990, Table 3.13).

(3) There is a low probability that the Darnley Bay body is a Franklin intrusion that ponded at the base of the Shaler Supergroup, forming a large sub-volcanic parent magma chamber to the Franklin igneous Events in the vicinity of the Brock Inlier. The distinctive layering seen in the seismic section could be either: gabbro sheets within the basal Shaler Supergroup; or part of a large layered igneous complex.

In any of the three above possibilities, sulfide accumulations could have contributed to the intense gravity anomaly. The very dense mass modelled by McGrath et al. (1993) at the top-centre of the Darnley Bay body is better explained as massive sulfides than magnetite, because it is no more magnetic than the remainder of the anomaly. Massive sulfides may also be associated with the margins of the Darnley Bay body, analogous to the Muskox intrusion (cf. Hulbert, 1992). Sources of sulfur must have to been of lower Shaler Supergroup (possibilities 2 and 3) or deeper origin. There is no indication of near-surface mineralization related to the Darnley Bay body (thin, weakly differentiated sills, no faults and no favourable geochemistry).

EXPLORATION GUIDELINES

Noril'sk Model in Amundsen Basin

1) One of the most critical criteria to consider is proximity to major feeders to the overlying Natkusiak basalt pile. Candidates for such feeders should be found close to major fault zones such as the northeast-striking array in the Glenelg Bay area (Fig. 6), and in the vicinity of the SW-NE facies changes in the Natkusiak basalts (see Jefferson et al., 1985) and the coincident SW-NE changes in underlying sedimentary stratigraphy (see **Foci of Franklin Magmatism**).

2) The most suitable gabbroic bodies to explore will be those having irregular shape, anomalous thickness, larger thermal metamorphic aureoles, lithological differentiation with preferential enrichment of olivine toward the base, an abundance of pegmatitic textures top and bottom, and features which indicate that their wall rocks were assimilated rather than pushed apart.

3) Exploration priority should be placed on gabbroic bodies known to have intruded sulfur-enriched sedimentary strata, e.g. black shales and sulphate evaporites, particularly the Wynniatt and Kilian formations.

4) Sulfur and sulfur isotope compositions of remaining Franklin intrusive bodies and enclosing sedimentary strata should be determined, employing high precision analytical facilities. For example, the wide range in S-isotope signatures associated with sills 4 to 8 relative to sills 9 to 29 in the Minto Inlier (Figs. 4, 18D) suggests that they incorporated a wider range of contaminants, and thus should be targeted for further investigation.

5) Remaining Franklin igneous bodies should be analysed for Ni, Co, Cu, S, Pt, Pd, Au, Se and As (see **New Petrochemical Data**) to test for significant metal depletion relative to the regional suite of gabbro-dolerites.

6) Natkusiak Formation flood basalts should be surveyed for zones of olivine-rich flows, and/or anomalous thicknesses of flows which can be related to regional faults (criterion 1). If one or both of these attributes are discovered then further exploration should be focussed on possible feeder sills.

7) Systematic infrared (heat from oxidizing massive sulfides), high-resolution aeromagnetic, and other spectral surveys from airborne and satellite platforms have promise in Amundsen Basin because of the lack of vegetation and excellent exposure of the Franklin sills and dykes. Landsat satellite images of Minto Inlier viewed by the authors show glacial dispersion trains very clearly, so that surfical geochemical surveys should be readily interpretable.

Sudbury Model in Amundsen Basin

Pursuing the model of a single large layered intrusion under Darnley Bay should begin with defining the depth, age and composition of the body responsible for the 130 mGal gravity anomaly. Danley Bay Resources Ltd. (1994) has proposed more geophysical surveys to do this. The least expensive way of acquiring more information on the Darnley Bay body would be by deep electromagnetic soundings (P. Keating and R.A. Gibb, pers. comm., 1994). More expensive would be the acquisition of additional seismic data across the anomaly and well into the exposed Proterozoic rocks of the Brock Inlier. Such seismic data could resolve the depth and stratigraphic context of the body. To maximize the data potential, the seismic line should be recorded for longer listening times than those recorded by Vye (1972).

New seismic data would also help to understand the entire seismic array over the northern interior platform (figured by Maclean and Cook, 1992), and to thus resolve conflicting interpretations of Proterozoic deformation in northwestern Canada (e.g. Cook, 1988, 1991; Cook and Mayers, 1990, 1991; Cook and MacLean, 1992). Cook and Aitken (1969) and new geology maps (Jones et al., 1992) of the Brock Inlier give no indication of thin-skinned tectonic structures, and are more compatible with the interpretations published by MacLean and Cook (1992) of the sub-Paleozoic geology under Colville Hills.

Deep drilling could follow the seismic survey, if seismic data indicate that the body is shallow enough to be economically feasible. Drill core must be analysed for physical properties in order to improve geophysical modelling. In addition the same petrochemical data, as presented here for the gabbro-dolerites, must be derived from the core in order to document the petrogenetic relationships between the inferred Darnley Bay intrusion and the Franklin, 779 Ma or Mackenzie igneous events.

Lynn Lake Model Applied to Intrusive Breccias in Northeastern Minto Inlier

Although this investigation has been focussed mainly toward the recognition of sills with favourable geochemistry for Noril'sk-type massive Ni-Cu sulfide orebodies, the possibility for other types of Ni-Cu orebodies should not be overlooked. The anomalous concentrations of pyrite and PGE associated with the gabbro-dolerites in the intrusive breccia complexes indicates that these bodies may also be favourable hosts for economic concentrations of Ni, Cu and PGE. Similar, highly altered, brecciated pipe-like gabbroic bodies in the Lynn Lake area of northern Manitoba are known to contain some of the best Ni-Cu orebodies in this mining camp although these gabbroic bodies are extremely small when compared to others in the camp (Pinsent, 1980).

In particular, the "EL" plug in the Lynn Lake camp has the form of a cored pipe which tapers from a surface diameter of 500m to a diameter of 200m on the 2000'(600 m) level. The pipe has a vertical attitude and has been traced for a depth of over 1500m. A high grade Ni-Cu massive sulphide orebody is located in the core of the upper portion of the pipe. The orebody has a diameter of 120m on surface, tapering to 92m on the 2000' (600 m) level, and is referred to as the upper "EL" orebody. The mined portion of the upper "EL" orebody contained 1,034,170 tons of ore grading 3.25% Ni and 1.09% Cu (Pinsent, 1980).

The attitude of the gabbroic pipe-like structure of the "EL" plug, evidence for multiple-intrusive events giving rise to the brecciation, and the amount of contained sulfide dictate that the sulfides could not have originated within the Lynn Lake intrusions. The sulfides within these pipes are believed to have been generated within a deeper level, crustally contaminated magma chamber that fed the overlying volcanics and intrusions by means of these small brecciated pipe feeder bodies. The analogy between the Lynn Lake pipes and the Franklin breccia bodies should not be overlooked.

NOTES

REFERENCES

Armstrong, R.L, Eisbacher, G.H. and Evans, P.D.

1982: Age and stratigraphic-tectonic significance of Proterozoic diabase sheets, Mackenzie Mountains, northwestern Canada; Canadian Journal of Earth Sciences, v. 19, p. 316-323.

Balkwill, H.R. and Yorath, C.J.

1971: Brock River map-area, District of Mackenzie (97D); Geological Survey of Canada, Paper 70-32, 25 p.

Baragar, W.R.A.

1976: The Natkusiak basalts, Victoria Island, District of Franklin; in Report of Activities, Geological Survey of Canada, Paper 76-1A, p. 347-352.

Baragar, W.R.A.

1977: Volcanism of the stable crust; in Volcanic regimes in Canada; edited by W.R.A. Baragar, L.C. Coleman and J.M. Hall; Geological Association of Canada, Special Publication No. 16, p. 377-405.

Baragar, W.R.A. and Donaldson, J.A.

1973: Coppermine and Dismal Lakes map areas; Geological Survey of Canada, Paper 71-39, 20 p.

Barnes, S.J., Hill, R.E.T. and Gole, M.J.

1988: The Perseverence ultramafic complex, western Australia: The product of a komatiite lava river; Journal of Petrology, V. 29, Part 2, p. 305-331.

Bell, R.T. and Jefferson, C.W.

1987: An hypothesis for an Australian-Canadian connection in the Late Proterozoic and the birth of the Pacific Ocean; in Proceedings Pacific Rim Congress '87; An International Congress of the Geology, Structure, mineralisation and Economics of the Pacific Rim; The Australasian Institute of Mining and Metallurgy, Parkville, Victoria, p. 39-50.

Bird, D.K., Brooks, C.K., Gannicott, R.A. and Turner, P.A.

1991: A gold-bearing horizon in the Skaergaard Intrusion, East Greenland; Economic Geology, v. 86, p. 1083-1092.

Blackadar, R.G.

1963: Somerset Island between Aston Bay and Creswell Bay. In: Y.O. Fortier et al. (editors); Geology of the north-central part of the Arctic Archipelago, Northwest Territories (Operation Franklin); Geological Survey of Canada, Memoir 320, p. 143-150.

Chai, G. and Naldrett, A.J.

1992a: The Jinchuan ultramafic intrusion: cumulate of a high-Mg basaltic magma; Journal of Petrology, V. 33, Part 2, p. 277-303.

1992b: Characteristics of Ni-Cu-PGE mineralization and genesis of the Jinchuan Deposit, northwest China; Economic Geology, v. 87, p. 1475-1495.

Chavez, R.E., Bailey, R.C., and Garland, G.D.

1987: Joint interpretation of gravity and magnetic data over axial symmetric bodies with respect to the Darnley Bay anomaly, N.W.T., Canada; Geophysical Prospecting, v. 35, p. 374-392.

Christie, R.L.

1964: Diabase-gabbro sills and related rocks of Banks and Victoria Islands, Arctic Archipelago; Geological Survey of Canada, Bulletin 105, 13 p.

Campbell, I.H. and Naldrett, A.J.

1979: The influence of silicate:sulfide ratios on the geochemistry of magmatic sulfides; Economic Geology, v.74, p. 1503-1505.

CIM

1992: The Inco Story; Canadian Institute of Mining, Metallurgy and Petroleum, CIM Directory Feature, p. 61-79.

Coles, R.L., Haines, G.V. and Hannaford, W.

1976: Large scale magnetic anomalies over western Canada and the Arctic: a discussion; Canadian Journal of Earth Sciences, v. 13, p. 790-802.

Cook, D.G. and Aitken, J.D.

1969: Erly Lake, District of Mackenzie (97A); Geological Survey of Canada, Map 5-1969, 1:250,000 scale (with marginal notes).

Cook, D.G. and Mayers, I.R.

1990: Precambrian structure and stratigraphy based on seismic interpretation, Colville Hills region, Northwest Territories; in Current Research, Part C, G logical Survey of Canada, Paper 90-1C, p. 339-348.

1991: Precambrian structure and stratigraphy based on seismic interpretation, Colville Hills region, Northwest Territories: Reply; in Current Research, Part E, Geological Survey of Canada, Paper 91-1E, p. 239-241.

Cook, D.G. and MacLean

1992: Proterozoic thick-skinned intracratonic deformation, Colville Hills region, Northwest Territories, Canada; Geology, v. 20, p. 67-70.

Cook, F.A.

1988: Proterozoic thin-skinned thrust and fold belt beneath the Interior Platform in northwest Canada; Geological Society of America, Bulletin, v. 100, p. 877-890.

1991: Precambrian structure and stratigraphy based on seismic interpretation, Colville Hills region, Northwest Territories: Discussion; in Current Research, Part E, Geological Survey of Canada, Paper 91-1, p. 233-238.

Darnley Bay Resources Ltd.

1994: Press release, February, 1994.

Dostal, W.A., Baragar, W.R.A. and Dupuy, C.

1986: Petrogenesis of the Natkusiak continental basalts, Victoria Island, Northwest Territories, Canada; Canadian Journal of Earth Science, Vol. 23, p. 622-632.

Duzhikov, O.A., Distler, V.V., Strunin, B.M., Mkrtychyan, A.K., Sherman, M.L., Sluzhenikan, S.S. and Lurje, A.M.

1992: Geology and metallogeny of sulfide deposits of Noril'sk region, USSR: Society of Economic Geologists, Special Publication 1, 242 p.

Eckstrand, O.R. and Hulbert, L.J.

1987: Selenium and the source of sulphur in magmatic nickel and platinum deposits (abstract) in: Geological Association of Canada.- Mineralogical Association of Canada, Abstracts with Programs, v. 12, p. 40.

Fahrig, W.F., Irving, E. and Jackson, G.D.

1971: Paleomagnetism of the Franklin diabases; Canadian Journal of Earth Sciences, v. 8, p. 455-467.

Fahrig, W.F. and West, T.D.

1986: Diabase dyke swarms of the Canadian Shield; Geological Survey of Canada, Map 1627A.

Genkin, A.D., Distler, V.V., Gladyshev, G.D., Filiminova, A.A., Evstigneeva, T.L., Kovalenker, V.A., Laputina, I.P., Smirnov, A.V. and Grokhovskaya, T.L.

1981: Copper-nickel sulphide ores of the Noril'sk deposits; in: A translation of "Sul'Fidnye Medno-Nikelevye Rudy Noril'skikh Mestorozhdenii" Nauka, Moskva, 263 p.

Geological Survey of Canada

1980: Non-hydrocarbon mineral resource potential of parts of northern Canada; Geological Survey of Canada, Open File 716, 376 p.

Geophysics Division

1992: Darnley Bay; Bouger Gravity Anomalies, Aeromagnetic Total Field, Calculated Vertical Gradient; Geological Survey of Canada, Open File 2517; three maps, scale 1:500,000.

Godlevsky, M.N. and Grinenko, L.N.

1963: Some data on the isotopic composition of sulphur in sulphides of the Noril'sk deposit; Geochemica v. 1, p. 335-341.

Goodacre, A.K., Grieve, R.A.F., Halpenny, J.F. and Sharpton, V.L.

1987: Gravity anomaly map of Canada, Geological Survey of Canada Geophysical Atlas, Map 3, scale 1:10,000,000.

Gorbachev, N.S. and Grinenko, L.N.

1973: The sulphur isotope ratios of sulphides and sulphates of the Oktyabr'sk sulphide deposit, Noril'sk region and the problem of its origin; Geokhimiya v. 8, p. 1127-1136.

Grinenko, L.N.

1967: The sulphur-isotope ratio of sulphides of some copper nickel deposits of the Siberian Platform; in The petrology of the trap-rocks of the Siberian Platform; Neda Press, Leningrad, p. 221-229.

Grinenko, L.N.

1985: Sources of sulphur of the nickeliferous and barren gabbro-dolerite intrusions of the northwest Siberian Platform; International Geology Review, p. 695-708.

Halls, H.C.

1978: The late Precambrian central North American rift system - a survey of recent geological and geophysical investigations: NATO Advanced Study Institute, Series C, v. 37, p. 111-123.

Hamlyn, P.R., Keays, R.R., Warringbon, E., Cameron, A.J. and Waldrow, H.M.

1985: Precious metals in magnesian low-Ti magmas: implications for metallogenesis and sulfur saturation in primary magmas: Geochemica et Cosmochimica Acta, v. 49, p. 1797-1811.

Heaman, L.M., LeCheminant, A.N. and Rainbird, R.H.

1992: Nature and timing of Franklin igneous events, Canada: Implications for a late Proterozoic mantle plume and break-up of Laurentia; Earth and Planetary Science Letters, 109 (1992), p. 117-131.

Henderson,M.N., Henderson,J.R., Jefferson,C.W., Wright,T.O., Wyllie,R. and Schaan, S.

1991: Preliminary geologic map of the Hood River Belt, NTS 76K/N; Geological Survey of Canada; Open File 2413.

Hildebrand, R.S. and Baragar, W.R.A.

1991: On folds and thrusts affecting the Coppermine River Group, Northwestern Canadian Shield; Canadian Journal of Earth Sciences, v. 28, p. 523-531.

Hole, J.A. and Bradley Isbell, W.

1990: Interpretation of seismic reflection data in the Darnley Bay region, N.W.T.; unpublished report to Cominco Ltd., 5 p, 2 maps.

Hooper, P.R.

1990: The timing of crustal extension and the eruption of continental flood basalts; Nature, v. 345, p. 246-249.

Hornal, R.W., Sobczak, L.W., Burke, W.E.F., and Stephens, L.W.

1973: Preliminary results of gravity surveys over the Mackenzie Basin and Beaufort Sea; Department of Energy , Mines and Resources, Earth Physics Branch, Gravity Map Series Nos. 117-119.

Hulbert, L.J.

1992: Platinum-group element mineralization associated with the Muskox, Rankin Inlet and Ferguson Lake intrusions, N.W.T., Canada; in Project Summaries, Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991 (Eds. D. Richardson and M. Irving); p. 117-122.

Hulbert, L., Duke, M., Eckstrand, O.R., Scoates, J., Cabri, L. and Lydon, J.

1988: Geological environments of the platinum-group elements, Geological Survey of Canada Open File 1440, p. 1-148.

Hulbert, L.J., Williamson, B., and Theriault, R.

1993: Geology of Middle Proterozoic Mackenzie diabase suites from Saskatchewan: An overview and their potential to host Noril'sk-type Ni-Cu-Pge mineralization; in: Summary of Investigations, Saskatchewan Geological Survey Miscellaneous Reports, v. 93-4, p. 112-126.

Jackson, G.D. and Iannelli, T.R.

1981: Rift-related sedimentation in the Neohelikian Borden Basin, northern Baffin Island; in: F.H.A. Campbell (editor); Proterozoic Basins in Canada; Geological Survey of Canada, Paper 81-10; p. 269-302.

Jefferson, C.W.

1983: The Upper Proterozoic Redstone Copper Belt, Mackenzie Mountains, N.W.T., Unpublished Ph.D. Thesis, The University of Western Ontario, London, Ontario, Canada, p. 445.

Jefferson, C.W and Young, G.M.

1988: Late Proterozoic orange-weathering stromatolite biostrome, Mackenzie Mountains and western Arctic Canada; in Reefs in Canada and Adjacent Areas, edited by H. Geldsetzer; Canadian Society of Petroleum Geologists, Memoir 13, p. 72-80.

Jefferson, C.W., Nelson, W.E., Kirkham, R.V., Reedman, J.H. and Scoates, R.F.J.

1985: Geology and copper occurrences of the Natkusiak basalts, Victoria, Island, District of Franklin, In: Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 203-214.

Jefferson, C.W., Scoates, R.F.J.S. and Smith, D.R.

1988: Evaluation of the regional non-renewable resource potential of Banks and northwestern Victoria Islands, Arctic Canada; Geological Survey of Canada, Open File 1695, 63 p.

Jefferson, C.W. and Parrish, R.R.

1989: Late Proterozoic stratigraphy, U-Pb zircon ages and rift tectonics, Mackenzie Mountains, northwestern Canada; Canadian Journal of Earth Sciences, 26, 1784-1801.

Jefferson, C.W., Henderson, M.N., Henderson, J.R. and Schaan, S.

1990: Geologic setting of gold occurrences in the Fish-hook -Turner Lake belt, Bathurst Inlet area, N.W.T.; in Current Research, Part C, Geological Survey of Canada, Paper 90-1C, p. 349-361.

Jefferson, C.W., Hulbert,L.J., Rainbird,R.H., Hall,G.E.M., Grégoire, D.C. and Grinenko, L.

1993: Mineral Resource Assessment of the 723 Ma Franklin Igneous Events of Arctic Canada: Comparison with the Paleozoic Noril'sk - Talnakh Ni-Cu-PGE Deposits of Russia; in Part 2, Preliminary reports on geological work in the NWT; Exploration Overview 1993, Northwest Territories; Mining, Exploration and Geological Investigations; NWT Geology Division, Northern Affairs Program, Indian and Northern Affairs Canada.

Johnston, R.M.

1990: Geology of the Torp Lake metasedimentary belt, parts of NTS 76N/3, 5, 6, 7, 11, 12, NWT; NWT Geology Division, Indian and Northern Affairs Canada, E.G.S. 1989-7.

Jones, P.B

1980: Evidence from Canada and Alaska on plate tectonic evolution of the Arctic Ocean; Nature, v. 285, p. 215-217.

Jones, T.A., Jefferson, C.W. and Morrell, G.R.

1992: Assessment of mineral and energy resource potential in the Brock Inlier - Bluenose Lake area, N.W.T.; Geological Survey of Canada, Open File 2434, 94 p.

Kerans, C., Ross, G.M., Donaldson, J.A. and Geldsetzer, H.

1981: Tectonism and depositional history of the Helikian Hornby Bay and Dismal Lakes groups, District of Mackenzie; in Proterozoic Basins of Canada, edited by F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 157-182.

Kovalenker, V.A., Gladyshev, G.D. and Nosik, L.P.

1975: Isotopic composition of sulfide sulfur from deposits of Talnakh ore node in relation to their selenium content; International Geology Review, v. 17, No. 6, p. 725-734.

LeCheminant, A.N. and Heaman, L.M.

1989: Mackenzie igneous events, Canada: Middle Proterozoic hotspot magmatism associated with ocean opening; Earth and Planetary Science Letters, v. 96, p. 38-48.

in press: 779 Ma mafic magmatism in the northwestern Canadian Shield and northern Cordillera: a new regional time marker (Abstract); in International Conference on Geochronology, Cosmochronology and Isotope Geology, Abstracts with Programs, V. 8, in press.

Lightfoot, P.C., Hawkesworth, C.J., Hergt, xx., Naldrett, A.J., Gorbachev, N.., Fedorenko, V.A., and Doherty, W.

1993: Remobilization of the continental lithosphere by a mantle plume: major and trace element, and Sr-, Nd-, and Pb-isotope evidence from picritic and tholeiitic lavas of the Noril'sk District, Siberian Trap, Russia; Contributions to Mineralogy and Petrology, v. 114, p. 171-188.

Lightfoot, P.C., Naldrett, A.J., Gorbachev, N.S., Doherty, W. and Federenko, V.A.

1991: Geochemistry of the Siberian trap of the Noril'sk area, USSR, with implications for the relative contribution of crust and mantle to flood basalt magmatism; Contributions to Mineralogy and Petrology, v. 104, p. 631-644.

Lustwerk, R.L.

1990: Geology and geochemistry of the Redstone stratiform copper deposit, Northwest Territories, Canada, a thesis in geochemistry and mineralogy; unpublished Ph.D. thesis, The Pennsylvania State University, 319 p + appendices.

1992: Unpublished report to D.G. Cook, Institute of Sedimentary and Petroleum Geology, Calgary.

McGrath, P.H., Broome, H.J., Klein, J. and Mariano, J.

1993: New models for the Darnley Bay, N.W.T., gravity anomaly (abstract); in Program with Abstracts, Forum 1993, Geological Survey of Canada, p. 15.

MacLean, B.C. and Cook, D.G.

1992: The influence of Proterozoic structures on the development of Laramide structures, northern Interior Plains, Northwest Territories, Canada; Bulletin of Canadian Petroleum Geology, v. 40, No. 3, p. 207-221.

Morin, J. and Rainbird, R.H.

1993: Sediimentology and sequence stratigraphy of the Reynolds Point Formation; in Current Research, Part A, Geological Survey of Canada, Paper 93-1A, p. 7-18.

Naldrett, A.J.

1989: Ores associated with flood basalts; in Ore deposits associated with magmas, edited by J.A. Whitney and A.J. Naldrett; Reviews in Economic Geology, v. 4, p. 103-118.

Naldrett, A,H,. Lightfoot, P.C., Fedorenko, V.A., Doherty, W., and Gorbachev, N.S.

1992: Geology and geochemistry of intrusions and flood basalts of the Noril'sk region, USSR, with implications for the origin of the Ni-Cu ores; Economic Geology, v. 87, p. 975-1004.

Naldrett, A.J.

1992: A model for the Ni-Cu-PGE ores of the Noril'sk region and its application to other areas of flood basalt; Economic Geology, v. 87, p. 1945-1962.

1994: Ni-Cu-PGE deposits of the Noril'sk region: a model for other world class magmatic sulphide deposits; in Program with Abstracts, Minerals Colloquium, Geological Survey of Canada, p. 4.

O'Neil, J.J.

1924: Part A: the geology of the arctic coast of Canada, west of the Kent Peninsula; Report of the Canadian Arctic Expedition 1913-1918, v. II, Geology and Geography, 91 p.

Petrini, R., Civetta, L., Piccirillo, E.M., Bellieni, G., Comin-Chiaramonti, P., Marques, L.S. and Melfi, A.J.

1987: Mantle heterogeneity and crustal contamination in the genesis of low-Ti continental flood basalts from the Piranha Plateau, Brazil: Sr-Nd isotopic and geochemical evidence; Journal of Petrology, v. 28, p. 701-726.

Pinsent, R.H.

1980: Nickel-copper mineralization in the Lynn Lake gabbro; Manitoba Department of Energy and Mines, Economic Geology Report ER79-3, 138 p.

Pye, E., Naldrett, A.J. and Giblin, P.

1984: The geology and ore deposits of the Sudbury structure; Ontario Geological Survey, Special Publication No. 1, 603 p.

Rainbird, R.H.

1991: Stratigraphy, sedimentology and tectonic setting of the upper Shaler Group, Victoria Island, N.W.T; Unpublished Ph.D. thesis, The University of Western Ontario, 257 p.

1992: Anatomy of a large-scale braid-plain quartzarenite from the Neoproterozoic Shaler Group, Victoria Island, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 29, p. 2537-2550.

1993: The sedimentary record of mantle plume uplift preceding eruption of the Neoproterozoic Natkusiak flood basalt; Journal of Geology, v. 101, p. 305-314.

in press: Stratigraphy and correlation of the Neoproterozoic Shaler Supergroup, Amundsen Basin, northwestern Canada; in Proceedings of the International Conference on Arctic Margins, Anchorage, Alaska, September 1992; edited by D.K. Thurston and K. Fujita.

Rainbird, R.H. and Jefferson, C.W.

1993: Geology and mineral resource assessment of Minto Inlier, Victoria Island; in Part 2, Preliminary reports on geological work in the NWT; Exploration Overview 1993, Northwest Territories; Mining, Exploration and Geological Investigations; NWT Geology Division, Northern Affairs Program, Indian and Northern Affairs Canada.

Rainbird,R.H., Darch,W., Jefferson,C.W., Lustwerk,R., Reese,M., Telmer, K. and Jones, T.A.

1992a: Preliminary stratigraphy and sedimentology of the Glenelg Formation, lower Shaler Group, and correlatives in the Amundsen Basin, Northwest Territories: relevance to sediment-hosted copper; in Current Research, Part C; Geological Survey of Canada, Paper 92-1C, p. 111-119.

Rainbird, R.H., Heaman, L.M. and Young, G.M.

1992b: Sampling Laurentia: detrital zircon geochronology offers evidence for an extensive Neoproterozoic river system originating from Grenville Orogen; Geology, v. 20, p. 351-354.

Rainbird, R.H., Jefferson, C.W., Hildebrand, R.S. and Worth, J.K.

1994a: The Shaler Supergroup and revision of Neoproterozoic stratigraphy in the Amundsen Basin, Northwest Territories; in Current Research, Part A; Geological Survey of Canada, Paper 94-1A, p. 61-70.

Rainbird, R.H., Hodgson, D.A., Darch, W. and Lustwerk, R.

1994b: Bedrock and surficial geology of northeast Minto Inlier, Victoria Island; NTS 76B7; Geological Survey of Canada, Open File 2781, scale 1:50,000.

Riddihough, R.P. and Haines, G.V.

1972: Magnetic measurements over Darnley Bay, N.W.T.; Canadian Journal of Earth Sciences, v. 9, p. 972-978.

Robertson, W.A. and Baragar, W.R.A.

1972: The petrology and paleomagnetism of the Coronation Sills; Canadian Journal of Earth Sciences, v. 9, p. 123-140.

Roscoe, S.M.

1984: Assessment of mineral resource potential in the Bathurst Inlet area, NTS 76J,K,N,O including the proposed Bathurst Inlet National Park; Geological Survey of Canada, Open File 788, 75 p + 1:250,000 map.

Rousseau, R.M.

1989a: Concepts of influence coefficients in XRF analysis and calibration; Advances in X-Ray Analysis, v. 32, p. 77-82.

1989b: Painless XRF analysis using new generation computer programs; Advances in X-Ray Analysis, v. 32, p. 69-75.

Scoates, R.F.J., Jefferson, C.W. and Findlay, D.C.

1986: Northern Canada mineral resource assessment; in Prospects for mineral resource assessments on public lands: proceedings of the Leesburg Workshop, edited by S.M. Cargill and S.B. Green; United States Geological Survey, Circular 980, p. 111-139.

Schaan, S.

1991: Geology of Turner Lake area, parts of 76N/2 and 76N/3; NWT Geology Division, Indian and Northern Affairs Canada, Economic Geology Series EGS 1991-6.

1993: Stratigraphy, structure and metamorphic petrology of the Turner Lake area, Archean Slave Province, Northwest Territories; unpublished M.Sc thesis, University of Ottawa, 232 p.

Staargaard, C.

1987: Report on a 1986 program of geological mapping, sampling and magnetic-VLF surveying on the Turner Lake property, Bathurst Inlet area, District of Mackenzie, N.W.T.; unpublished report for Silver Hart Mines Ltd., 30 p. with 6 maps.

Stacey, R.A.

1971: Interpretation of the gravity anomaly at Darnley Bay, N.W.T; Canadian Journal of Earth Science, v. 8, p. 1037-1042.

Stewart, W.D.

1987: Late Proterozoic to early Tertiary stratigraphy of Somerset Island and northern Boothia Peninsula, District of Franklin, N.W.T.; Geological Survey of Canada, Paper 83-26, 78 p.

Tamrazyan, G.P.

1971: Siberian continental drift; Tectonophysics, v. 11, p. 433-460.

Thompson, M. and Walsh, J.N.

1983: A handbook of inductively coupled plasma spectrometry; Blackie & Sons Ltd., Glasgow, Scotland, 273 p.

Thorsteinsson, R. and Tozer, E.T.

1962: Banks, Victoria and Stefannson Islands, Arctic Archipelago; Geological Survey of Canada, Memoir 330, 85 p.

Vye, R.J.

1972: Interpretation of Darnley Bay area seismic data, NTS 97 C/1, C/8; Indian and Northern Affairs assessment report # 19684; unpublished assessment report, Arjay Kirker Resources.

Wadsworth, W.J.

1961: The ultrabasic rocks of south-west Rhum; Philosophical Transactions of the Royal Society, v. B244, p. 21-64.

Wager, L.R. and Brown, G.M.

1968: Layered Igneous Rocks; Oliver and Boyd Ltd., Edinburgh, 588 p.

Young, G.M.

1977: Stratigraphic correlation of upper Proterozoic rocks of northwestern Canada; Canadian Journal of Earth Sciences, V. 14, p. 323-336.

1979: Correlation of middle and upper Proterozoic strata of the northern rim of the North American craton; Transactions of the Royal Society of Edinburgh, v. 20, p. 323-336.

1981: The Amundsen Embayment, Northwest Territories: relevance to the Upper Proterozoic Evolution of North America; in Proterozoic Basins of Canada, edited by F.H.A. Campbell, Geological Survey of Canada, Paper 81-10, p. 203-217.

APPENDICES

I Sample and Station Data (2789app1.txt on diskette**) are in ascii text format.

II Geochemical Data (2789app2.wk1 on diskette**) are in Lotus format. If anyone requires a different format, please contact L.J. Hulbert.

The complete text of this report is also on the diskette** (2789read.txt), in ascii text. Table 4 is in Word for Windows format (2789tb4.doc). Table 2 (MAC format) and diagrams are NOT included in digital format.

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