GEOLOGICAL SURVEY OF CANADA
BULLETIN 475

STUDIES OF RARE-METAL DEPOSITS IN THE NORTHWEST TERRITORIES

edited by
W.D. Sinclair and D.G. Richardson

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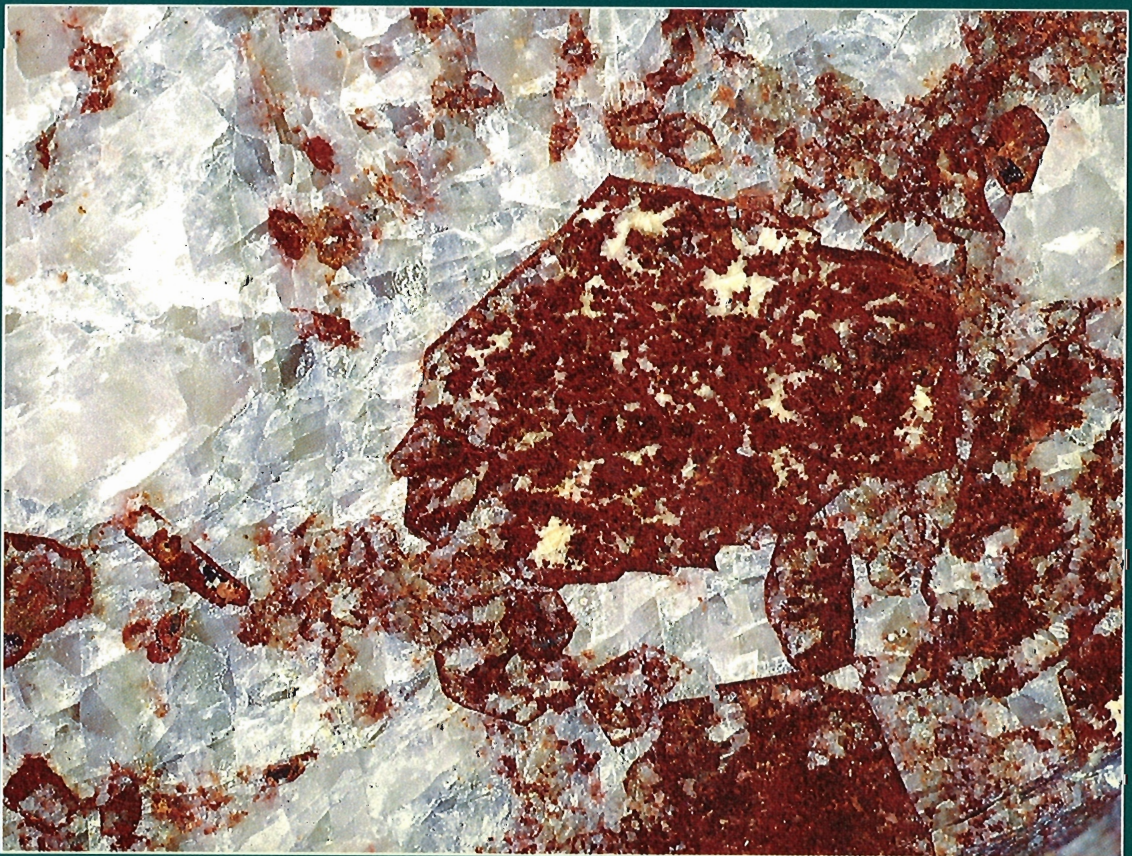

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Cover description:

Rare-earth-rich fluor-carbonate minerals, mainly bastnaesite (red) in quartz, North T zone, Thor Lake; sample collected by D.G. Richardson from high grade stockpile next to decline. Outline of crystal in centre of photograph is 4.5 cm across. GSC 1994-022

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Erratum

GSC Bulletin 475
W.D. Sinclair and D.R. Richardson

Due to a production error, English text on page 2 was inadvertently transposed. This revised version of pages 1 and 2 should be inserted in the volume.

Bulletin 475 de la CGC
W.D. Sinclair et D.R. Richardson

Par suite d'une erreur de production, il y a eu transposition du texte anglais à la page 2. Cette version révisée des pages 1 et 2 est à insérer dans le volume.

Studies of Rare-Metal Deposits in the Northwest Territories

INTRODUCTION

During the late 1980s and early 1990s, significant exploration was conducted in Canada for deposits of rare metals, including niobium, tantalum, zirconium, beryllium and, in particular, yttrium and rare-earth elements. The interest in these elements was primarily due to their increasing demand in highly specialized, technological applications in various industrial sectors, including electronics, glass and ceramics, aerospace, and the nuclear industry. This interest was reflected in scientific meetings such as the Joint Annual Meeting of the Geological Association of Canada and the Mineralogical Association of Canada in May, 1989, where several sessions were held on "High Technology Metal Deposits: Metallogeny and Exploration". At the Annual General Meeting of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) in May, 1990, two sessions highlighted "Recent Developments and the Future of Rare Earths".

This volume contains four papers that report on a wide range of geoscientific activities related to various rare-metal deposit types in the Northwest Territories. Much of the research presented in these papers was funded under the 1987-1991 Canada-Northwest Territories Mineral Development Subsidiary Agreement (MDA).

The two papers authored by Birkett et al. and by Charbonneau and Legault present the results of work that was carried out on the Blatchford Lake Intrusive Suite and the associated Thor Lake rare-metal deposits of niobium, tantalum, beryllium, yttrium, rare-earth elements and gallium. The detailed gravity survey and computer modelling by Birkett et al. provides an understanding of the three dimensional

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À la fin des années 80 et au début des années 90, des travaux d'exploration assez importants ont été effectués au Canada à la recherche de gisements de métaux rares, dont le niobium, le tantale, le zirconium, le béryllium et en particulier l'yttrium et les éléments des terres rares. L'intérêt que l'on portait à ces éléments reposait surtout sur la demande accrue occasionnée par les applications technologiques hautement spécialisées des divers secteurs industriels, dont l'électronique, le verre et les céramiques, l'aérospatiale et l'industrie nucléaire. Cet intérêt s'est manifesté dans des rencontres scientifiques comme la réunion annuelle conjointe de l'Association géologique du Canada et de l'Association minéralogique du Canada, en mai 1989, au cours de laquelle plusieurs communications ont été présentées sous le thème «Gisements de métaux utilisés en haute technologie : métallogénie et exploration». À la réunion générale annuelle de l'Institut canadien des mines, de la métallurgie et du pétrole (ICM) tenue en mai 1990, deux séances ont souligné les «développements récents et l'avenir dans le domaine des terres rares».

Le présent volume réunit quatre études qui rendent compte de diverses activités géoscientifiques reliées à plusieurs types de gisements de terres rares dans les Territoires du Nord-Ouest. La majeure partie des travaux de recherche présentés dans ces études ont été subventionnés en vertu de l'Entente auxiliaire Canada-Territoires du Nord-Ouest sur l'exploitation minérale 1987-1991.

Les deux études signées par Birkett et al. et par Charbonneau et Legault présentent les résultats des travaux qui ont été effectués sur le Suite intrusive de Blatchford Lake et sur les gisements de métaux rares associés de Thor Lake (niobium, tantale, béryllium, yttrium, éléments des terres rares et gallium). Le levé gravimétrique détaillé et la modélisation sur ordinateur qu'ont effectués Birkett et al.

geometry of the 23 km wide Blatchford Lake Intrusive Suite. The results suggest that much of the suite is relatively thin and flat-lying, rather than vertical and cylindrical in shape. As in many cases involving gravity modelling, the results are not unequivocal; however, the paper provides a good example of the application of the gravity technique to geological problems, in this case the determination of the sizes and shapes of intrusive rock units in the third dimension.

Charbonneau and Legault present the results of airborne radiometric, magnetic and very low frequency (VLF) electromagnetic surveys conducted over the Blatchford Lake Intrusive Suite by the GSC; they also present the results of detailed ground follow-up investigations of anomalies outlined by the airborne surveys. The radiometric patterns are relatively flat over much of the Blatchford Lake Intrusive Suite, except over the Thor Lake rare-metal deposits which are more radioactive than the surrounding host rocks by one to two orders of magnitude. Magnetic variations outlined several anomalous areas outside the limits of the Thor Lake deposits, which are related to magnetite produced by metasomatic alteration of ferromagnesian minerals. This magnetite may be autometasomatic or due to fenitization associated with nepheline syenite that underlies the rare-metal deposits. The VLF patterns relate primarily to conductive lake bottom material and faults.

The paper by Tomascak et al. summarizes some of the extensive pegmatite research done by the University of Manitoba throughout the Northwest Territories during the 1980s. This paper, however, does not deal with the well known Yellowknife pegmatite field, but instead provides information on the geological setting, geochemistry, and economic potential of four previously undocumented or poorly known rare-element pegmatite occurrences in the Northwest Territories: Aylmer Lake and Torp Lake fields in the Slave Province, and Chantry Inlet and Foxe fields in the Rae Province. The work presented on the Aylmer Lake pegmatite field was completed under a 1987-1991 MDA contract with Energy, Mines & Petroleum Resources, Government of the Northwest Territories.

fournissent une vue de la géométrie tridimensionnelle de la Suite intrusive de Blatchford Lake qui s'étend sur une largeur de 23 km. Les résultats démontrent que la majeure partie de la suite est relativement mince, horizontale plutôt que verticale et cylindrique de forme. Comme dans beaucoup de cas en modélisation gravimétrique, les résultats ne sont pas complètement non équivoques. L'étude cependant fournit un bon exemple de l'application de la technique gravimétrique aux problèmes géologiques et dans ce cas, dans la détermination des dimensions et des formes des unités lithologiques intrusives dans leur troisième dimension.

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CONTENTS

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The paper by S.S. Gandhi presents a thorough documentation of the geological settings, characteristics, and metallogeny of selected mineral occurrences in the southern part of the Proterozoic Great Bear magmatic zone. This work is significant in that it has resulted in the recognition of small, but potentially significant, examples of the polymetallic Olympic Dam-type copper-uranium-gold-rare-earth deposits and related Kiruna-type magnetite-apatite-actinolite deposits within the Great Bear magmatic zone. It also provides the first comprehensive regional metallogenic synthesis of the southern Great Bear magmatic zone.

The papers presented in this volume represent the culmination of several years of geological investigations, some of which are on-going. All have contributed significantly to the knowledge of various Northwest Territories rare-metal environments.

The editors wish to thank those scientists who assisted in the production of this volume by reviewing the papers presented here. They are as follows:

F.W. Breaks, Ontario Geological Survey
A. Davidson, Continental Geoscience Division, GSC
S.S. Gandhi, Mineral Resources Division, GSC
M.D. Thomas, Continental Geoscience Division, GSC
R.I. Thorpe, Mineral Resources Division, GSC

The editing, layout, and printing of this volume was funded by the GSC's Federal-Provincial/Territorial Liaison Office (Project 303078 00).

L'étude de S.S. Gandhi donne une documentation exhaustive des milieux géologiques, des caractéristiques et de la métallogénie d'indices minéralisés choisis dans la partie sud de la zone magmatique du Grand lac de l'Ours du Protérozoïque. Cette étude est significative par ce qu'elle a mené à l'identification, dans la zone magmatique du Grand lac de l'Ours, de petits, mais potentiellement significatifs, exemples de gisements polymétalliques de cuivre-uranium-or-terres rares de type Olympic-Dam et de gisements apparentés de magnétite-apatite-actinote de type Kiruna. Les auteurs fournissent aussi la première synthèse métallogénique régionale complète de la partie sud de la zone magmatique du Grand lac de l'Ours.

Toutes les études contenues dans le présent volume représentent le point culminant de plusieurs années de recherches géologiques et certains de ces travaux se poursuivent toujours. Tous les auteurs ont contribué de façon significative à l'accroissement des connaissances sur les divers milieux à métaux rares des Territoires du Nord-Ouest.

Les coordonnateurs veulent remercier ces scientifiques qui ont apporté leur aide à la production du volume en faisant la revue des études présentées ici. Ce sont :

F.W. Breaks, Commission géologique de l'Ontario
A. Davidson, Division de la géologie du continent, CGC
S.S. Gandhi, Division des ressources minérales, CGC
M.D. Thomas, Division de la géologie du continent, CGC
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La révision, la mise en page et l'impression du présent volume ont été financés par le Bureau de liaison fédéral-provincial/territorial de la CGC (Projet 303078 00).

W.D.Sinclair *D.G. Richardson*

Gravity modelling of the Blatchford Lake Intrusive Suite, Northwest Territories[1]

T.C. Birkett[2], D.G. Richardson[3], and W.D. Sinclair[3]

Birkett, T.C., Richardson, D.G., and Sinclair, W.D., 1994: Gravity modelling of the Blatchford Lake Intrusive Suite, Northwest Territories; in Studies of Rare-Metal Deposits in the Northwest Territories, (ed.) W.D. Sinclair and D.G. Richardson; Geological Survey of Canada, Bulletin 475, p. 5-16.

Abstract: The geometry of the Blatchford Lake Intrusive Suite, a complex of alkaline igneous rocks on the north shore of Hearne Channel, Great Slave Lake, Northwest Territories, was investigated by a detailed gravity survey (1-2 km station spacing) along two east-west traverses. Modelling of the resulting gravity profiles indicates that the granitic and syenitic rocks in the eastern part of the complex have the form of a thin tabular body; the maximum thickness of these rocks is modelled as 1 km. The gravity data suggest that mafic rocks in the western part have a deep root, and that a related, sill-like branch may extend under the granitic and syenitic rocks for as much as one-half of the area of the complex.

Résumé : La géométrie de la Suite intrusive de Blatchford Lake, qui est un complexe de roches ignées alcalines sur la rive nord du chenal Hearne (Grand lac des Esclaves, Territoires du Nord-Ouest) a été étudiée à l'aide d'un levé gravimétrique détaillé (espacement des stations de 1 à 2 km) le long de deux cheminements d'orientation est-ouest. La modélisation des profils gravimétriques que l'on a obtenus indique que les roches granitiques et syénitiques dans la partie orientale du complexe ont la forme d'un corps tabulaire mince; l'épaisseur maximale de ces roches, selon le modèle, est d'un kilomètre. Les données gravimétriques montrent que les roches mafiques dans la partie occidentale possèdent une racine profonde et qu'un embranchement apparenté en forme de filon-couche peut s'étendre sous les roches granitiques et syénitiques sur une superficie peut-être égale à la moitié de l'étendue du complexe.

[1] Contribution to Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991.
[2] Quebec Geoscience Centre, Geological Survey of Canada, 2700 Einstein Street, P.O. Box 7500, Sainte-Foy, Quebec G1V 4C7
[3] Mineral Resources Division, Geological Survey of Canada, Ottawa, Ontario K1A 0E8

INTRODUCTION

In 1988, a helicopter-supported, ground gravity survey of the Blatchford Lake Intrusive Suite was completed under the auspices of the 1987-91 Canada-Northwest Territories Mineral Development Subsidiary Agreement. This study was initiated in order to complement airborne geophysical surveys of the intrusive suite undertaken by the Geological Survey of Canada. The latter included airborne gamma-ray spectrometer, magnetometer, and VLF surveys conducted along flight-lines spaced 250 m apart (Geological Survey of Canada, 1989; Charbonneau and Legault, 1994). The gravity survey was used to estimate thicknesses of the component lithological units of the Blatchford Lake Intrusive Suite and to model their geometrical relationships. The results of this study help to place into a three-dimensional context the research completed by Highwood Resources Limited and by the Geological Survey of Canada on the Thor Lake rare-metal (beryllium, yttrium, rare-earth elements, niobium, tantalum, zirconium, gallium) deposits (Trueman, 1986; Trueman et al., 1984, 1985, 1988; Pinckston, 1989).

REGIONAL GEOLOGICAL SETTING

The Blatchford Lake Intrusive Suite is situated near the south edge of the Archean Slave craton, approximately 100 km southeast of Yellowknife and immediately north of the Hearne Channel of Great Slave Lake (Fig. 1, 2). The name "Blachford Lake Intrusive Suite", originally porposed by Davidson (1978), is changed in this paper to reflect the current spelling of Blatchford Lake (officially corrected in 1978). This suite is a subcircular ring complex 23 km in diameter that contains gabbro, leucocratic ferrodiorite, syenite, and both metaluminous and peralkaline granites. The mafic rocks of the complex were first mapped by the Geological Survey of Canada during the 1930s (Stockwell, 1932; Jolliffe, 1936; Henderson, 1938). Subsequent work (Davidson, 1972, 1978, 1981, 1982) has shown that the Blatchford Lake Intrusive Suite is divisible into two parts, referred to here as the western lobe and the eastern lobe. The older western lobe rocks include mafic intrusive rocks (Caribou Lake Gabbro), Whiteman Lake Quartz Syenite, Hearne Channel Granite, and Mad Lake Granite (the last three units are grouped together as western lobe syenites and granites in Fig. 3). The eastern lobe rocks, which are laterally more extensive and geographically subcircular, consist mainly of Grace Lake Granite and Thor Lake Syenite.

The Blatchford Lake complex intrudes metasedimentary rocks of the Yellowknife Supergroup and Archean calc-alkaline granitoids (Fig. 2, 3). The complex is intruded in turn by east-northeast-trending diabase dykes of the Hearne swarm, small plutons of Compton Suite diorite and quartz monzonite, and northwest-trending diabase dykes of the Mackenzie swarm (Davidson, 1978; Hoffman, 1988). South of the Blatchford Lake complex on Blanchet Island are Early Proterozoic carbonate, shale, and greywacke of the Great Slave Supergroup (Fig. 2). Although the contact between the Blatchford Lake complex and the Great Slave Supergroup is not exposed, Davidson (1978) considered the Blatchford Lake complex to be older than the Great Slave Supergroup, which lies above an unconformity that truncates Hearne diabase dykes. To account for the absence of Blatchford Lake complex rocks on Blanchet Island, Davidson (1978) postulated that either the Blatchford Lake Intrusive Suite had been eroded south of Hearne Channel, or Hearne Channel is the site of a major fault, down-dropped on the south side. Both the Compton Intrusive Suite plutons and the Mackenzie dyke swarm are younger than Great Slave Supergroup rocks (Hoffman, 1988). According to Hoffman (1988), the brittle dextral transcurrent McDonald fault system developed before the intrusion of the Mackenzie dyke swarm but followed the emplacement of the Compton intrusive rocks. If a fault truncates the Blatchford Lake complex on its southern side, as postulated by Davidson (1978), it may be related to the McDonald fault system.

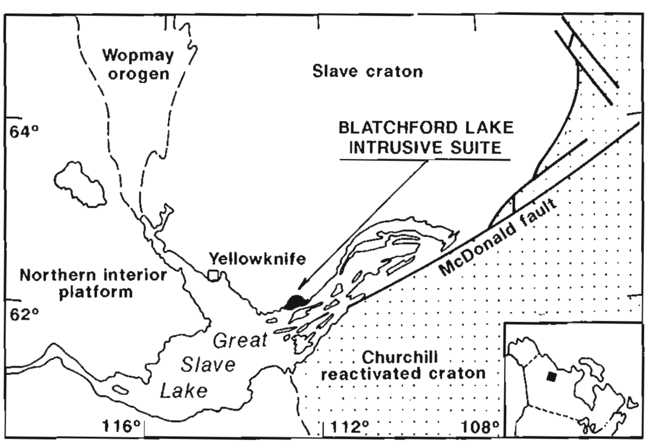

Figure 1. Location map and regional setting of the Blatchford Lake Intrusive Complex. Based on Hoffman (1988).

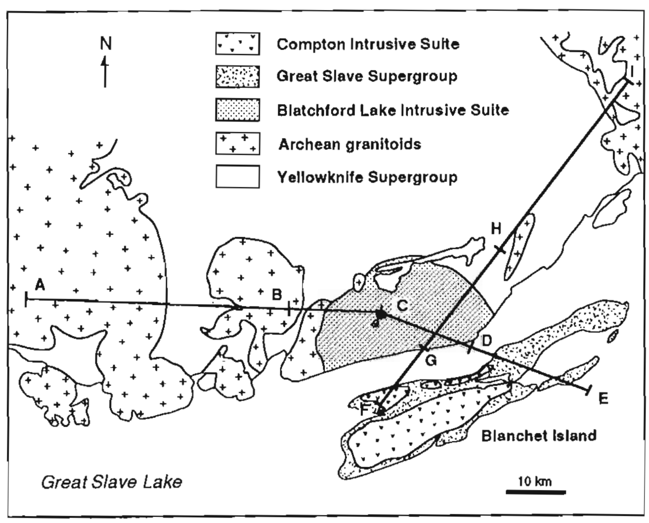

Figure 2. Regional geological setting of the Blatchford Lake Intrusive Suite, and trace of gravity lines studied.

Isotopic ages indicate an Early Proterozoic age for the Blatchford Lake Intrusive Suite. According to Bowring et al. (1984), Hearne Channel Granite and Whiteman Lake Quartz Syenite of the western lobe yielded U-Pb zircon ages of 2175 ± 5 Ma and 2185 ± 5 Ma, respectively. Rocks on the eastern side are younger, based on field relationships and less precise K-Ar and Rb-Sr ages (Davidson, 1982). A U-Pb zircon age of 2094 ± 10 Ma was reported by Bowring et al. (1984) as the age of the Thor Lake Syenite. However, the zircon dated was obtained from a vein of carbonate and zircon in altered Thor Lake Syenite that is part of the Thor Lake rare-metal deposits; this date therefore represents an age of alteration and mineralization rather than the age of the Thor Lake Syenite.

GEOLOGY OF THE BLATCHFORD LAKE INTRUSIVE SUITE

As noted previously, the Blatchford Lake Intrusive Suite can be subdivided into two parts, a western portion consisting of alkaline to subalkaline mafic to granitic rocks (western lobe) and an eastern portion consisting mainly of peralkaline granitic and syenitic rocks (eastern lobe). The following is a brief summary of the rocks types and contact relationships within the two lobes, based mainly on Davidson (1978, 1982) and Trueman et al. (1988).

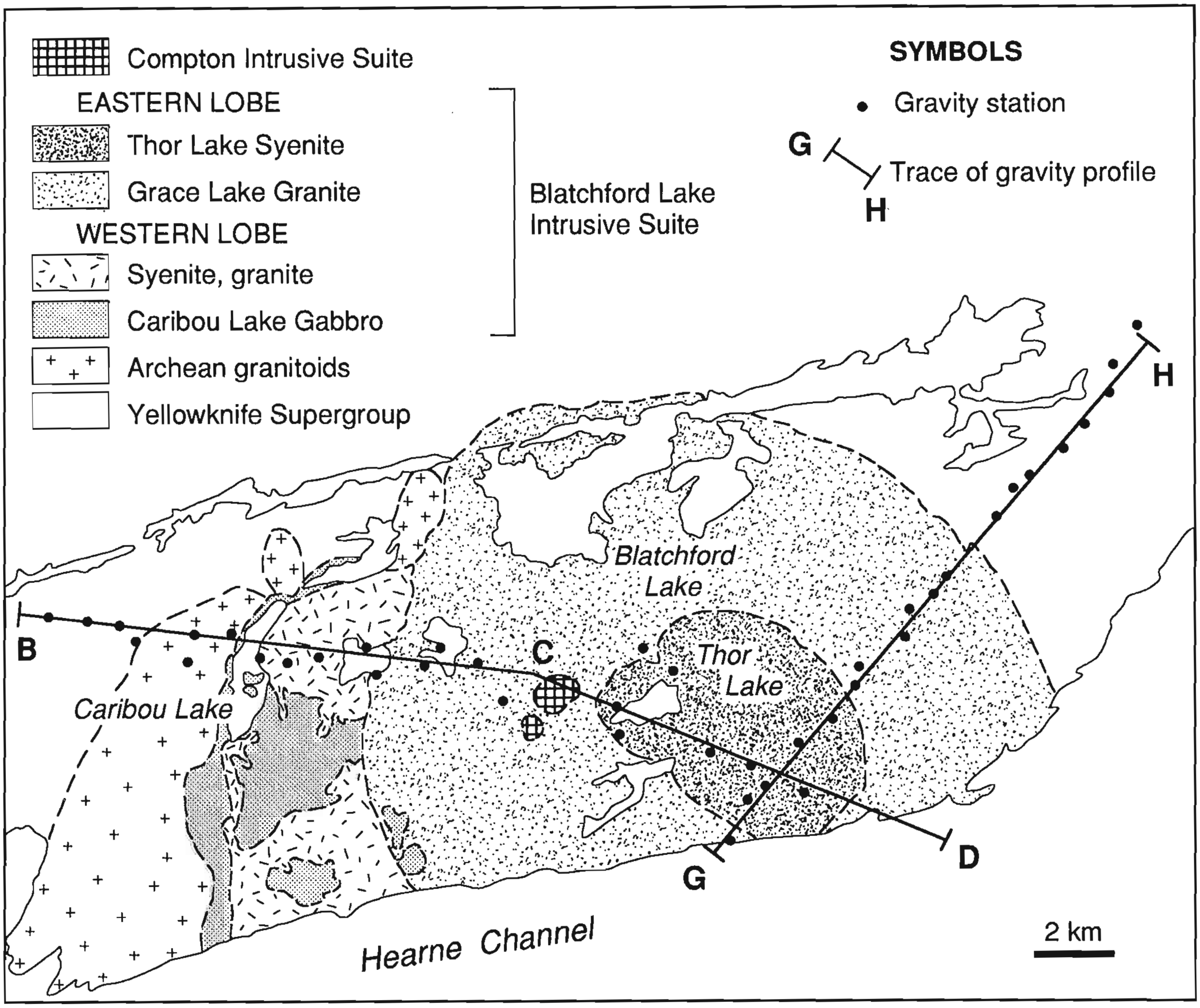

Figure 3. The Blatchford Lake Intrusive Suite illustrating the geology as mapped by Davidson (1978) and the location of the gravity stations measured in this study. Lines and locations on the lines are the same as in Figures 2 and 4.

Western lobe

Mafic intrusive rocks of the Caribou Lake Gabbro underlie an area of approximately 20 km^2 along the western side of the Blatchford Lake complex. From their westernmost contact, these rocks change gradationally in composition from olivine gabbro-noritic gabbro to plagioclase-rich leucoferrodiorite towards their eastern contact. Both of these phases contain rounded to angular xenoliths of coarse anorthosite and anorthositic gabbro. In places, the gabbroic rocks have a high magnetite content that is reflected in a pronounced aeromagnetic anomaly (cf. Charbonneau and Legault, 1994).

The western lobe syenite and granite unit shown in Figure 3 consists of three distinct lithologies. According to Davidson (1978, 1982), the oldest of these, the Whiteman Lake Quartz Syenite, forms dykes in the Caribou Lake Gabbro and includes large blocks of it along with numerous xenoliths of Yellowknife Supergroup metasedimentary rocks. The Whiteman Lake Quartz Syenite is predominantly medium grained hornblende-perthite quartz syenite. The massive, medium grained, subequigranular, brownish-pink Hearne Channel Granite and the younger massive to subporphyritic, pink Mad Lake Granite are the other two lithologies comprising the western lobe. Both the Hearne Channel and Mad Lake granites are relatively aluminous and contain hornblende and biotite (Davidson, 1982). Northwest- and east-northeast trending diabase dykes cut all geological units in the western lobe.

Eastern lobe

The eastern lobe consists mainly of Grace Lake Granite and Thor Lake Syenite. Other rock types present are areally restricted and include xenoliths of Caribou Lake Gabbro in the western part of the Grace Lake Granite, and xenoliths of Yellowknife Supergroup rocks in the Thor Lake Syenite (not shown in Fig. 3). Two small plutons of diorite and quartz monzonite (Compton Intrusive Suite) intrude the Grace Lake Granite to the west of Thor Lake. Diabase dykes trending northwest and east-northeast cut both Grace Lake Granite and Thor Lake Syenite. Nepheline syenite, which underlies at least part of the Thor Lake rare-metal deposits, has been encountered only in diamond-drill core and is not shown in Figure 3.

Grace Lake Granite, the largest unit of the Blatchford Lake Intrusive Suite, underlies an area of 155 km^2 (Davidson, 1978). This unit consists of buff- to pink-weathering, massive, medium- to coarse-grained, equigranular riebeckite-alkali feldspar granite. Mineralogically, it is composed predominantly of subhedral to euhedral perthite enclosed by riebeckite (averaging 7% by volume), and interstitial quartz (averaging 25% by volume), acmite, astrophyllite, Fe- and Ti-oxides, secondary biotite, and accessory amounts of fluorite, zircon, and monazite (Trueman et al., 1988). The mineralogy is typical of silica-saturated agpaitic igneous rocks (Davidson, 1978).

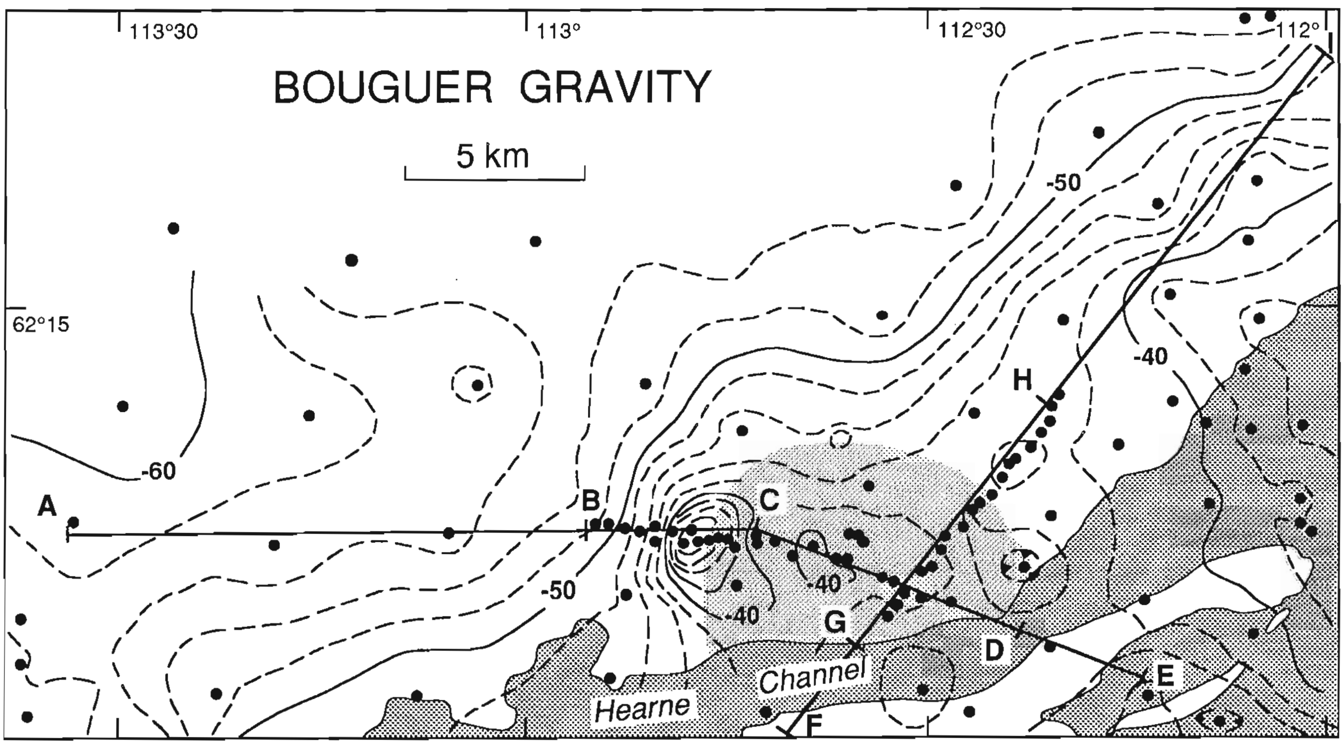

Figure 4. Regional Bouguer gravity contoured at 2 mGal intervals for the Blatchford Lake Intrusive Suite (shown by the light stippled pattern) and surrounding area. Regional data are from the National Gravity Data Base.

Thor Lake Syenite occupies a roughly oval, 30 km^2 area in the centre of the Grace Lake Granite (Fig. 3). Compositionally and texturally, this unit is significantly more varied than the surrounding Grace Lake Granite. Although the Thor Lake Syenite consists predominantly of amphibole-rich (ferrorichterite) syenite, with an outer border zone of fayalite-pyroxene syenite ("rim" syenite), four textural variants of the amphibole-bearing syenite are discernible in the field (Davidson, 1978; Trueman et al., 1988). Similar to the Grace Lake Granite, all variants of the Thor Lake Syenite have mineralogy consistent with a peralkaline composition.

The Thor Lake Syenite appears to overlie the Grace Lake Granite, although the contact between the two units is generally obscure and commonly marked only by abrupt variations in quartz content and texture (Trueman et al., 1988). Davidson (1982) suggested that Thor Lake Syenite was possibly a thin, horizontal sheet overlying the Grace Lake Granite; his previous observation of steeply plunging alignments of feldspar in the mafic "rim" syenite that dip toward the centre of the complex (Davidson, 1978) suggests that the Thor Lake Syenite-Grace Lake Granite contact is locally steep.

The nepheline syenite that underlies the Thor Lake rare-metal deposits has not been observed at surface, and was considered to be a relatively minor phase at the time the gravity survey was conducted. The nature and distribution of this unit are still poorly known; the following description is based mainly on studies of diamond-drill core by Pinckston (1989). The nepheline syenite appears to be centred immediately southeast of Thor Lake and has minimum lateral dimensions of 1 km by 1 km. It comes to within 100 m of the present surface and extends to a depth of at least 400 m. Unaltered rock consists of nepheline, aegirine, albite, K-feldspar, and analcime; however, the upper parts of the nepheline syenite are extensively altered to albite, hematite, magnetite, ankerite, chlorite, and quartz.

Thor Lake Syenite, Grace Lake Granite and nepheline syenite are important host rocks for deposits of rare metals, including beryllium, yttrium, rare-earth elements, niobium, tantalum, zirconium, and gallium. The Lake deposit, which underlies much of Thor Lake and the adjacent area to the south, is a large deposit in brecciated and altered Thor Lake Syenite and nepheline syenite; it contains 64 Mt grading 0.03% Ta, 0.4% Nb, 1.7% combined REEs, and 3.5% Zr (Trueman et al., 1988). The T deposit, situated 1 km north of the Lake deposit, occurs in altered phases of both Thor Lake Syenite and Grace Lake Granite; reserves are 1.6 Mt grading 0.85% BeO, including 435 000 t grading 1.4% BeO and 0.26% Y_2O_3 (Trueman et al., 1988). Details of these deposits have been described by Trueman (1986), Trueman et al. (1984, 1985, 1988), de St. Jorre (1986), and Pinckston (1989).

GRAVITY SURVEY

The Blatchford Lake gravity survey was tied to a base station at the site of the T deposit. This station was established by tying it to the National Gravity Network through the station at the Yellowknife airport. Gravity measurements, using Lacoste and Romberg geodetic meter G173, were taken along two lines that crossed the Blatchford Lake complex and extended into the surrounding country rocks (lines B-C-D and G-H, Fig. 2, 3). Wherever possible, stations were established at one kilometre spacing on the lines. Elevations were estimated through barometric measurements using two barometers, with temperature and relative humidity recorded at each station. Instrumental drift and changes in barometric pressure were monitored by returning to the base station at intervals of one hour. Data reduction was carried out by the Geophysics Division of the Geological Survey of Canada.

The data from this survey were combined with previously collected regional gravity measurements to produce the contoured Bouguer gravity anomaly map of Figure 4. This map provides a regional picture of the gravity field in the area, which is important for evaluating the respective contributions to the field of the more local geological features such as the Blatchford Lake complex, and more regional structures, not always obvious in the surface geology, that produce longer wavelength anomalies. In several cases, gravity stations measured in the course of this study were located near stations measured in the earlier regional surveys. Agreement between the old and new surveys is generally good. Differences between nearby stations of the two surveys are 0.3 mGal or less (1 mGal = 10^{-5} m/s^2), except for one pair of stations located near Caribou Lake, where the difference attains 0.4 mGal. As the latter pair of stations are located in an area where the gravity gradient is relatively steep, the difference between these two stations is not unexpected.

ROCK DENSITIES AND CONTACT RELATIONSHIPS

Gravity data modelling is generally constrained only by rock densities and geological relationships. For this study, rock densities were determined from 72 samples collected at all gravity stations, as well as from other portions of the intrusive complex. Weathered rinds were removed from samples prior to density measurements. Histograms of measured densities of samples from the various geological units are presented in Figure 5.

Samples of Yellowknife Supergroup metasedimentary rocks contained as xenoliths within the Blatchford Lake complex have undergone contact metamorphism; they have a higher density than similar rocks outside the complex and therefore may be atypical. The mean density of Yellowknife Supergroup rocks outside the complex (2.76 g/cm^3) was adopted as the background density against which all other densities were compared for gravity modelling. The mean densities of the various lithologies and density contrasts with respect to background are listed in Table 1. Data for the Caribou Lake Gabbro are limited and reflect greater sampling of the anorthositic rocks in the southwestern portion of the complex compared to the gabbroic rocks along the western margin. The anorthositic rocks are less dense than the gabbros and commonly show alteration to hydrous mineral assemblages. Three samples of gabbro taken near the gravity traverse at the northern end of Caribou Lake and one sample of Compton Intrusive Suite diorite were used to estimate the mean density of the mafic rocks for the interpretation of the gravity results (3.01 g/cm^3). Data from the western lobe granites and syenites are sparse. As the available density determinations do not distinguish the western lobe granites from the Grace Lake Granite, all of these rocks have been modelled with the same density (2.66 g/cm^3). Specific gravity determinations on 19 samples of Thor Lake Syenite yielded a mean density of 2.69 g/cm^3.

The dips of contacts mapped by Davidson (1978) were also used in preparing the gravity model. The contacts of the Caribou Lake Gabbro on the western margin of the Blatchford Lake complex are steep, as is the outer contact of the Grace Lake Granite in most places. Although gradational over distances of one to several metres, the contact of the Thor Lake Syenite with the Grace Lake Granite at surface also appears to be steep. Some of the observed contacts of the Caribou Lake anorthosites with the granites and syenites of the western part of the complex, on the other hand, are subhorizontal (Davidson, 1972). Although they are cut in places by vertical granitic and syenitic dykes, a large part of the Caribou Lake anorthositic rocks occupy geographically higher areas and appear to be underlain by granitic and syenitic rocks. Caribou Lake anorthositic rocks also occur as roof pendants exposed on hilltops in the southwest part of the Grace Lake Granite (Davidson, 1978).

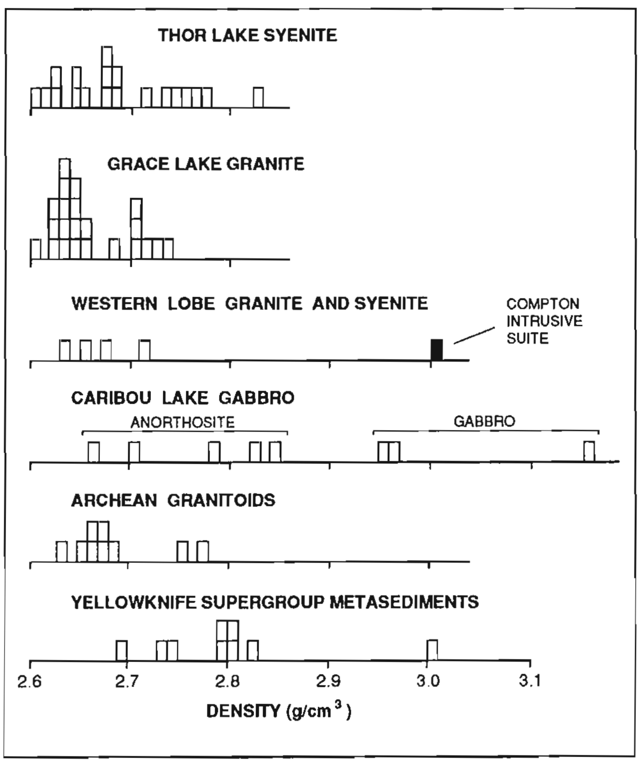

Figure 5. *Histograms of measured rock densities from the Blatchford Lake Intrusive Suite and the surrounding area.*

BOUGUER GRAVITY FIELD AND ITS RELATIONSHIP TO GEOLOGY

The Bouguer gravity anomaly map compiled from the detailed observations made in this study and from earlier regional surveys is portrayed in Figure 4. In spite of the detail along the two lines, gravity information over much of the Blatchford Lake complex is sparse. It is important, therefore, to note the distribution of gravity stations and contours with respect to individual geological units.

The most prominent feature of the local gravity field is the strong positive anomaly along the west side of the Blatchford Lake complex. This anomaly coincides with magnetite-rich gabbroic phases of the Caribou Lake Gabbro, which form a narrow band along the western margin of the complex, underlying Caribou Lake. This anomaly reaches peak values of about -32 mGal at the western margin of the complex, about 8 mGal higher than the local field over the complex, and 20 mGal higher than the field to the immediate west of the complex.

Regionally, the gravity field is dominated by a northeast-trending belt of steep gradients on the northwestern margin of the complex. The gradient separates a region of lower values (<-60 mGal) to the northwest from higher values (>-44 mGal) to the southeast. The Blatchford Lake complex falls more or less within the southeastern plateau of higher values. The complex as a whole does not coincide with a distinct gravity anomaly. The Grace Lake Granite and the Thor Lake Syenite are associated with a field that undulates gently and varies less than about 5 mGal. The contours defining the northeast-trending regional gravity gradient are deflected northwestward in the region of the gravity high associated with the Caribou Lake gabbroic rocks (observation by M.D. Thomas, pers. comm., 1991). Although possibly fortuitous, this coincidence suggests that the regional deflection may be due to buried Caribou Lake or related mafic rocks. Because the Caribou Lake gabbroic rocks display evolved rather than primitive compositions (Davidson, 1982), the larger gravity anomaly may be related to a deeper body of mafic rock which was parental to the Caribou Lake gabbroic rocks now exposed at surface.

APPROACH TO GRAVITY MODELLING

The graphical technique described by Thomas and Willis (1989) was used to separate longer wavelength signals due to regional gravity variations from the shorter, more local wavelength signals associated with the Blatchford Lake complex. Regional gravity signals were estimated by comparison of the gravity contour map shown in Figure 4 and the regional-scale gravity profiles of Figure 6. Regional gravity curves were estimated from the profiles of Figure 6, with the constraint that they coincide where the two gravity lines intersect. These curves were then subtracted from the observed curves to produce residual gravity profiles which were used for modelling.

Only minor limitations to the gravity study of the Blatchford Lake complex were imposed by the topography of the region. Because the area is mainly a peneplain, corrections for local relief should not significantly change the interpretations of this study. The presence of the very deep (400 m) Hearne Channel immediately south of the Blatchford Lake complex, however, makes it impossible to differentiate the effect of this marked topographic feature from any gravitational change attributable to differences in rock densities. The bottom configuration of the channel is not well known and cannot be incorporated into the modelling with acceptable precision. For this reason, gravity interpretations shown in Figure 7 have not been carried beyond the shore of Great Slave Lake.

The gravity modelling of geological bodies in this study utilized a two-and-a-half-dimensional interpretation technique as outlined by Thomas and Willis (1989). In this, the shapes of geological bodies are approximated using horizontal prisms with finite lengths and polygonal cross-sections. Modelling was accomplished using the MAGRAV program, which was initially developed by Wells (1979), and later modified by P.H. McGrath of the GSC to accommodate two-and-a-half-dimensional features. Broome (1986) subsequently adapted the program for use on IBM-compatible computers (MAGRAV2). Using the residual gravity values interpolated from the profiles in Figure 6 and determined density contrasts, MAGRAV2 was used to plot both the actual observed gravity profiles and model profiles which are dependent on the shapes of the modelled geological bodies. The shapes of bodies were progressively modified until the model profiles closely matched the observed profiles (Fig. 7). The surface geology along the gravity lines was used to constrain the locations of contacts and the extent of units perpendicular to the gravity lines for the two-and-a-half dimensional model presented here. The modelling also included reconciliation of the two profiles at the intersection of the lines B-C-D and G-H (indicated by the vertical dashed line in Fig. 7).

Examination of the two lines of Figure 7 shows that the residual gravity anomaly of line B-C-D is positive along its entire length, although some of the rocks exposed at surface are less dense than the background rocks of the Yellowknife Supergroup. Consequently, rocks of greater density must be present at depth in this area. Although the presence of rocks more dense and less dense than the background rocks in the vertical column below line B-C-D allows the gravity to be modelled with arbitrary shapes and thicknesses of the Grace Lake Granite and Thor Lake Syenite (provided the net result fits the curve), the surface geology and the subhorizontal contacts in this portion of the plutonic suite suggest that a simple, layered model is appropriate. In contrast, line G-H shows a negative residual gravity anomaly associated with the northeastern edge of the Blatchford Lake complex. This portion of the complex can be modelled with more confidence; dense rocks at depth are not required, and rocks observed at surface can explain the entire gravity response.

GRAVITY MODEL OF THE BLATCHFORD LAKE INTRUSIVE SUITE

The results of the MAGRAV2 modelling are shown in the two gravity profiles (Fig. 7); a geological cross-section based on the results of the gravity modelling and incorporating geologic observations is presented in Figure 8. The main features of the Blatchford Lake complex displayed by these figures is as follows:

1) The Blatchford Lake Intrusive Suite is a relatively thin, tabular body with a deeper root of mafic rocks along its western margin.

Table 1. Densitites and density contrasts for rock types in the Blatchford Lake Intrusive Suite and surrounding rocks.

Lithology	n	Density g/cm^3			Density contrast g/cm^3
		average	s.d.	used	
Yellowknife Supergroup	9	2.77	0.043	2.76	0.0
Archean granitoids	9	2.67	0.028	2.66	-0.1
Caribou Lake Gabbro	3	3.02	0.114	3.01	+0.25
Granites and syentites					
Western lobe	4	2.67	0.032	2.66	-0.1
Eastern lobe					
Grace Lake Granite	22	2.66	0.038	2.66	-0.1
Thor Lake Syentite	19	2.69	0.066	2.69	-0.07
Compton Intrusive Suite	1	3.01	-	3.01	+0.25

n is the number of samples in the group.
s.d. is the standard deviation.

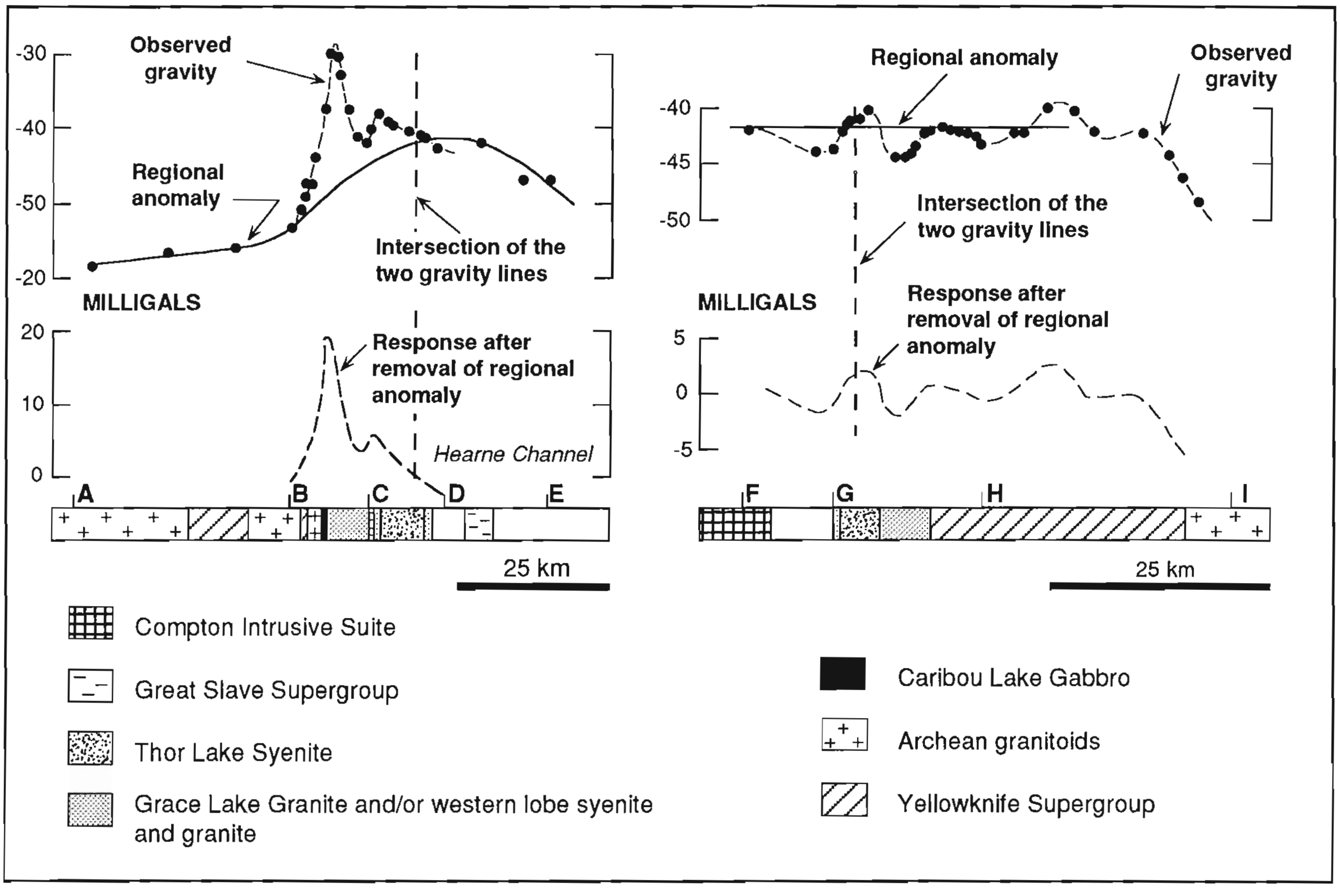

Figure 6. *Regional scale observed gravity profiles along lines A-E and F-I, indicating the geology at the surface, gravity stations (dots), estimated regional anomalies, and response after removal of regional anomalies (residual gravity).*

2) Caribou Lake Gabbro appears to extend under the Grace Lake Granite for one-half the area of the entire complex.
3) The Compton Intrusive Suite plutons are thin tabular bodies without great vertical extent; root zones for these plutons, if present, were not detected.
4) The Grace Lake Granite and Thor Lake Syenite are relatively thin bodies having great horizontal extent and nearly horizontal lower surfaces.
5) Root zones indicating the intrusive source areas of the Grace Lake Granite and Thor Lake Syenite were not observed.
6) The cumulative thickness of the granitic rocks of the complex is on the order of one kilometre.

As only two units, the Caribou Lake Gabbro and the Compton Intrusive Suite, have densities greater than background (Yellowknife Supergroup), the gravity model is restricted by the assumption that any area displaying positive residual gravity indicates the presence of one of these lithologies. Although this assumption constrains the precision of gravity modelling in terms of assigning specific geological units to gravity features, it does not affect the overall geometry of the gravity images. Therefore, the presence of a steeply-dipping root under the Caribou Lake Gabbro at the western extremity of the complex, and a flat, thin form for the Grace Lake Granite and Thor Lake Syenite, are considered to be correct. Extension of Caribou Lake mafic rocks under the central portion of the complex, however, is not a unique solution and must be regarded as less certain than the other modelled features. Supporting this interpretation, though, is the presence of less dense rocks at surface in an area of positive residual gravity.

Trueman et al. (1988) reported on the results of a detailed gravity survey completed over the Lake deposit, which is associated with a subcircular zone of altered rocks about 1 km across at surface. Their study outlined a small gravity high (maximum 1.5 mGal) related to the slightly denser rocks of the deposit as contrasted with the surrounding rocks, including Grace Lake Granite, Thor Lake Syenite, and the underlying body of nepheline syenite. Gravity data from our study did not detect the Lake deposit, nor did it indicate the presence of a deeper zone of less dense rock under the Lake deposit which could be correlated with the nepheline syenite. Consequently,

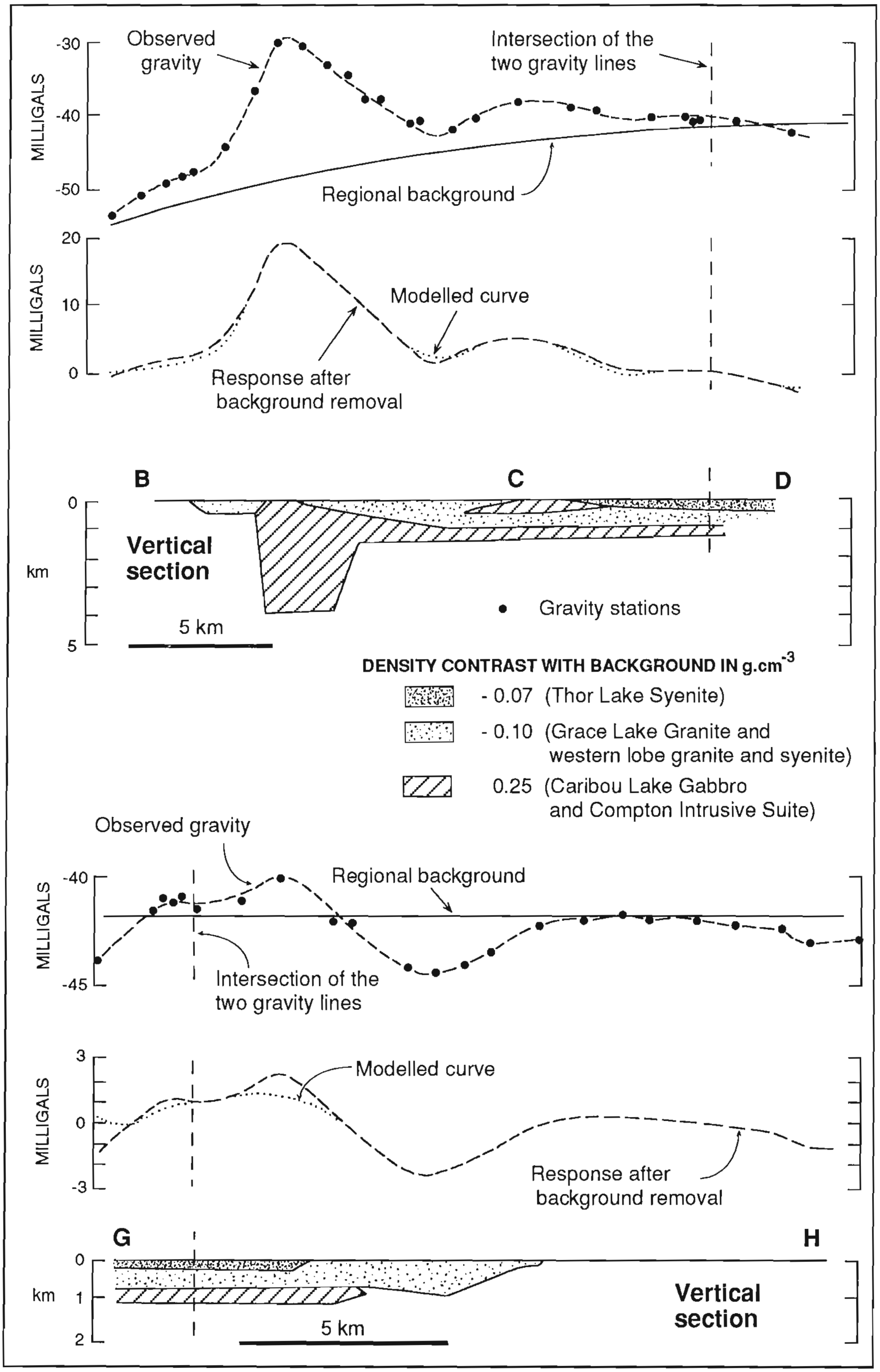

Figure 7. Results of the gravity survey on lines B-D and G-H, indicating the observed gravity profiles, the estimated regional background, the residual response after removal of the regional profiles, and the modelled gravity profiles based on density contrasts in the cross-sections. The modelled profiles generally match the residual gravity profiles to within 0.1 mGal. Where the model profiles deviate from the residual gravity profiles, they are indicated as a dotted line. The cross-sections are drawn as true sections, without vertical exaggeration.

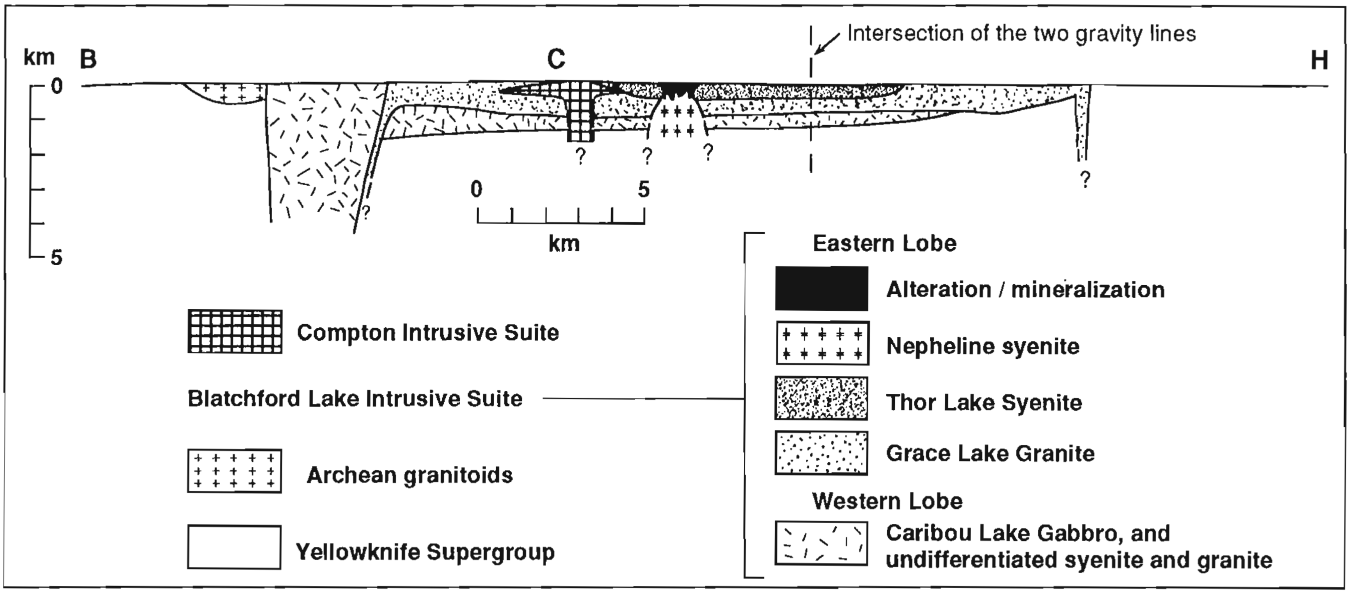

Figure 8. Geological cross-section B-C-H, based on the gravity modelling in Figure 7. Profiles B-D and G-H are joined at their intersection (indicated by the vertical dashed line). The zone of alteration and mineralization above the nepheline syenite corresponds to the Lake rare-metal deposit.

the lateral and vertical extensions of the nepheline syenite are unknown, although it is interpreted here as a small, subvertical intrusive body (Fig. 8).

Two features of the gravity model presented here appear to be inconsistent with observed field relationships. One is the tabular shape of the Compton Suite plutons with gently outward-dipping contacts and the other is the shallow extent of the Archean granitoid body at the western edge of the Blatchford Lake Intrusive Suite (Fig. 8); field relationships indicate that these plutons have steeply-dipping contacts at surface (Davidson, 1978). Either the dips of the contacts observed in outcrop are local features, or else further modification of the gravity model is required, which is beyond the scope of this study.

DISCUSSION

Combined with the geology of the Blatchford Lake complex, the gravity data offer a better understanding of the intrusive history of the complex. As first noted by Davidson (1978), the spatial distribution of intrusive complex rocks as regional interfering subcircular bodies suggests a complex history of emplacement. The earliest portions of the complex, the Caribou Lake Gabbro and the western lobe syenites and granites, are considered to be the remnants of a subcircular body centred near Hearne Channel in the west-central part of the complex (centre 1, Fig. 9). The spatial distributions of both the Grace Lake Granite and the main body of the Thor Lake Syenite also have a subcircular pattern, with centre 2 in Figure 9. It is important to note that the centres of these subcircular features are not interpreted as zones along which the magmas ascended and from which they spread laterally, but rather as centres of regional subcircular fracture patterns. The subcircular feature associated with centre 3 corresponds to the extensive zone of alteration and mineralization that hosts the Thor Lake rare-metal deposits. This zone is underlain, at least in part, by nepheline syenite, which may have intruded along the locus represented by centre 3.

Emplacement of the Blatchford Lake Intrusive Suite appears to have been at a relatively shallow level in the crust, subsequent to crustal fracturing and associated vertical tectonic movement. Rocks presently exposed at surface were likely close to surface at the time of their intrusion.

The nearly circular form of the Grace Lake Granite suggests that its emplacement was controlled by failure and subsidence of a block of the country rocks, i.e., Yellowknife Supergroup metasedimentary rocks (Davidson, 1982). The magma (or magmas) that formed the Grace Lake Granite and the Thor Lake Syenite probably ascended along fracture zones at one or several areas around the circumference of the subsided block, and then flowed laterally to fill the space created by the downward displacement of the block. The feeder zones for the magma(s), if they exist, must be too small or narrow to have been detected by this gravity survey.

According to the above scenario, the downfaulted extension of the western lobe rocks should be part of the subsided block of country rock. The gravity model does, in fact, indicate that a layer of dense rocks is present beneath at least part of the eastern lobe granitic rocks. This layer is likely related to the western lobe mafic rocks.

The gradational contact between the Grace Lake Granite and Thor Lake Syenite, and the similarities in trace element contents as documented by Davidson (1981, 1982), suggest that the two units are related. Although contacts between these two units are

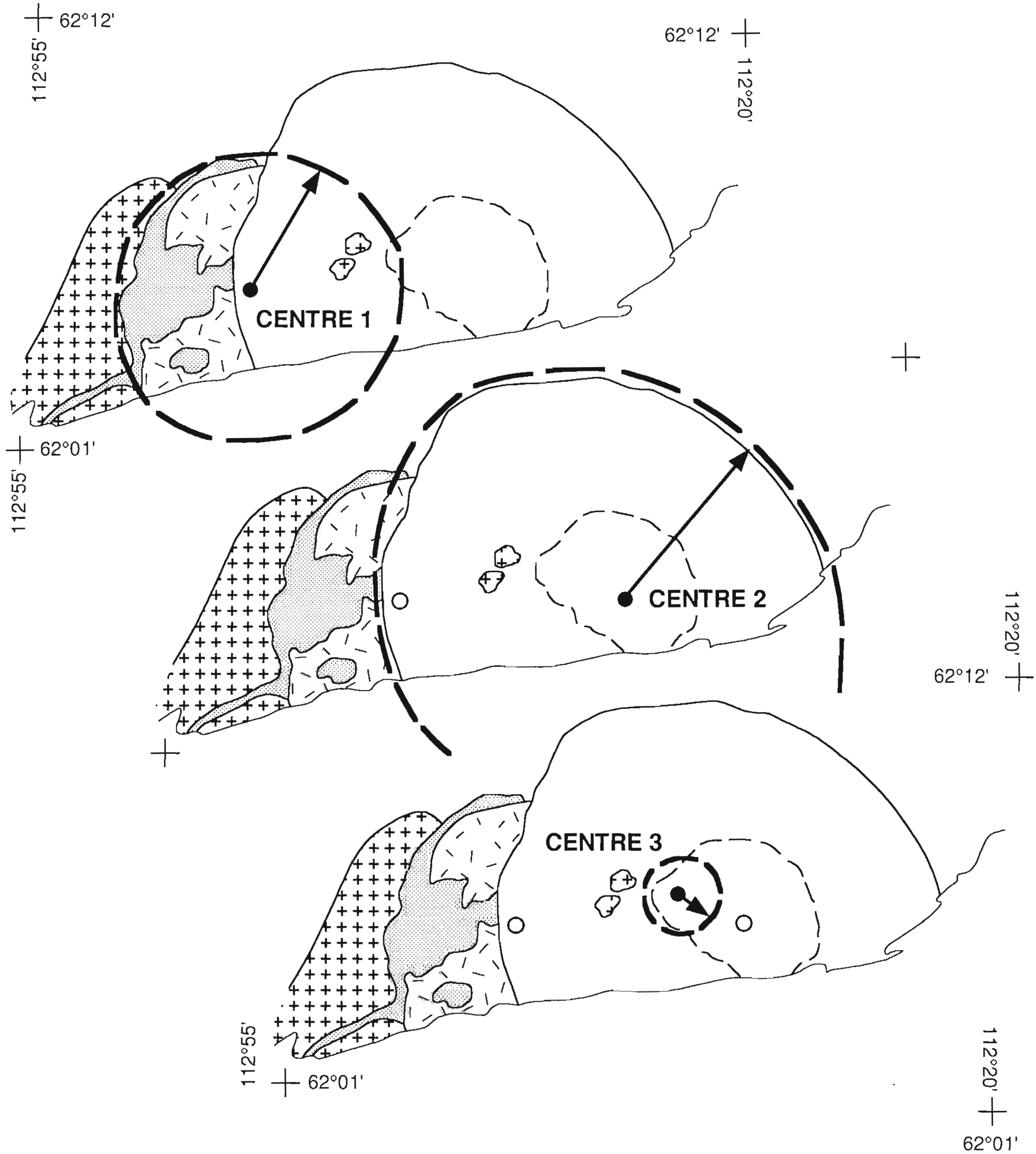

Figure 9. Simplified geological map of the Blatchford Lake Intrusive Complex indicating geographical centres of the three subcircular patterns identified within the complex. Centre 1 represents the approximate geographic centre of the western lobe of the complex; the extrapolated subcircular pattern is shown by the dashed line. Centres 2 and 3 represent the approximate geographic centres of the Grace Lake Granite, and the northwestern extension of the Thor Lake Syenite (and underlying nepheline syenite), respectively.

steep at surface, they must flatten at depth to be consistent with the gravity modelling which suggests that the Thor Lake Syenite is a relatively thin, flat-lying body overlying the Grace Lake Granite. If the steep contacts observed at surface were to extend to depth, the density contrast between these two units (0.03 g/cm^3) would result in steeper gravity profiles in the vicinity of the contact, and stepped lower contacts in the modelled cross-sections shown in Figure 7 would be required to fit the observed gravity anomaly.

The rocks of the northwestern portion of the Thor Lake Syenite are atypical with respect to the other rocks of this unit. These rocks vary from quartz syenite (locally granite) to varieties of syenite which have a large proportion of zoned K-feldspar crystals that reflect a complex history of crystallization. Furthermore, the distinctive unit of fayalite ("rim") syenite which marks the outer margin of the Thor Lake syenite along much of its boundary to the east is not present. Although the rocks in this area do not appear to be metasomatically altered, they have a high magnetic response (Charbonneau and Legault, 1994) and may have been affected by the buried nepheline syenite and associated alteration related to centre 3 (Fig. 9).

CONCLUSIONS

Gravity modelling indicates that the eastern part of the Blatchford Lake Intrusive Suite is a thin, horizontal body of mainly granitic and syenitic rocks about 1 km thick, whereas the western part consists of mafic to granitic rocks with a deep root of mafic rocks. The mafic rocks of the western part may extend as a thin body below the granitic rocks of the eastern part for as much as one-half the area of the entire Blatchford Lake complex. The gravity survey did not detect any roots or feeder zones to the granitic rocks, nor did it provide any information about the nepheline syenite that underlies the Thor Lake rare metal deposits.

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REFERENCES

Bowring, S.A., Van Schmus, W.R., and Hoffman, P.F.
1984: U-Pb zircon ages from Athapuscow Aulocogen, East Arm of Great Slave Lake, N.W.T., Canada; Canadian Journal of Earth Sciences, v. 21, p. 1315-1324.

Broome, J.
1986: MAGRAV2: an interactive magnetic and gravity modelling program for IBM-compatible microcomputers; Geological Survey of Canada, Open File 1334.

Charbonneau, B.W. and Legault, M.
1994: Interpretation of airborne geophysical data for the Thor Lake area, Northwest Territories; in Studies of Rare-Metal Deposits in the Northwest Territories, (ed.) W.D. Sinclair and D.G. Richardson; Geological Survey of Canada, Bulletin 475 p. 17-31.

Davidson, A.
1972: Granite studies in the Slave Province; in Report of Field Activities, Part A; Geological Survey of Canada, Paper 72-1A, p. 109-115.
1978: The Blachford Lake Intrusive Suite: an Aphebian alkaline plutonic complex in the Slave Province, Northwest Territories; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 119-127.
1981: Petrochemistry of the Blachford Lake complex, District of Mackenzie; Geological Survey of Canada, Open File 764.
1982: Petrochemistry of the Blachford Lake complex near Yellowknife, Northwest Territories; in Uranium in Granites, (ed.) Y.T. Maurice; Geological Survey of Canada, Paper 81-23, p. 71-80.

de St. Jorre, L.
1986: The economic mineralogy of the North T-Zone rare-metal deposit, Thor Lake, Northwest Territories; M.Sc. thesis, University of Alberta, Edmonton, Alberta, 247 p.

Geological Survey of Canada
1989: Airborne gamma ray spectrometric maps, Blatchford Lake (Thor Lake) alkaline complex, Northwest Territories (Parts of 85I/1, 2); Geological Survey of Canada, Open File 1922.

Henderson, J.F.
1938: Preliminary report, Beaulieu River area, Northwest Territories; Geological Survey of Canada, Paper 38-1, 20 p.

Hoffman, P.F.
1988: Geology and tectonics, East Arm of Great Slave Lake, Northwest Territories; Geological Survey of Canada, Map 1628A.

Jolliffe, F.
1936: Preliminary report, Yellowknife River area, Northwest Territories; Geological Survey of Canada, Paper 36-5, 10 p.

Pinckston, D.R.
1989: Mineralogy of the Lake Zone Deposit, Thor Lake, Northwest Territories; M.Sc. thesis, University of Alberta, Edmonton, Alberta, 155 p.

Stockwell, C.H.
1932: Great Slave Lake-Coppermine River area, Northwest Territories; Geological Survey of Canada, Summary Report, Part C, p. 37-64.

Thomas, M.D. and Willis, C.
1989: Gravity modelling of the Saint George batholith and adjacent terrane within the Appalachian Orogen, southern New Brunswick; Canadian Journal of Earth Sciences, v. 26, p. 561-576.

Trueman, D.L.
1986: The Thor Lake rare-metals deposits, Northwest Territories, Canada; in Proceedings of the 7th Industrial Minerals International Congress - Volume 1 (Papers), (ed.) G.M. Clarke and J.B. Griffiths, p. 127-131.

Trueman, D.L., Pedersen, J.C., and de St. Jorre, L.
1984: Geology of the Thor Lake beryllium deposits: an update; in Contributions to the Geology of the Northwest Territories, Volume 1, (ed.) J. Brophy; Department of Indian and Northern Affairs, Economic Geology Series 1984-6, p. 115-120.

Trueman, D.L., Pedersen, J.C., de St. Jorre, L., and Smith, D.G.W.
1985: The Thor Lake, N.W.T. rare-metal deposits; in Granite-Related Mineral Deposits: Geology, Petrogenesis and Tectonic Setting, (ed.) R.P. Taylor and D.F. Strong; Extended Abstracts for the Canadian Institute of Mining and Metallurgy Conference on Granite-Related Mineral Deposits, September 15-17, 1985, Halifax, Nova Scotia, p. 279-284.
1988: The Thor Lake rare-metal deposits, Northwest Territories; in Recent Advances in the Geology of Granite-Related Mineral Deposits, (ed.) R.P. Taylor and D.F. Strong; Canadian Institute of Mining and Metallurgy, Special Volume 39, p. 280-290.

Wells, I.
1979: MAGRAV users guide - a computer program to create two-dimensional gravity and/or magnetic models; Geological Survey of Canada, Open File 597.

Interpretation of airborne geophysical data for the Thor Lake area, Northwest Territories[1]

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Abstract: Radiometric, magnetic, and electromagnetic patterns detected over the Blatchford Lake Intrusive Suite were investigated on the ground in order to gain a better understanding of this complex and the related Thor Lake rare-metal deposits (beryllium, yttrium, rare-earth elements, niobium, tantalum, zirconium, gallium).

Bedrock radioelement concentrations in the Grace Lake Granite and Thor Lake Syenite, two major units of the Blatchford Lake complex, average 4.6% K_2O (3.8% K), 3 ppm equivalent uranium, and 18 ppm equivalent thorium. Principal radioactive minerals in these rocks are zircon and bastnaesite with minor REE-rich apatite and monazite. Although the radioactivity of the Thor Lake deposits is typically one to two orders of magnitude higher than surrounding rocks, there is no apparent halo of uranium or thorium around the deposits. Felsic dykes within the Grace Lake Granite and Thor Lake Syenite are one order of magnitude more uraniferous or thoriferous than host rocks and are enriched in elements found in the Thor Lake deposits.

A prominent magnetic anomaly in the western part of the complex is related to the Caribou Lake Gabbro. Two significant magnetic anomalies are present in the eastern part of the complex. One occupies the western half of the Thor Lake Syenite, and the other forms a crescent-shaped feature within the Grace Lake Granite. These two anomalies are related to magnetite produced by alteration of ferromagnesian minerals. The alteration may be either autometasomatic or related to fenitization by a nepheline syenite body which underlies the rare-metal deposits.

The electromagnetic patterns relate primarily to conductive lake bottom material and faults.

Résumé : La configuration des anomalies radiométriques, magnétiques et électromagnétiques relevée au-dessus de la Suite intrusive de Blatchford Lake a donné lieu à des vérifications au sol afin d'améliorer les connaissances que nous possédions de ce complexe et des gisements apparentés de métaux rares de Thor Lake (béryllium, yttrium, éléments des terres rares, niobium, tantale, zirconium et gallium).

Dans le granite de Grace Lake et la syénite de Thor Lake, qui sont deux unités majeures du complexe de Blatchford Lake, les concentrations moyennes de radioéléments dans la roche en place sont de 4,6 % en K_2O (3,8 % en K), 3 ppm d'équivalent d'uranium et 18 ppm d'équivalent de thorium. Les principaux minéraux radioactifs dans ces roches sont le zircon et la bastnaesite ainsi qu'un peu d'apatite et de monazite riches en ETR. Quoique la radioactivité des gisements de Thor Lake soit typiquement de dix à cent fois supérieure à celle des roches environnantes, il n'existe pas de halo apparent d'uranium ou de thorium autour

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des gisements. Les dykes felsiques, dans le granite de Grace Lake et la syénite de Thor Lake, sont dix fois plus uranifères ou thorifères que les roches encaissantes et ils sont enrichis en éléments que l'on trouve dans les gisements de Thor Lake.

Une anomalie magnétique proéminente dans la partie occidentale du complexe est rattachée au gabbro de Caribou Lake. Deux anomalies magnétiques significatives sont présentent dans la partie orientale du complexe. L'une occupe la moitié occidentale de la syénite de Thor Lake et l'autre forme un élément en forme de croissant dans le granite de Grace Lake. Ces deux anomalies sont rattachées à de la magnétite produite par l'altération de minéraux ferromagnésiens. L'altération pourrait être soit autométasomatique ou reliée à la fénitisation causée par le corps de syénite néphélinique qui se trouve sous les gisements de métaux rares.

La configuration des anomalies électromagnétique se rapporte avant tout aux matériaux conducteurs de fond de lac et aux failles.

INTRODUCTION

In the summer of 1988, a detailed airborne geophysical survey covering 500 km^2 was conducted with 250 m line spacing over the Blatchford Lake Intrusive Suite, an alkaline complex which hosts the Thor Lake rare-metal deposits (Fig. 1). The objectives of the survey were to demonstrate the application of this type of geophysical survey to explore for this style of mineralization, and to improve the understanding of the genesis of the Thor Lake deposits.

The Blatchford Lake Intrusive Suite is located at the southern margin of the Archean Slave craton in the East Arm of Great Slave Lake (Fig. 2a; Davidson, 1978; 1981; 1982). The name "Blachford Lake Intrusive Suite", originally proposed by Davidson (1978), is changed in this paper to reflect the current spelling of Blatchford Lake (officially corrected in 1978). This suite was first identified by Stockwell (1932) and later by Henderson (1938) as a complex of gabbro, diorite, and anorthosite, intruded by granitic rocks. Further investigations by Davidson (1972, 1978) recognized the Blatchford Lake Intrusive Suite as a multiphase intrusion of alkaline character. The Thor Lake deposits, which are hosted by, and genetically related to, this suite, were originally discovered through follow-up by Highwood Resources of a Geological Survey of Canada reconnaissance airborne gamma-ray survey in 1976 (Trueman et al., 1988). Further investigations revealed that radioactive mineralization was more widespread than previously suspected and was associated with a wide range of rare metals (Davidson, 1978). Since the original discovery, several studies on the complex geology and mineralogy of the Thor Lake deposits have been conducted (Trueman et al., 1988; Pinckston and Smith, 1991; Taylor and Pollard, 1992; Birkett et al., 1992, 1994). In addition, several assessment reports by mining companies have been filed with the Department of Indian and Northern Affairs in Yellowknife (e.g., Hylands, 1980). This study is an investigation of airborne geophysical anomalies outlined over the Blatchford Lake Intrusive Suite, and their relationship to the petrographic and geochemical features of the underlying rocks.

GEOLOGY

The Blatchford Lake Intrusive Suite as defined by Davidson (1978) is a complex of alkaline and peralkaline rocks (Fig. 2a, 3). The complex has intruded a terrane of Archean granite and metasedimentary rocks of the Yellowknife Supergroup. It is composed of several distinct, successively intruded plutonic phases, including from oldest to youngest:

1) Caribou Lake Gabbro, a marginal unit of gabbro (unit 2) that grades inward to a plagioclase-rich leucoferrodiorite phase (unit 1). These rocks contain abundant inclusions of anorthosite.
2) Whiteman Lake Quartz Syenite (unit 3), which varies from quartz syenite to granite composition and contains hornblende, biotite, clinopyroxene, and altered fayalite.
3) Hearne Channel Granite (unit 4) and Mad Lake Granite (unit 5), both of which are moderately aluminous and contain hornblende and biotite.
4) Grace Lake Granite (unit 6), a coarse grained amphibole (mostly riebeckite)-alkali feldspar granite, and Thor Lake Syenite (units 7 to 11), an alkalic syenite that ranges from coarse grained fayalite-pyroxene syenite to subporphyritic hornblende syenite. Both of these units are peralkaline and contain alkali amphiboles. The feldspars are perthitic to antiperthitic in both the granite and syenite. Minor mineral constituents include Fe-Ti oxides, biotite, fluorite, apatite, and accessory radioactive minerals.

The Grace Lake Granite and Thor Lake Syenite dominate the eastern part of the Blatchford Lake Intrusive Suite and have been referred to as the Eastern Series (Pedersen and LeCouteur, 1990). Together they occupy a semi-circular area of some 200 km^2 on the north shore of Hearne Channel (Fig. 2a). The contact between these two units is typically gradational over a few metres; the main difference observed between them in the field is the scarcity or absence of quartz in the syenite. Fine grained dykes of similar lithology to their host rocks occur within both the Thor Lake Syenite and the Grace Lake Granite (Fig. 4).

5) A body of nepheline syenite, which lies 100 to 200 m below surface, was discovered by diamond drilling beneath the central part of the complex; it may be an important component of the intrusive complex although the nature and extent of this unit are not yet clear (Pinckston and Smith, 1991).

Deposits of rare metals, including beryllium, yttrium, rare-earth elements, niobium, tantalum, zirconium, and gallium (shown as unit 12 in Fig. 2a), are located near the centre of the Blatchford Lake Intrusive Suite, underlying and adjacent to a small lake referred to locally as Thor Lake. These deposits, designated the R, S, T, Lake, and Fluorite (F) zones (Fig. 3), have been described in considerable detail by Trueman et al. (1988). The deposits, especially the T zone, transgress the contact between the Thor Lake Syenite and Grace Lake Granite. The R, S, and T zones, situated north of Thor Lake, include black rocks comprised mostly of quartz, albite, fluorite, and white mica heavily dusted with fine opaque material. Black rocks of the T zone contain veins and irregular masses of fluorite and albite, whereas black rocks of the R and S zones are associated with pegmatitic syenite and acmite-albite veins. The Lake and Fluorite zones are located under and south of Thor Lake. The Fluorite zone consists of black rocks containing carbonate, fluorite, and albite; the Lake zone consists mostly of massive to brecciated and altered syenite. All mineralized zones are in sharp contact with partly altered syenite or granite. In addition to the minerals listed above, the mineralized zones contain a wide range of radioactive and other granophile minerals of economic significance (cf. Table 1 in Trueman et al., 1988).

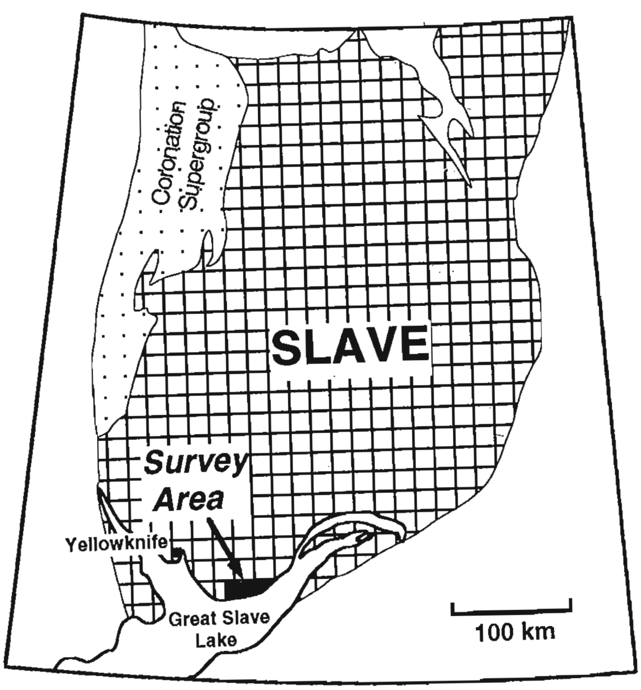


Figure 1. Location map indicating the Blatchford Lake survey area within the Slave Province.

Two phases of the Blatchford Lake Intrusive Suite have been dated by U-Pb zircon method at 2175 ± 5 Ma (Hearne Channel Granite) and 2094 ± 10 Ma (Thor Lake Syenite) (Bowring et al., 1984). However, the younger date is from an alteration zone in the Thor Lake Syenite and likely does not represent the true age of the Thor Lake Syenite (Birkett et al., 1994). The Blatchford Lake Intrusive Suite is cut by Proterozoic east-northeast-trending diabase dykes of the Hearne swarm, small plutons of Compton Suite diorite and quartz monzonite, and northwest-trending diabase dykes of the Mackenzie swarm (Davidson, 1978, 1982).

GEOPHYSICAL INVESTIGATIONS

Results of the airborne geophysical survey

The 1988 airborne geophysical survey combined gamma-ray spectrometric, magnetic, and VLF-EM sensors. The survey data are available as a set of twelve maps at 1:100 000 scale and a set of stacked profiles for each flight line (Geological Survey of Canada, 1989). The gamma-ray data are on eight colour maps, in the following formats: ternary radioelement, exposure rate, potassium, equivalent uranium (eU) and equivalent thorium (eTh) concentrations, and as the ratios eU/eTh, eU/K, and eTh/K. The aeromagnetic data are represented as colour maps of total field and calculated vertical magnetic gradient. The VLF-EM data consist of a total field colour map and a quadrature profile map. A geological compilation at 1:100 000 scale accompanies the geophysical maps. The stacked profiles show seven radiometric parameters, magnetic total field, and VLF total field and quadrature components for each flight line.

The essential features of the geophysical patterns are shown on Figure 2b (total field aeromagnetic map), Figure 2c (total count radioactivity map), and Figure 2d (equivalent uranium to potassium ratio map). Results of the VLF-EM survey are not presented here. Most of the anomalies on the VLF-EM maps relate to surficial features (i.e., low areas and lake basins with conductive overburden); however, a few linear features and offsets can be seen on these maps including one which trends northwest along the Fluorite zone and may indicate a fracture control of the mineralization.

The magnetic map (Fig. 2b) shows three anomalous features in addition to the linear anomalies relating to the northeast-trending Hearne diabase dyke set, and the large northwest-trending Mackenzie diabase dyke, which strikes through the deposits north of Thor Lake. "Anomalous" here refers to total magnetic fields that exceed 60 800 nanoTesla(nT) or are 400 nT above background (i.e., 60 400 nT). The largest and most prominent anomaly (>62 400 nT) occurs in the western part of the area and is related to the Caribou Lake Gabbro, including portions of the associated leucoferrodiorite phase.

The other two anomalous features, situated in the central part of the map, have maximum amplitudes of more than 61 400 nT. The larger anomaly overlies the western half of the Thor Lake Syenite and extends westward over the Grace Lake Granite. To the east, a gradational boundary is apparent

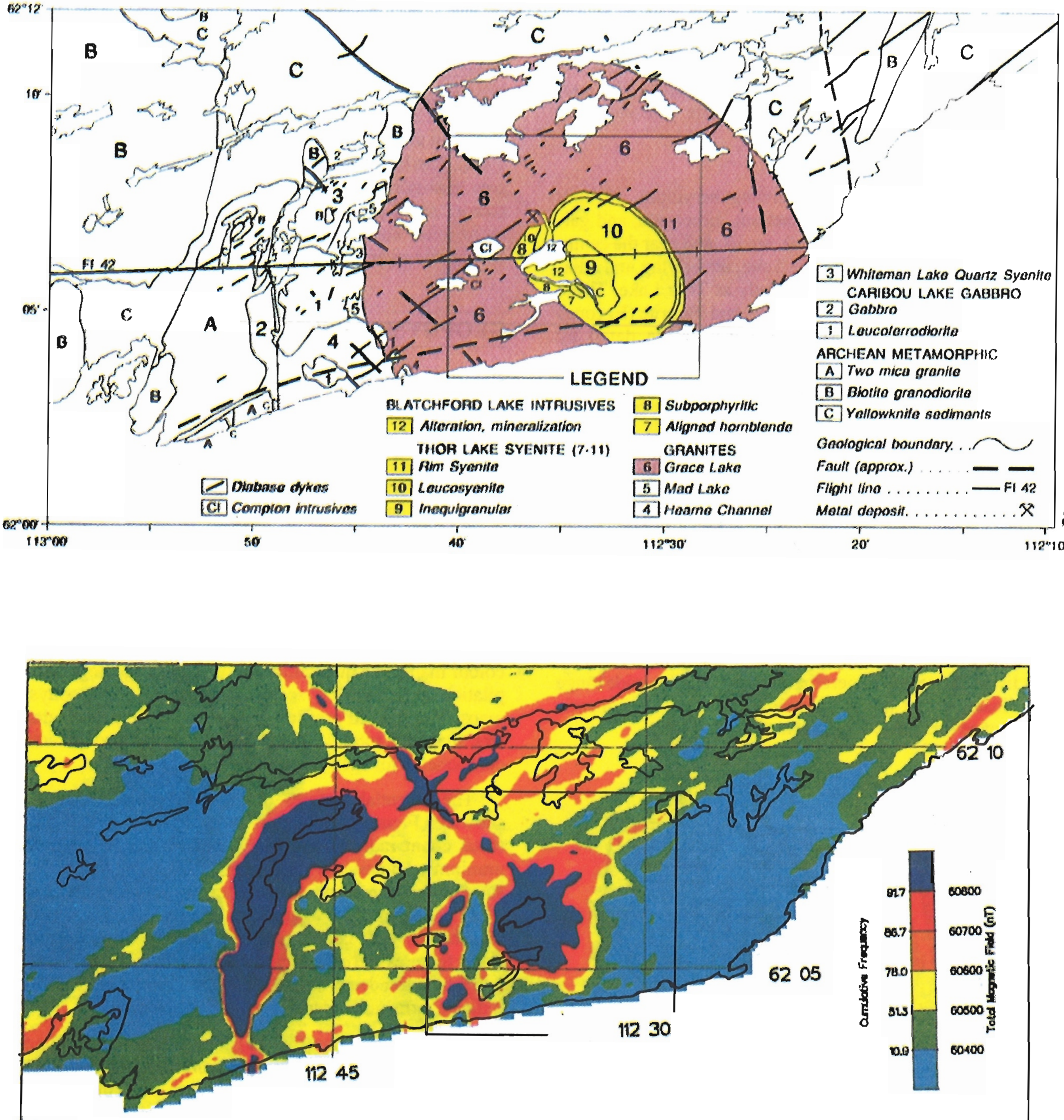
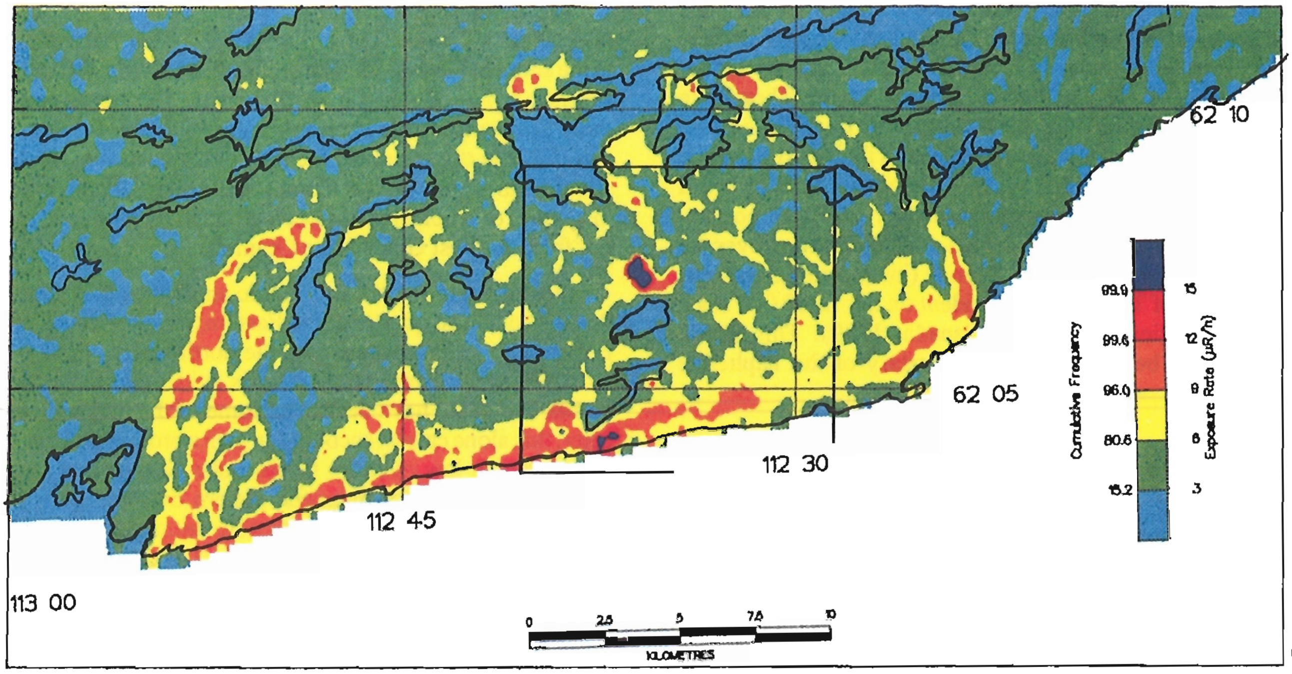
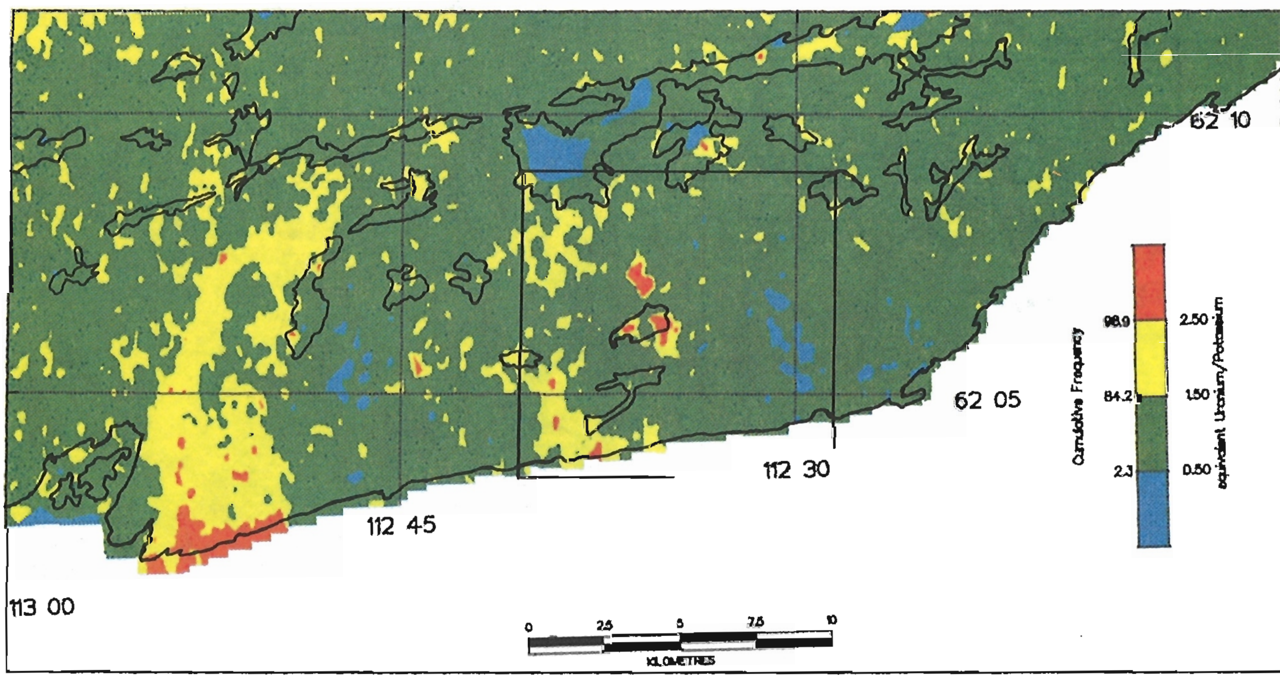


Figure 2. a) Geology map of the Blatchford Lake Intrusive Suite (after Davidson, 1982); b) total magnetic field (nanoTesla = nT) over area shown in Figure 2a, (modified from Geological Survey of Canada, 1989); c) total count radioactivity/exposure rate (microRoentgen/hour =μR/H over area shown in Figure 2a, (modified from Geological Survey of Canada, 1989); d) eU/K map, same area as Figure 2a, (modified from Geological Survey of Canada, 1989).


62 10
62 05
112 30
112 45
113 00
Cumulative Frequency
99.9
99.6
96.0
80.6
15.2
15
12
9
6
3
Exposure Rate (μR/h)
0
2.5
5
7.5
10
KILOMETRES

c


62 10
62 05
112 30
112 45
113 00
Cumulative Frequency
98.9
84.2
2.3
2.50
1.50
0.50
equivalent Uranium/Potassium
0
2.5
5
7.5
10
KILOMETRES

d

between the magnetic and nonmagnetic halves of the Thor Lake Syenite. The nonmagnetic eastern half of the Thor Lake Syenite correlates roughly with the coarse grained leucosyenite (Fig. 3). The magnetic intensity of the Thor Lake Syenite also decreases near the shoreline of Great Slave Lake; this change may reflect the presence of a fault postulated by Davidson (1978) which possibly truncates the Blatchford Lake Intrusive Suite on its southern side. Although not discernible in Figure 2b, a ring-shaped magnetic feature over the western half of the Thor Lake Syenite (intersecting the southern shoreline of Thor Lake) is evident on the 1:100 000 scale maps (Geological Survey of Canada, 1989). This subtle anomaly may be related to the boundary of the nepheline syenite body.

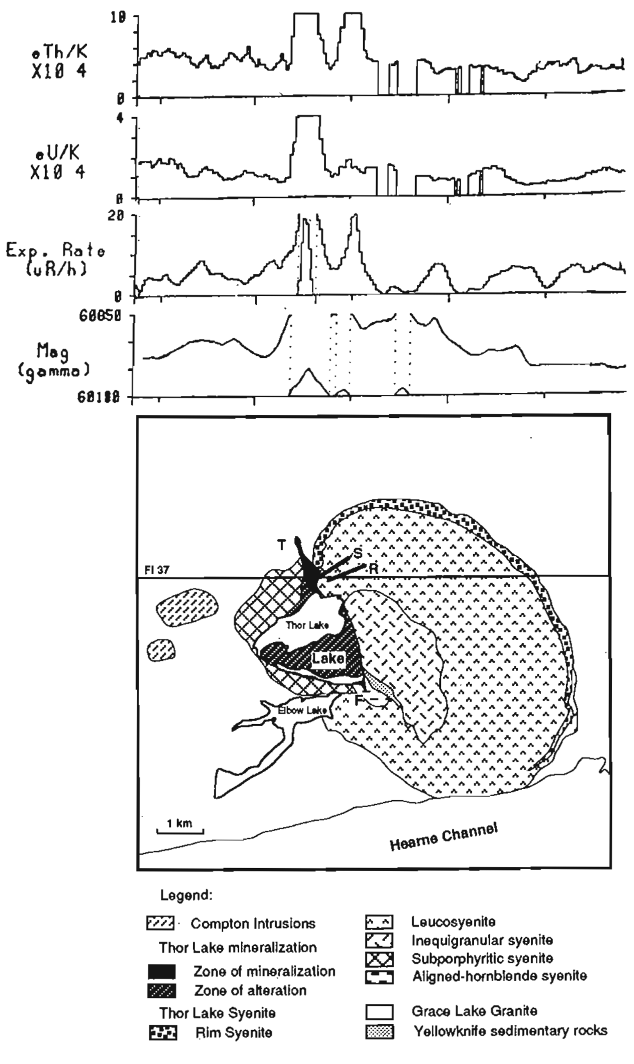


Figure 3. *Detailed area of maximum exploration interest (100 km²) of the Blatchford Lake Intrusive Suite showing the R, S, T, Lake, and F zones of mineralization. After Davidson (1978). The area of this map is outlined in Figure 2. Four geophysical profiles (eTh/K, eU/K, exposure rate, and total magnetic field) for flight line (Fl) 37 are also shown.*

The other major anomaly is a crescent-shaped feature which extends southerly from west of the Thor Lake deposits to the shore of Hearne Channel, entirely within the Grace Lake Granite. A plug of quartz monzonite of the Compton Intrusive Suite lies partly within the northern extremity of the anomaly and partly in the nonmagnetic area to the east. It is not clear whether this part of the Compton Intrusive body is itself magnetic, or whether it has been affected by magnetic material from the host Grace Lake Granite.

In addition to the above specific anomalies, it is apparent that the southeast quarter of the Eastern Series of the complex is distinctly less magnetic than the northwestern three quarters. Although surface weathering is evident in the southeast corner and could have destroyed some of the magnetic character, this alone cannot account for such a prominent low. This aeromagnetic low over the Grace Lake Granite is truncated by the slightly higher magnetic pattern over the Thor Lake Syenite, which suggests a possible intrusive relationship between Thor Lake Syenite and Grace Lake Granite.

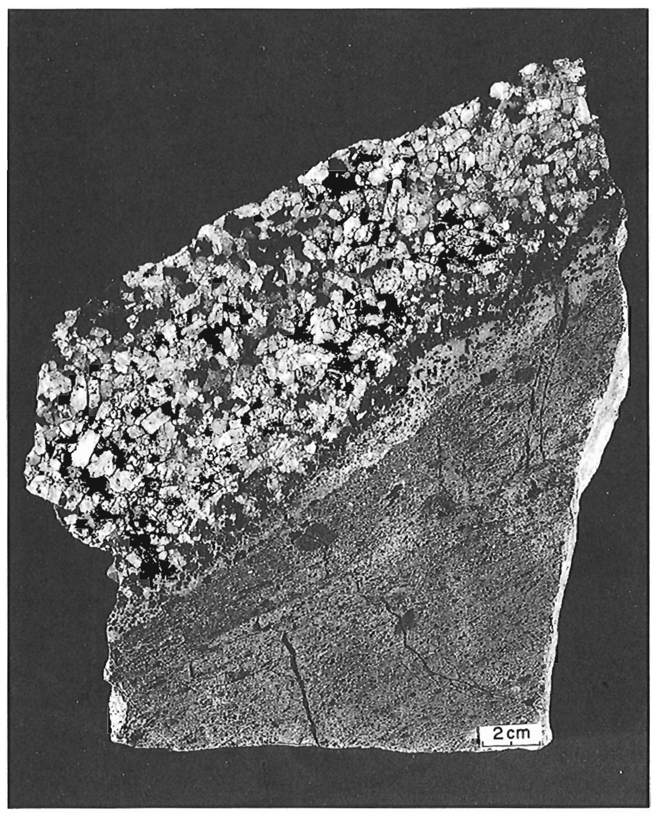


Figure 4. *Sample of fine grained granite dyke cutting Grace Lake Granite. GSC 1991-170-H*

Radiometric variations within the Blatchford Lake complex are illustrated by the total radioactivity (exposure) map (Fig. 2c) which indicates average levels of about 6 microRoentgen/hour (μR/h) over most of the complex. This is only slightly above average airborne levels for the Canadian Shield (Grasty et al., 1984). The main radiometric anomaly on the map, near the western boundary of the area, is related to the presence of an Archean two-mica granite. Within the area of the Blatchford Lake complex, which is characterized by generally low radioactivity, the Hearne Channel and Mad Lake granites are anomalously radioactive. The small, isolated anomaly north of Thor Lake corresponds to the Thor Lake rare-metal deposits. This anomaly is about 1 km wide and has relatively sharp boundaries; no halo of widespread uranium or thorium surrounding the Thor Lake deposits is evident.

A pronounced linear anomaly trends parallel to the shoreline of Hearne Channel, between the previously mentioned linear magnetic break and the shoreline. The boundary of the Blatchford Lake Intrusive Suite elsewhere is slightly anomalous but this is due mainly to greater bedrock exposure. The southeastern quadrant of the Eastern Series of the complex, which is underlain by relatively nonmagnetic Grace Lake Granite, is slightly more radioactive than the rest of the Grace Lake Granite (Fig. 2c). Examination of air photos indicates that this area has a higher outcrop exposure than the rest of the complex which could explain, in part, the radiometric anomaly.

The equivalent uranium/potassium map (Fig. 2d) shows three anomalies. The most westerly anomaly is related to Archean two-mica granite. The central anomaly is in two parts

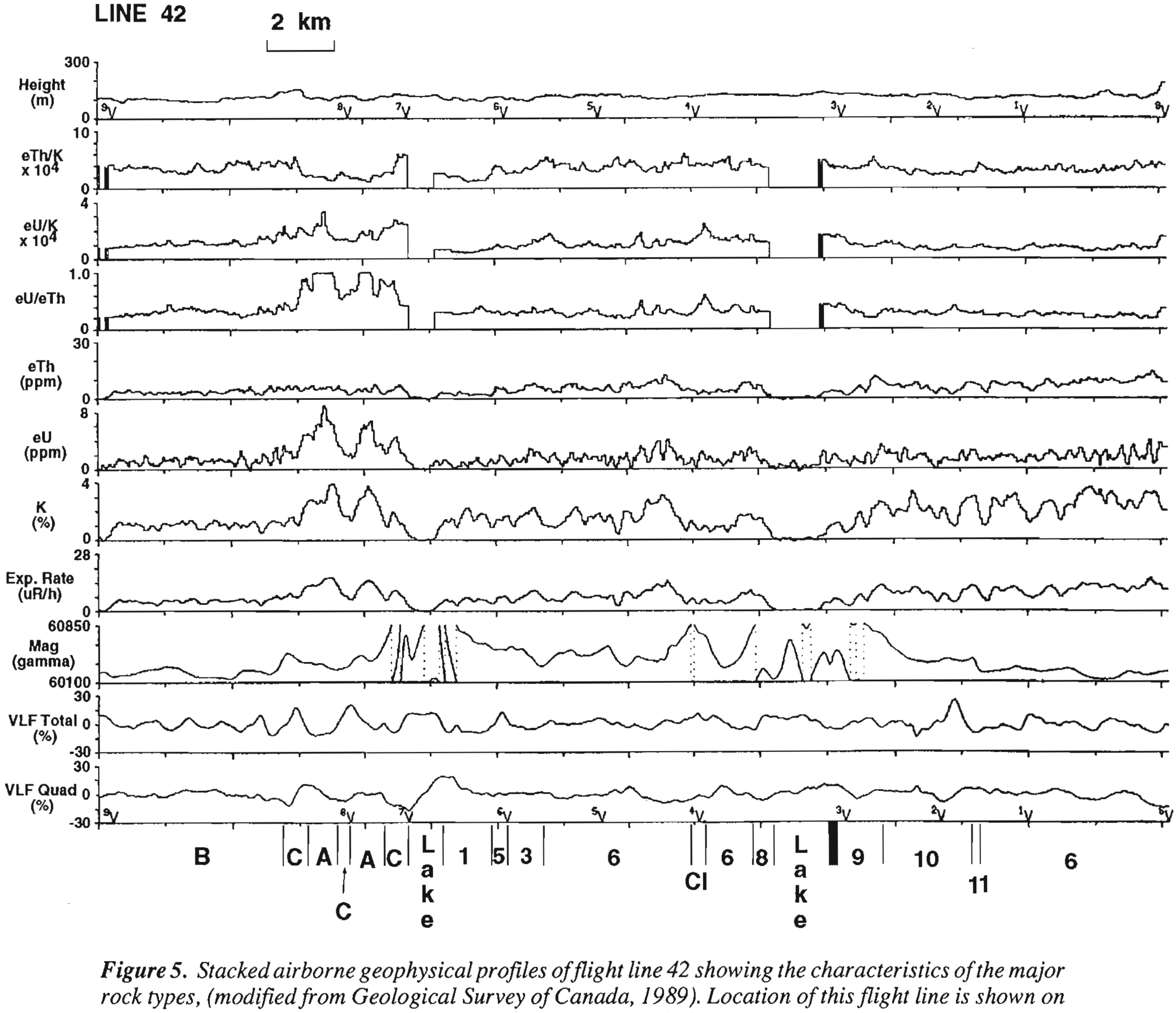


Figure 5. Stacked airborne geophysical profiles of flight line 42 showing the characteristics of the major rock types, (modified from Geological Survey of Canada, 1989). Location of this flight line is shown on Figure 2a. Letters and numbers along abscissa represent lithological units shown in Figure 2a.

which correspond to the Thor Lake deposits; the northern part overlies the R, S, and T zones (Fig. 3) which are characterized by both high total radioactivity and high equivalent uranium/potassium, except for the R zone, whereas the southern part is related to the Lake and Fluorite zones which are characterized by high equivalent uranium/potassium but are only weakly radioactive. Equivalent uranium/thorium values (not shown) are slightly higher over the Lake zone than over the R, S, and T zones. The third anomaly is an arcuate pattern of high equivalent uranium/potassium values to the southwest of the Thor Lake deposits, which corresponds to the crescent-shaped magnetic anomaly mentioned previously. Equivalent thorium/potassium anomalies (not shown) also correlate with the uranium/potassium and magnetic anomalies.

Many of the magnetic and radiometric anomalies discussed above are evident in the stacked profiles of the geophysical parameters from an east-west flight line across the intrusive complex (Fig. 5). Another profile (Fig. 3) shows the pertinent geophysical signatures along a flight line (Fl 37) that passes over the Thor Lake deposits, specifically, the T, S, and R zones. Although not easily discernible on the total count radioactivity map (Fig. 2c), the variable radiometric characteristics of the mineralized zones are clearly delineated by the geophysical parameters recorded along Fl 37 (Fig. 3).

The airborne geophysical patterns neither support nor refute the model of the Blatchford Lake Intrusive Suite based on the gravity survey by Birkett et al. (1992, 1994). According to Birkett et al. (1994), the Grace Lake Granite and Thor Lake Syenite (Eastern Series) comprise an extensive sheet about 1 km thick that is underlain in part by mafic rocks which correspond to the Caribou Lake Gabbro to the west. The eastern boundary of the magnetic anomaly related to the Caribou Gabbro does extend over part of the area underlain by the leucoferrodiorite phase and Whiteman Lake Quartz Syenite (Fig. 2a, b), and possibly reflects extension of the Caribou Lake Gabbro under the eastern part of the Blatchford Lake Intrusive Suite as suggested by Birkett et al. (1994). An alternative explanation, however, is that a shoulder of the Caribou Lake Gabbro extends to depth below the leucoferrodiorite phase and the Whiteman Lake Quartz Syenite. If a thin sheet of magnetic Caribou Lake Gabbro does extend further under the eastern part of the complex, a higher background magnetic level in that area would be expected but is not obvious on Figure 2b.

Furthermore, one might also expect the contact between a sheet-like Blatchford Lake complex and the country rock to be irregular because of the variable topographic relief; however, the contact is sharply circumscribed. This could be rationalized with a sheet-like geometry for the Blatchford Lake complex if a ring dyke feeder is invoked (Davidson, 1982). Only deep drilling or seismic work can resolve with certainty the question of the overall three dimensional shape of the complex.

Results of the ground follow-up

In order to assess the significance of the airborne geophysical patterns, ground studies involving gamma-ray spectrometry, scintillometry, and magnetic susceptibility were undertaken during the 1989 field season (Charbonneau and Legault, 1992). The VLF-EM anomalies were not investigated on the ground. The location of the ground traverses are shown on Figure 6. Traverses A-B and C-D correspond to the

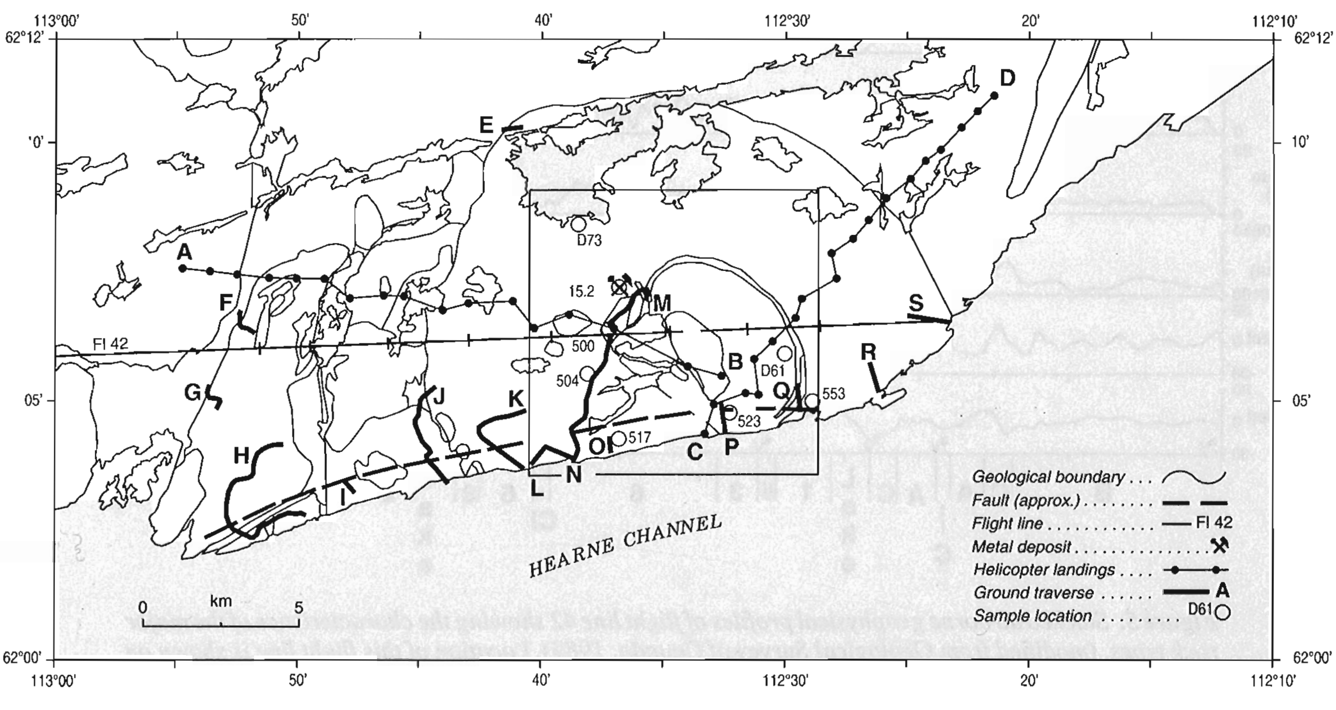


Figure 6. Map showing the location of key samples collected, and traverses along which geophysical measurements were obtained.

Table 1. Average gamma-ray spectrometer measurements of rocks from the Blatchford Lake Intrusive Suite. Total number of in situ gamma spectrometric measurements (N) = 353.

	N	K%	eU ppm	eTh ppm	eU/eTh	eU/K $x10^{-4}$	eTh/K $x10^{-4}$
Thor Lake mineralization	52	-	207.1	893.9	0.23	-	-
Fine grained dykes	5	2.4	37.9	118.2	0.32	16	49
Thor Lake Syenite	51	4.0	3.4	21.6	0.16	0.9	5.4
Thor Lake Syenite (Rim Syenite)	6	3.8	1.2	8.2	0.15	0.3	2.2
Grace Lake Granite	81	3.7	3.2	17.4	0.18	0.9	4.7
Crescent-shaped magnetic anomaly	57	3.8	8.3	39.9	0.21	2.2	11
Hearne Channel-Mad Lake Granite	29	4.3	7.7	29.9	0.26	1.8	6.9
Compton Intrusive	12	1.8	1.6	5.4	0.29	0.9	3.0
Archean two-mica granite	50	4.2	12.9	11.4	1.13	3.1	2.7
Archean biotite granodiorite	3	1.3	1.7	4.3	0.39	1.3	3.3
Yellowknife metasedimentary rocks	7	2.4	2.3	7.7	0.30	1.0	3.3

helicopter-supported gravity survey done by Birkett et al. (1994), whereas the other traverses were done on foot. Polished thin sections and geochemical analyses were obtained for many of the rock samples collected.

Three hundred and fifty-three in situ gamma-ray spectrometric measurements with corresponding magnetic susceptibility readings were made on bedrock exposures to characterize the lithological variations. Ground geophysical instruments utilized were an Exploranium GR101A scintillometer, an Exploranium DISA 400 gamma-ray spectrometer, and a Scintrex SM-5 magnetic susceptibility meter. The gamma-ray spectrometric readings were taken at representative parts of the outcrops selected by scanning the outcrop with a scintillometer.

Table 1 presents average gamma-ray spectrometry measurements on different lithologies in the study area. A potassium value for Thor Lake mineralization is not shown because of statistical uncertainty in the gamma-ray spectrometric measurements introduced by high uranium and thorium concentrations. The radioelement concentrations in the table are consistent with the geophysical patterns on the maps.

The average equivalent uranium (eU) and thorium (eTh) contents of the Thor Lake deposits are high, but the ratio of these elements is only slightly above average crustal levels (Galbraith and Saunders, 1983). The high eU and eTh concentrations result in anomalous eU/K and eTh/K values. The fine grained dykes of the Grace Lake Granite and Thor Lake Syenite also have elevated levels of eU and eTh, but eU/eTh values are constant. The rim syenite (Fig. 2a) is low in eU (1.2 ppm) and eTh (8.2 ppm), and has reasonably high potassium levels of 3.8% K or 4.6% K_2O.

Measurements on Thor Lake Syenite and Grace Lake Granite gave comparable results: Thor Lake Syenite contains 4.0% K (4.7% K_2O), 3.4 ppm eU, and 21.6 ppm eTh, and Grace Lake Granite contains 3.7% K (4.3% K_2O), 3.2 ppm eU, and 17.4 ppm eTh. The combined averages for all measurements over the Eastern Series are 3.8% K (4.5% K_2O), 3.2 ppm eU, and 18.5 ppm eTh. These values are close to potassium and uranium concentrations reported by Davidson (1982), but are slightly higher with respect to thorium concentrations. These levels are close to average crustal values expected for acidic rocks (Galbraith and Saunders, 1983). The ground-based values are consistent with the airborne maps which indicate, for example, that typical eU values are on the order of 1.5-2.0 ppm. The lower airborne values are due to the subduing effects of overburden, swamp, and other surface features; bedrock uranium concentrations of 3 ppm are therefore consistent with the airborne map values. The effect of overburden, swamp and other surface phenomenon on gamma-ray spectrometry surveys over the Canadian Shield have been reported by Charbonneau et al. (1976). The bedrock radioelement values measured on the Hearne Channel and Mad Lake granites are higher than those for the Thor Lake Syenite and Grace Lake Granite, and are also consistent with the distinct anomaly outlined over these units on the airborne map (Fig. 2c).

The linear radiometric anomaly along the shoreline of Hearne Channel is a prominent feature on the radioelement maps (Fig. 2c). The bedrock underlying this anomaly is probably bounded on the north side by an east-northeast-trending fault which is reflected by a sharp break on magnetic gradient and VLF-EM maps (not shown). On the ground, the fault is indicated by sheared rocks and by a distinct topographic lineament. A greater area of bedrock exposure within the terrane to the south of the fault, compared to the terrane to the north, contributes to the prominent radioelement signal on the maps. For example, high concentrations of eU and eTh are present in the Archean two-mica granite in the west, in the Hearne Channel Granite, and in the rocks underlying the crescent-shaped magnetic anomaly west of Thor Lake. The presence of bedrock units with higher intrinsic uranium and thorium concentrations within this fault-bounded terrane, as well as the accentuating effect of increased bedrock exposure, explain the linear "shoreline" feature.

The arcuate crescent-shaped eU/K (and eTh/K) anomaly southwest of the Thor Lake deposits (Fig. 2d) indicates a significant enrichment in uranium with respect to potassium with average equivalent uranium concentrations of 8.3 ppm and eU/K of about 2.2×10^{-4} compared to an average ratio of about 1.1×10^{-4} for acidic rocks (Galbraith and Saunders, 1983). This anomaly corresponds closely to the crescent-shaped magnetic anomaly; a similar correlation based on earlier radioactivity measurements was noted by S.M. Roscoe of the Geological Survey of Canada (pers. comm. in Davidson (1978), p. 126). Near Hearne Channel, the southern portion

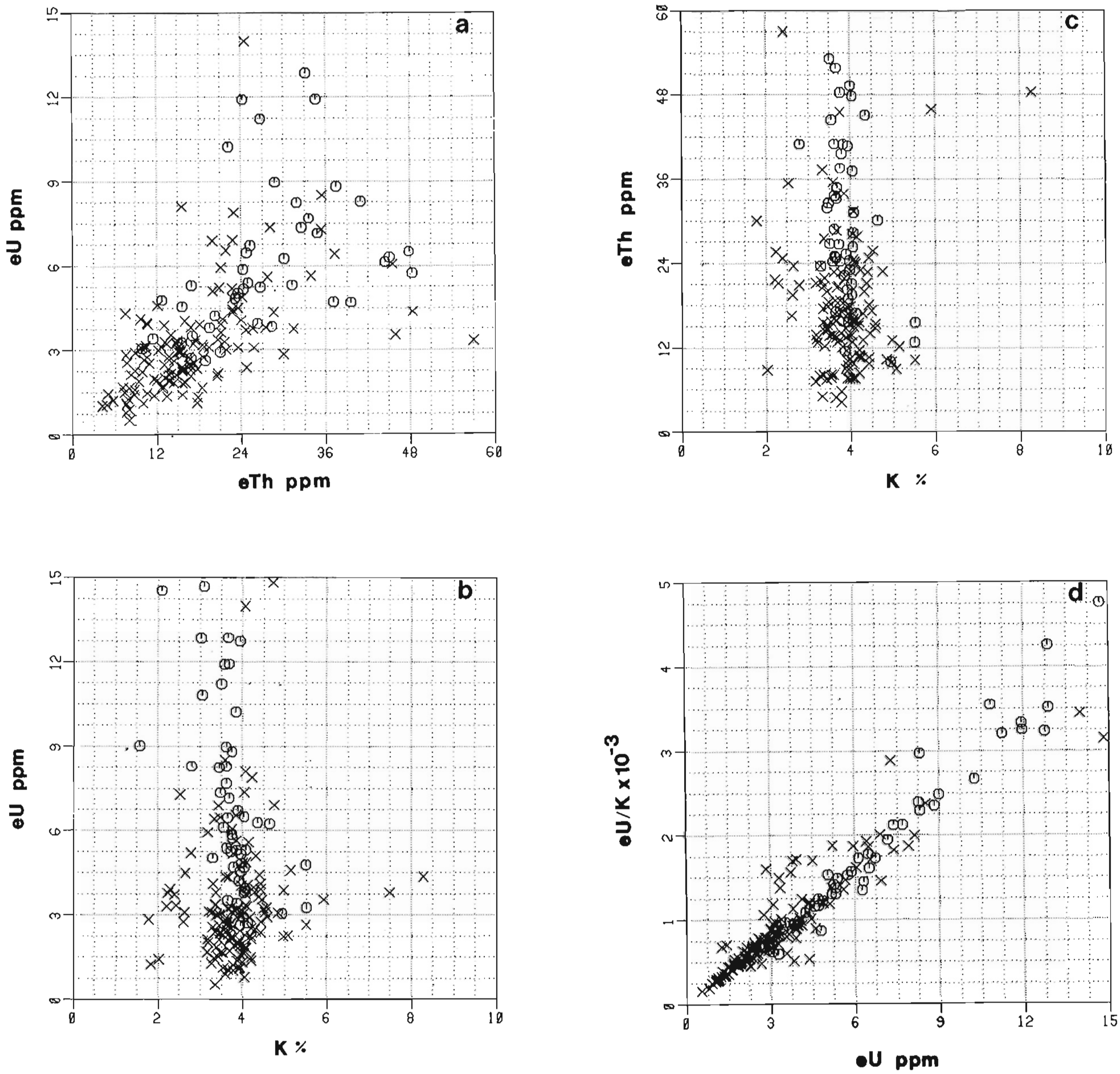


Figure 7. In situ gamm-ray spectrometric measurements from thte Eastern (peralkaline) Series of the Blatchford Lake Intrusive Suite: a) eU versus eTh; b) eU versus K: c) eTh versus K; d) eU/K versus eU. Grace Lake Granite and Thor Lake Syenite samples are represented by crosses; open circles are Grace Lake Granite samples from the crescent-shaped magnetic anomaly. Measurements on Thor Lake mineralization are not included.

of the eU/K anomaly (which corresponds to the crescent-shaped magnetic anomaly) is relatively high in U and Th (total radioactivity); chemical analyses indicate high levels of other granophile elements such as Be and Sn and may warrant further exploration consideration. Maximum values of Be (43 ppm), Sn (1520 ppm), U (475 ppm), and Th (130 ppm) were obtained in samples from the area of this anomaly (i.e., in the vicinity of the location of sample 517; Table 2, Fig. 6).

The ratio anomalies in Figure 2d compare closely with bedrock values. This is because the factors which reduce the airborne signal for individual radioelements (e.g., overburden, wetness, and vegetation) affect equally the numerator and denominator, thereby leaving the ratio relatively unchanged (Charbonneau et al., 1976).

The plots shown in Figures 7a, b, c, d show variations of eU versus eTh, eU versus K, eTh versus K, and eU/K versus eU based on two hundred in situ readings within the Grace Lake Granite and Thor Lake Syenite. Figure 7a shows that eU varies proportionally with eTh (r=0.82) at a relatively fixed ratio of about 0.2, generally between 0.1 and 0.3. This ratio is very close to average values for acidic rocks (Galbraith and Saunders, 1983). Figures 7b and 7c indicate that uranium and thorium vary with respect to a relatively fixed potassium value. The strong correlation of eU/K with eU (r=0.98) and eTh/K versus eTh (r=0.97; not shown) affirms the above.

The airborne magnetic pattern (Fig. 2b) is consistent with in situ magnetic susceptibility measurements made on outcrops. Over most of the eastern part of the complex, magnetic susceptibility readings were low, although a few random high values were found. The two major magnetic anomalies, one over the western half of the Thor Lake Syenite and the other, the crescent-shaped anomaly within the Grace Lake Granite, are related to rocks which have higher magnetic susceptibility relative to background levels. Outcrops within the anomalous areas generally registered between 1 and 3 x 10^{-3} cgs units* although some outcrops registered significantly higher values (>10 x 10^{-3} cgs units). Values outside the anomalies were generally less than 0.1 x 10^{-3} cgs units. Extremely low values of magnetic susceptibility were measured on outcrops within the southeast quadrant of the complex (< 0.1 x 10^{-3} cgs units). These values are consistent with airborne patterns on Figure 2b.

PETROCHEMISTRY

The petrochemistry of the Blatchford Lake Intrusive Suite has been described by Davidson (1982), who demonstrated the alkalic nature of the suite and attributed the development of both earlier aluminous and later peralkaline rocks to differentiation. He showed that successive intrusive units display predictable trends in their major element contents, namely increases in silica and alkali elements, and decreases in iron, magnesium, and calcium towards the younger rocks. Among minor elements, S and base metals such as Cu, Ni, Cr, and Co are concentrated mainly in the early mafic units; lithophile elements such as Be, Zr, Rb, REE, Nb, Ta, and Th, and volatiles such as F, are concentrated in younger granitic and syenitic rocks. The contents of F, Nb, and REE are highest in the peralkaline rocks (Grace Lake Granite and Thor Lake Syenite), whereas U, Th, and Rb contents are slightly higher in the older, aluminous Whiteman Lake Quartz Syenite. Analytical data on the mafic minerals in the Blatchford Lake complex illustrate extreme enrichment in iron with respect to magnesium during differentiation (Davidson, 1982).

The chemical composition of representative samples of the peralkaline rocks in the eastern part of the complex are presented in Table 2. The compositions of the relatively unaltered samples of Thor Lake Syenite and Grace Lake Granite (D-61 and D-73) are from Davidson (1981); samples of altered Thor Lake Syenite and Grace Lake Granite (500 and 517), the fine grained dyke (523), and the T-zone sample (15.2) were analyzed as part of this study. Compared to Davidson's unaltered samples, the altered Thor Lake Syenite and Grace Lake Granite samples have slightly higher contents of iron and slightly lower content of silica and alumina. In terms of minor elements, the altered samples are enriched in a wide range of granophile elements (i.e., Be, U, Th, Zr, Ba, La, Ta, and F) compared to their unaltered counterparts.

The fine grained dyke rock has a higher silica content, but lower sodium and potassium contents than the unaltered samples of Thor Lake Syenite and Grace Lake Granite. The dyke has considerable amounts of Zr (12500 ppm), La (1640 ppm), Nb (430 ppm), and Sn (67 ppm). The T-zone sample is from a radioactive part of the mineralized zone and is notable for its extremely high content of Th (10000 ppm); it also has high contents of Zr, REEs, Be, Ta, and F.

MINERALOGICAL INVESTIGATIONS OF MAGNETIC AND RADIOACTIVE ROCKS

Petrographic and electron-microprobe studies were undertaken on selected samples in order to identify the radioactive and magnetic minerals of the rocks of the eastern part of the Blatchford Lake Intrusive Suite. The nature of the mineralogical changes which result in an increase of magnetic susceptibility in the Grace Lake Granite and Thor Lake Syenite are relatively straightforward. The Fe-Ti oxides in these rocks are magnetite, hematite, and minor ilmenite. Magnetite and hematite commonly occur as inclusions in altered mafic minerals (generally amphiboles) although oxides also occur in quartz and feldspar. Unaltered granites and syenites contain little magnetite or hematite and have low magnetic susceptibility. Altered granites and syenites may contain magnetite or hematite or a mixture of both; high susceptibility rocks are magnetite-rich whereas low susceptibility rocks are hematite-rich or have low oxide content. Ilmenite occurs in all rocks, but is more common in the more magnetite-bearing samples. Alteration resulting in Fe-Ti oxides is a relatively common late autometasomatic feature in alkaline complexes (O'Halloran, 1985).

* One volume per cent of magnetite corresponds to approximately 3 x 10^{-3} cgs units. In currently used SI units, one volume per cent magnetite would correspond to $4\pi(3 \times 10^{-3}$ cgs units) or ~38 x 10^{-3} SI units.

Table 2. Geochemical analyses of representative samples from the Eastern (peralkaline) Series of the Blatchford Lake Intrusive Suite and Thor Lake deposits

Element	Representative samples (locations shown in Fig. 6)					
	D-61	500	D-73	517	523	15.2
SiO_2 (wt.%)	62.5	60.7	71.6	63.4	75.3	68.3
TiO_2 (wt.%)	0.51	0.73	0.56	1.82	0.50	0.92
Al_2O_3 (wt.%)	14.1	13.2	12.7	7.62	8.04	1.68
$Fe_2O_{3(tot)}$ (wt.%)	8.6	10.3	4.02	16.4	6.94	6.30
MnO (wt.%)	0.25	0.12	0.09	0.06	0.12	4.03
MgO (wt.%)	0.39	0.86	0.08	0.50	0.18	1.52
CaO (wt.%)	1.55	1.89	0.89	2.25	0.01	1.10
Na_2O (wt.%)	5.80	5.26	4.32	1.85	3.42	0.21
K_2O (wt.%)	4.89	5.50	4.81	3.56	2.88	1.18
P_2O_5 (wt.%)	0.10	0.12	0.02	0.07	0.07	0.44
U (ppm)	2.6	2.7	3.4	14.1	19.6	30.6
Th (ppm)	10	15	17	130	66	10000
Zr (ppm)	595	1370	625	1350	12500	2890
La (ppm)	150	178	155	379	1640	711
Nb (ppm)	115	179	120	468	430	<10
Be (ppm)	5.7	88	4.6	33	24	4830
Ba (ppm)	22	202	110	165	266	219
Sr (ppm)	34	30	26	21	43	5
Rb (ppm)	130	189	153	207	223	39
F (ppm)	2900	9200	9000	10000	390	8800
Sn (ppm)	-	19	-	28	67	5
Ta (ppm)	-	11	-	22	29	

Sample	Description
D-61	- unaltered leucosyenite phase of Thor Lake Syenite from Davidson (1981)
500	- altered Thor Lake Syenite
D-73	- unaltered Grace Lake Granite from Davidson (1981)
517	- altered Grace Lake Granite
523	- fine grained dyke in Thor Lake Syenite
15.2	- Thor Lake mineralization; T zone

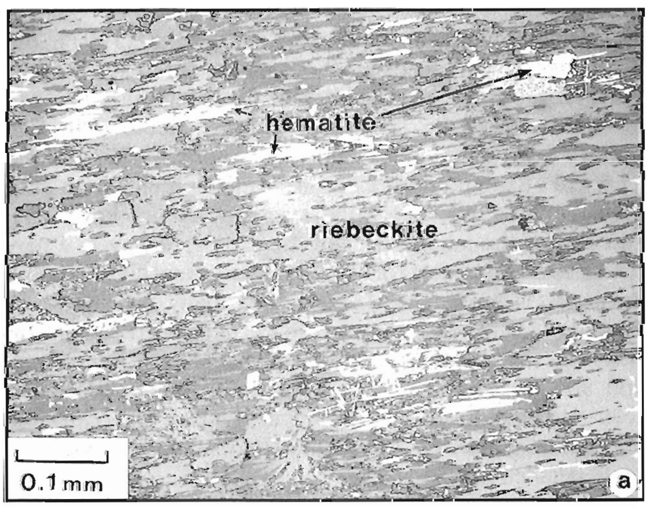
Major oxides plus Zr, Nb, Sn, Ba, Sr, Rb analyzed by X-ray fluorescence spectrometry;
Be and F analyzed by wet chemical methods; U, Th, La, and Ta analyzed by neutron activation.

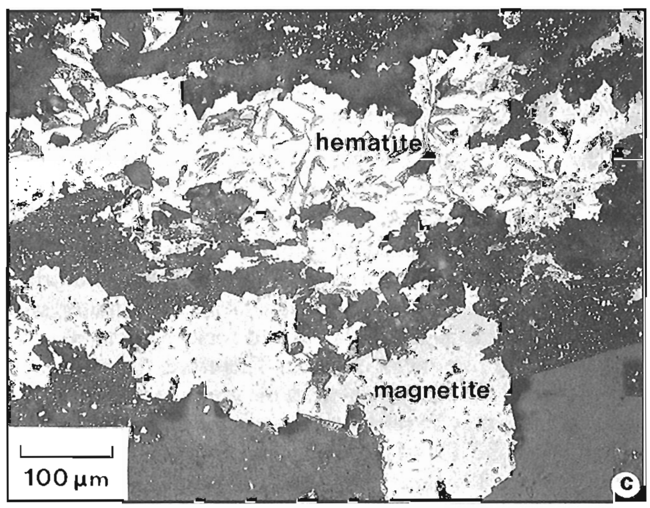
The rocks underlying the two magnetic highs that lie within the eastern peralkaline part of the Blatchford Lake complex contain a substantial proportion of iron oxides as magnetite. These magnetic highs define areas where oxidation potential was suitable for magnetite formation as opposed to hematite. Some of the syenite and granite rocks outside these two anomalies contain substantial quantities of oxides (e.g., the southeast quadrant of the survey) within altered amphiboles; however, in these rocks, hematite, much of it limonitic, predominates over magnetite.

The textural characteristics of these rocks are typified by photomicrographs of three samples of the Grace Lake Granite (Fig. 8a, b, c). Figure 8a (sample 553) is a rock with low magnetic susceptibility showing hematite slivers in weakly altered riebeckite. Sample 504 (Fig. 8b) has a high magnetic susceptibility indicating 2-3% magnetite. The amphiboles are preserved as pseudomorphs composed of extensive amounts of magnetite and hematite in a straw-coloured matrix (mostly quartz and biotite). Feldspars are highly altered to micas and may be partly replaced by Fe-rich minerals. Rocks of high magnetic susceptibility (>3% magnetite; i.e., sample 517) typically contain veinlets and masses of magnetite and hematite (Fig. 8c).

In summary, the central magnetic anomaly and the crescent-shaped magnetic anomaly are related to areas where a substantial magnetic iron-oxide component is present compared to the outer parts of the complex where the rocks are either oxide-poor, or the principal oxide mineral is hematite (southeast quadrant). Rocks within the central magnetic anomaly tend to be slightly more iron-rich (e.g., sample 500, Table 2) than rocks in the peripheral parts of the eastern complex although the anomaly corresponds primarily to the relative proportion of Fe-Ti mineral phases rather than the absolute amount of iron.

The radioactive minerals within the Grace Lake Granite and Thor Lake Syenite are zircon, REE-rich carbonate (bastnaesite?) and rare grains of REE-rich apatite and monazite. In the fine grained dykes, which cut the Grace Lake Granite and Thor Lake Syenite, monazite and allanite are common as well as zircon (sample 523; Table 2). The Thor Lake mineralized zones are mineralogically varied and contain a number of additional radioactive minerals such as thorite, uranothorite, uraninite, and U-rich pyrochlore (Pinckston and Smith, 1991). The radioactive minerals in the fine grained dykes and at the Thor Lake deposits are accompanied by minerals





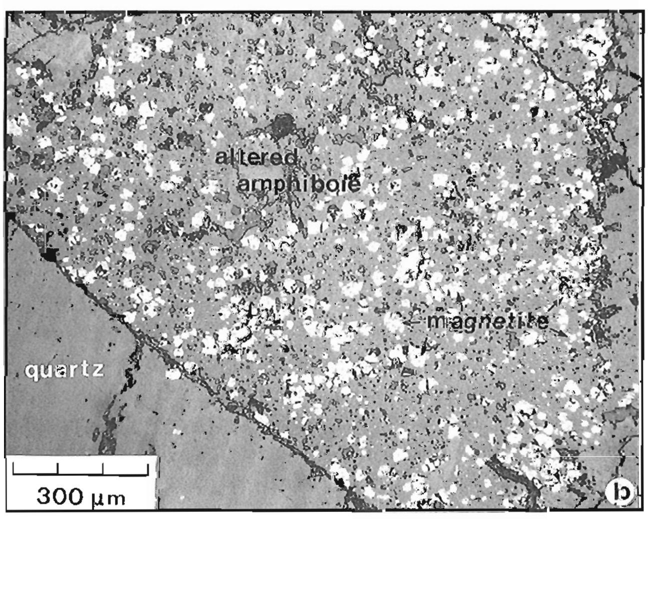


Figure 8. Fe-oxide minerals of the Grace Lake Granite: a) hematite laths in slightly altered riebeckite; b) magnetite grains in a moderately altered amphibole; c) massive hematite and magnetite in an altered granite sample.

containing increased concentrations of a wide range of other granophile elements including Be (samples 523 and 15.2, Table 2).

DISCUSSION

The radiometric and magnetic variations over the Blatchford Lake Intrusive Suite, particularly within the eastern part of the complex, show sharp, abrupt changes in the geophysical patterns over the rare-metal deposits. Apart from the strong uranium and thorium anomalies in the immediate vicinity of the Thor Lake deposits, the radiometric data do not focus on the deposits in any way, i.e., there is no broad radiometric halo around the deposits. This reflects the fact that the mineralized bodies have sharp, crosscutting boundaries with the granite and syenite. This evidence supports a late stage magmatic to postmagmatic origin for the Thor Lake mineralization.

The principal radioactive minerals in the Grace Lake Granite and the Thor Lake Syenite, zircon and bastnaesite, tend to crystallize relatively late in alkaline rocks (Maurice and Charbonneau, 1987) and therefore would be expected to be strongly enriched in late volatile-rich phases of the Blatchford Lake complex. The enrichment of uranium and thorium, along with other granophile elements such as tin, beryllium, and niobium, in the Thor Lake Syenite, the Grace Lake Granite, and the fine grained late stage dykes, indicates that metal contents in the source magma were sufficient to produce the Thor Lake deposits.

The crescent-shaped magnetic anomaly west of Thor Lake is a feature which may be related to the formation of the Thor Lake deposits and has possible implications for future exploration. Rocks associated with the southern part of this anomaly are enriched in iron, uranium, thorium, and other granophile elements, and have magnetic and radiometric signatures similar to those of the altered rocks associated with the Thor Lake rare-metal deposits. Therefore, the processes that produced the rocks related to the crescent-shaped magnetic anomaly may be related to the processes involved in the formation of the Thor Lake deposits. If this is the case, the crescent-shaped magnetic anomaly may indicate a similar mineralized zone, which may represent a separate new zone or an extension of the Thor Lake deposits which has been separated by faulting. For example, the nonmagnetic rocks which separate the main magnetic anomaly from the crescent-shaped feature may represent a segment of rock that was vertically juxtaposed. Alternatively, the faulting may be at a lower angle and the crescent-shaped magnetic anomaly may have previously been part of the main magnetic anomaly. In any case, this feature deserves further investigation.

Although a relationship of the Thor Lake rare-metal deposits to the Blatchford Lake Intrusive Suite is generally accepted, various models concerning the genesis have been proposed. For example, Davidson (1982) concluded that the deposits formed by concentration of the rare metals in residual fluids produced by differentiation of the Grace Lake Granite and the Thor Lake Syenite. Trueman et al., (1988) considered that the Thor Lake deposits formed from a number of late stage magmatic processes, including fenitization and pegmatite crystallization, but that neither the Grace Lake Granite nor the Thor Lake Syenite was the progenitor. As Pinckston and Smith (1991) pointed out, metasomatically-altered or fenitized rocks have been enriched in iron, along with sodium and potassium. This tendency has been noted generally in alkaline complexes by Bonin and Giret (1985), who considered that it is due, at least in part, to late stage hydrothermal fluids produced by vesiculation of late magmatic liquids and/or by the remobilization of interstitial ground water in a convective-type geothermal field.

Pinckston and Smith (1991) proposed a model that involved the nepheline syenite body which is not exposed at surface but which underlies the Thor Lake deposits. This body has been intersected by diamond drilling at depths of 100 to 200 m below surface, mainly beneath the Lake zone, although the limits of its lateral extent were not defined (Pinckston and Smith, 1991). The annular magnetic high within the magnetic anomaly associated with the Lake zone referred to previously (discernible in the magnetic survey data released in Geological Survey of Canada, 1989, Open File 1922) corresponds to the approximate boundaries of the nepheline syenite indicated by Pinckston and Smith (1991). This magnetic response is likely due to the formation of magnetite related to fenitization of host rocks associated with the emplacement of the nepheline syenite. It appears to confirm that the nepheline syenite is centred beneath the Lake zone.

As postulated by Pinckston and Smith (1991), the nepheline syenite represents the last phase of the Blatchford Lake Intrusive Suite and may have had a significant role in the formation of the Thor Lake deposits. Because the fine grained felsic dykes that intrude the Grace Lake Granite and Thor Lake Syenite are enriched in the metals found in the Thor Lake deposits, the nepheline syenite may not have been essential as the main source of the metals; however, it may have had an important role in remobilizing and concentrating the metals in the deposits. In this regard, many of the observed alteration features associated with the deposits (i.e., albitization, microclinization, iron-metasomatism, greisenization, and silicification) are consistent with alteration patterns related to emplacement of nepheline syenites. The role of the nepheline syenite, however, remains uncertain and requires a more detailed investigation.

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REFERENCES

Birkett, T.C., Richardson, D.G., and Sinclair, W.D.
1994: Gravity modelling of the Blatchford Lake Intrusive Suite, Northwest Territories; in Studies of Rare-Metal Deposits in the Northwest Territories, (ed.) W.D. Sinclair and D.G. Richardson, Geological Survey of Canada, Bulletin 475, p. 5-16.

Birkett, T.C., Sinclair, W.D., and Richardson, D.G.
1992: Geochemical, isotopic and gravity studies of the Thor Lake deposits and associated host rocks of the Blatchford Lake Intrusive Suite; in Project Summaries, Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991, Geological Survey of Canada, Open File 2484, p. 127-128.

Bonin, B. and Giret, A.
1985: Contrasting roles of rock forming minerals in alkaline ring complexes; Journal of African Earth Sciences, Vol. 3, no. 1/2, p. 41-49.

Bowring, S.A., Van Schmus, W.R., and Hoffman, P.F.
1984: U-Pb zircon ages from Atuthapuscow Aulacogen, East Arm of Great Slave, NWT, Canada; Canadian Journal of Earth Sciences, v. 21, p. 1315-1324.

Charbonneau, B.W. and Legault, M.I.
1992: Interpretation of airborne geophysical data for the Lupin and Thor areas, NWT; in Project Summaries, Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991, Geological Survey of Canada, Open File 2484, p. 107-112.

Charbonneau, B.W., Killeen, P.G., Carson, J.M., Cameron, G.W., and Richardson, K.A.
1976: The significance of radioelement concentration measurements made by airborne gamma-ray spectrometry over the Canadian Shield; in Exploration for Uranium Ore Deposits; International Atomic Energy Agency, Vienna, Austria, Ser. No. STI/PUB/434, p. 35-53.

Davidson, A.
1972: Granite studies in the Slave Province; in Report of Activities, Part A; Geological Survey of Canada, Paper 72-1A, p. 109-115.
1978: The Blachford Lake intrusive suite: An Aphebian alkaline plutonic complex in the Slave Province, Northwest Territories; in Current Research, Part A; Geological Survey of Canada, Paper 78-1A, p. 119-127.
1981: Petrochemistry of the Blachford Lake complex, District of Mackenzie; Geological Survey of Canada, Open File 764 (two 1:50 000 scale maps: Geology of the Blatchford Lake complex, and sample locations).
1982: Petrochemistry of the Blachford Lake Complex near Yellowknife, NWT; in Uranium in Granites, (ed.) Y.T. Maurice; Geological Survey of Canada, Paper 81-23, p. 71-79.

Galbraith, J.H. and Saunders, D.F.
1983: Rock classification by characteristics of aerial gamma ray measurements; Journal of Geochemical Exploration, v. 18, p. 49-73.

Geological Survey of Canada
1989: Airborne geophysical survey Blatchford Lake (Thor Lake) alkaline complex, Northwest Territories; Open File 1922 (1:100 000 scale colour maps displaying gamma-ray spectrometry, aeromagnetic data, VLF electromagnetic data and stacked profiles).

Grasty, R.L., Carson, J.M., Charbonneau, B.W., and Holman, P.B.
1984: Natural background radiation in Canada; Geological Survey of Canada, Bulletin 360, 39 p.

Henderson, J.F.
1938: Beaulieu River area, Northwest Territories; Geological Survey of Canada, Paper 38-1, 20 p.

Hylands, J.J.
1980: Placer Development Limited (Thor Lake area), Mackenzie; Department of Indian and Northern Affairs, Document 081258.

Maurice, Y.T. and Charbonneau, B.W.
1987: U and Th concentration processes in Canadian granitoids, their detection by airborne gamma ray spectrometry and their relationship to granophile mineralization; Revista Brasileira de Geosciências, Proceedings of the International Symposium on Granites and Associated Mineralizations, v. 17, no. 4, p. 644-646.

O'Halloran, D.A.
1985: Ras ed Dom migrating ring complex: A-type granites and syenites from the Bayuda Desert, Sudan; Journal of African Earth Sciences v. 3, p. 61-75.

Pedersen, J.C. and LeCouteur, P.C.
1990: The Thor Lake beryllium-rare metal deposits, Northwest Territories; in Mineral Deposits of the Slave Province, Northwest Territories, (ed.) W.A. Padgham and D. Atkinson; Geological Survey of Canada, Open File 2168, p. 128-136.

Pinckston, D.R. and Smith, D.G.W.
1991: Mineralogy and petrogenesis of the Lake zone, Thor Lake rare metals deposit, NWT, Canada; EGS 1991-5, NWT Geology Division, Department of Indian and Northern Affairs, Canada, 27 p.

Stockwell, C.H.
1932: Great Slave Lake-Coppermine River Area, NWT; Geological Survey of Canada, Summary Report, Part C, p. 37-64.

Taylor, R.P. and Pollard, P.J.
1992: Study of the peralkaline granite-syenite contact in the Thor Lake area, NWT and its relationship to the T-Zone mineralization and alteration; in Project Summaries, Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991, Geological Survey of Canada, Open File 2484, p. 123-125.

Trueman, D.L., Pedersen, J.C., de St. Jorre, L., and Smith D.G.W.
1988: The Thor Lake rare-metal deposits, NWT; in Recent Advances in the Geology of Granite-Related Mineral Deposits, (ed.) R.P. Taylor and D.F. Strong; Canadian Institute of Mining and Metallurgy, Special Volume 39, p. 280-290.

Reconnaissance studies of four pegmatite populations in the Northwest Territories

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Tomascak, P.B., Wise, M.A., Černý, P., and Trueman, D.L.,1994: Reconnaissance studies of four pegmatite populations in the Northwest Territories; in Studies of Rare-Metal Deposits in the Northwest Territories, (ed.) W.D. Sinclair and D.G. Richardson; Geological Survey of Canada, Bulletin 475, p. 33-62.

Abstract: The Aylmer Lake and Torp Lake pegmatite fields in the Slave Province of the Canadian Shield are composed primarily of beryl type and beryl-columbite-phosphate subtype pegmatites, with a portion of each field attaining the characteristics of the complex-spodumene type. The Chantrey Inlet and Foxe pegmatites in the Rae Province are of the beryl-columbite and beryl-columbite-phosphate subtypes.

Detailed study of the Aylmer Lake field documents the distribution of at least 227 pegmatites and 18 granitic plutons. Parts of the Aylmer Lake field (Reid and Nebbish lakes) display regional mineralogical and geochemical zoning of pegmatite groups about parental granites. Series containing spodumene-bearing dykes display the best potential for economic Be and Li mineralization.

Most pegmatites of the Torp Lake field are geochemically simple. Some dykes, however, are complex, and one intrusion is rich in spodumene, lepidolite, albite (cleavelandite), and elbaite. Pegmatites may be regionally zoned about a two-mica granite. The potential for pegmatites with substantial Be and Li is considered good.

The Chantrey Inlet field contains abundant pegmatites and evolved granites. Fractionated pegmatites contain columbite-tantalite and Li, Fe, Mn phosphate minerals. Pegmatite-granite relations are complex and patterns of regional zonation of pegmatite series are not apparent.

The Foxe field contains small leucogranitic sheets and a series of beryl-bearing pegmatites, including the PLEX pegmatite. This pegmatite contains columbite-tantalite, spessartine-rich garnet, beryl, and schorl and the degrees of rare alkali fractionation are typical of the beryl-columbite subtype. This field has minor potential for pegmatites enriched in Nb,Ta-oxides.

Résumé : Les champs de pegmatite d'Aylmer Lake et de Torp Lake, dans la Province des Esclaves du Bouclier canadien, sont composés surtout de pegmatites du type à béryl et du sous-type à béryl-columbite-phosphate et dont une partie, dans chaque champ, montre les caractéristiques du type complexe à spodumène. Les pegmatites de Chantrey Inlet et de Foxe, dans la Province de Rae sont des sous-types à béryl-columbite et à béryl-columbite-phosphate.

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Une étude détaillée du champ d'Aylmer Lake documente la distribution d'au moins 227 pegmatites et de 18 plutons granitiques. Des parties du champ d'Aylmer Lake (région des lacs Reid et Nebbish) montrent des zonations minéralogiques et géochimiques régionales des groupes de pegmatite en fonction des granites parentaux. La série qui renferme des dykes à spodumène montre les meilleures possibilités de découverte de minéralisations économiques de Be et Li.

La majeure partie des pegmatites du champ de Torp Lake sont géochimiquement simples. Quelques dykes, cependant, sont complexes et une intrusion est riche en spodumène, en lépidolite, en albite (cleavelandite) et en elbaite. Les pegmatites peuvent montrer une zonation régionale par rapport à un granite à deux micas. Le potentiel de découverte de pegmatites à teneurs substantielles en Be et Li est considéré bon.

Le champ de Chantrey Inlet contient d'abondantes pegmatites et des granites évolués. Les pegmatites fractionnées contiennent de la columbite-tantalite et des minéraux phosphatés à Li, Fe et Mn. Les relations entre les pegmatites et les granites sont complexes et une zonation régionale des séries de pegmatite n'est pas apparente.

Le champ de Foxe contient de petits feuillets de leucogranite et une série de pegmatites à béryl, dont la pegmatite PLEX. Cette pegmatite renferme de la columbite-tantalite, du grenat riche en spessartine, du béryl et du schorl et les degrés de fractionnement d'alcalis rares sont typiques du sous-type à béryl-columbite. Ce champ possède un certain potentiel pour la découverte de pegmatites enrichies en Nb et en oxydes de Ta.

INTRODUCTION

Pegmatite studies were initiated in the Northwest Territories by the Department of Geological Sciences, University of Manitoba in 1981. A thorough re-investigation of the Yellowknife pegmatite field (Meintzer, 1987; Wise, 1987; Meintzer and Wise, 1987; Meintzer et al., 1984, 1988a, b, in press; Meintzer and Černý, 1988; Wise et al., 1985, 1988; Wise and Černý, 1990a, b) upgraded the knowledge of this pegmatite population which was the only one in the Northwest Territories that was reasonably well known from previous work (e.g., Jolliffe, 1943, 1944; Rowe, 1952; Hutchinson, 1955; Kretz, 1968, 1970, 1985) and locally industrially exploited. Since 1981 and mainly after 1987, further work was focused on regions known to contain only a few pegmatites, and at recently discovered pegmatites reported to the Geology Office, Indian and Northern Affairs Canada (INAC), Yellowknife. This paper provides information on these virtually unknown pegmatite occurrences, including: the Aylmer Lake field in west-central Northwest Territories, the Chantrey Inlet field and Torp Lake field along the arctic coastline, and the Foxe field on Baffin Island (Fig. 1). Characterization of the diverse chemical, mineralogical and field aspects of these four pegmatite-bearing regions demonstrates:

1) the rare-element potential hidden in areas in which only a few barren pegmatite bodies were previously identified, and
2) the existence of many other pegmatite populations that require specialized examination to assess their economic significance.

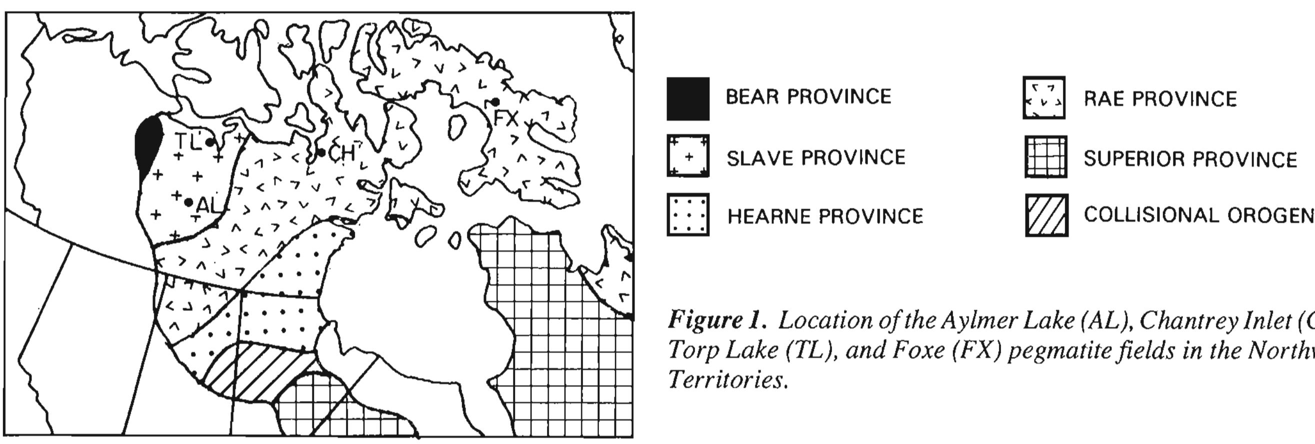


Figure 1. Location of the Aylmer Lake (AL), Chantrey Inlet (CH), Torp Lake (TL), and Foxe (FX) pegmatite fields in the Northwest Territories.

SLAVE PROVINCE

Aylmer Lake pegmatite field

This pegmatite field covers an area of approximately 10 900 km^2, roughly centred on Aylmer Lake in southeastern Slave Province (Fig. 1, 2). Regional mapping drew attention to the presence of the pegmatites, some of them spodumene- and beryl-bearing (Barnes, 1950; Folinsbee, 1952; Lord and Barnes, 1954). Similarities in the regional geology and character of plutonic rocks with the Yellowknife pegmatite field, and the evolved nature of the reported pegmatites prompted a reconnaissance study of this area. In total, 22 pegmatite series were identified, with a minimum of 227 individual pegmatites and 18 granitic plutons; of these pegmatites, 104 were examined in detail. The following summary is condensed from the M.Sc. thesis of Tomascak (1991), which provides considerable additional detail based on field work in 1988 and 1989 by P.B. Tomascak, M.A. Wise, and in part P. Černý.

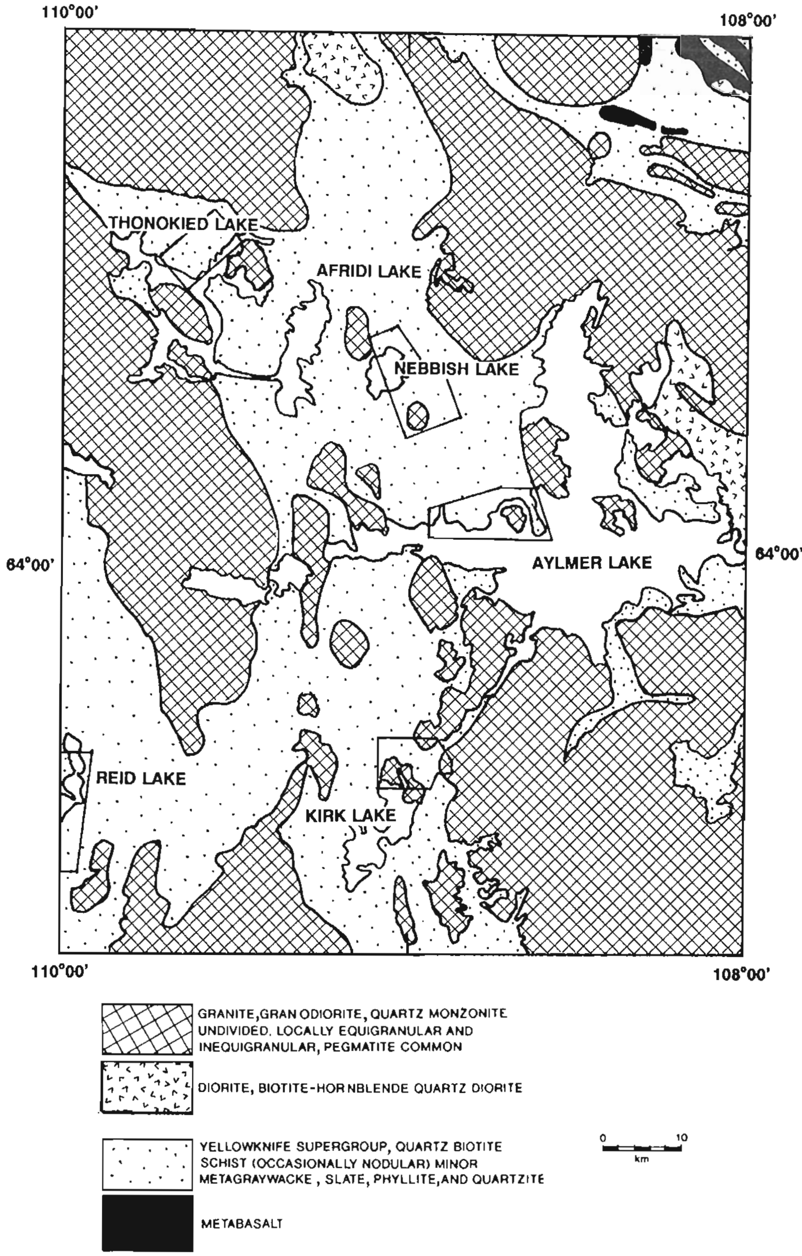


Figure 2. Schematic geology of the Aylmer Lake pegmatite field. Geology after Lord and Barnes (1954) and Folinsbee (1952). The areas outlined near Aylmer Lake, Reid Lake, Kirk Lake, Nebbish Lake, and Thonokied Lake correspond approximately to Figures 3, 4, 5, 6, and 7, respectively.

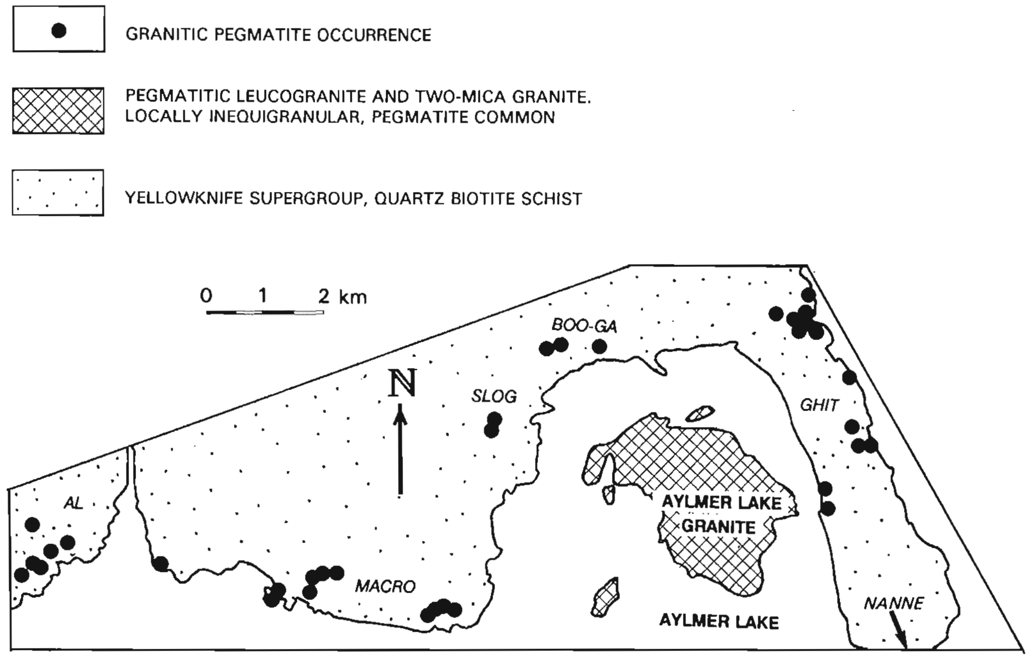
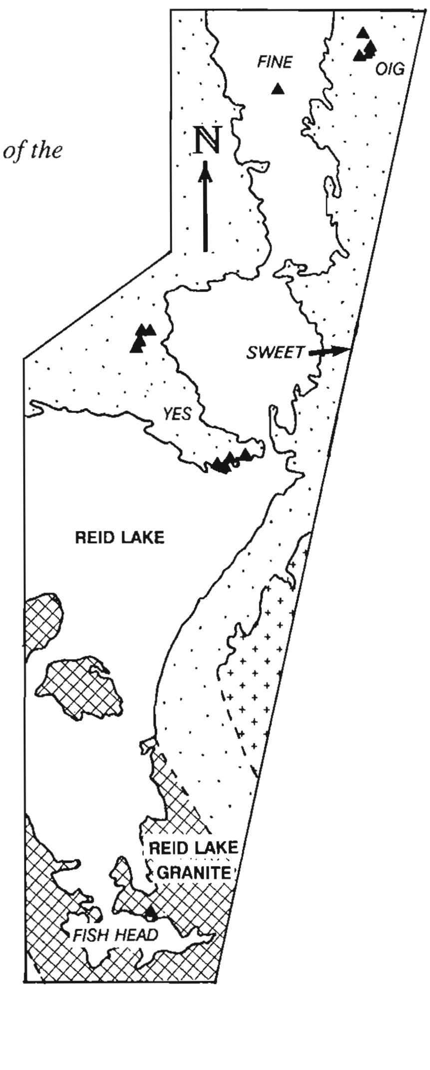
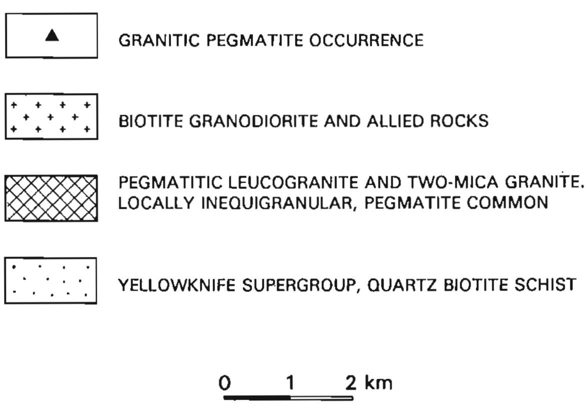


Figure 3. Fertile granites and pegmatite series in the immediate vicinity of Aylmer Lake. Geology after Lord and Barnes (1954).

Figure 4. Fertile (and other) granites and pegmatite series of the Reid Lake area. Geology after Folinsbee (1952).





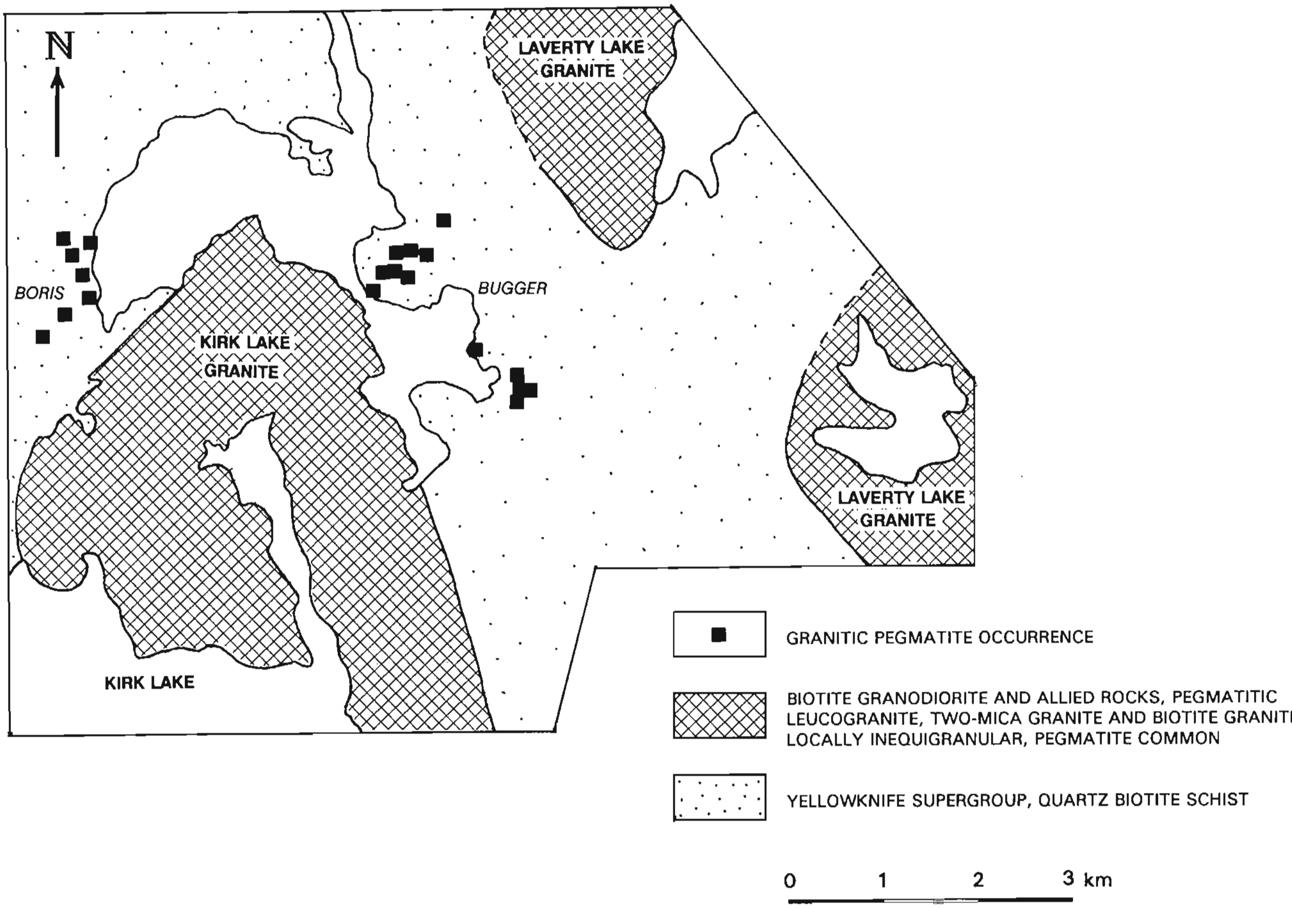


Figure 5. *Fertile (and other) granites and pegmatite series of the Kirk Lake area. Geology after Folinsbee (1952).*

Pegmatites and granitoid rocks of the Aylmer Lake area are hosted predominantly by quartz-biotite schist of the Yellowknife Supergroup. Granitoid intrusions were mapped locally, but rarely in contact with metavolcanic rocks. The quartz-biotite schist is derived from a uniform package of metagreywackes. Besides quartz and biotite, these rocks contain plagioclase and cordierite, which is minor but widespread throughout the Aylmer Lake and MacKay Lake metasedimentary basins (Fyson and Helmstaedt, 1988). Analogous to country rocks at Lac de Gras (approximately 30 km north-northeast of the study area), Aylmer Lake area schists are of lower to middle amphibolite facies of metamorphism, with peak conditions of 525-600°C and 3-4.5 kbars (Thompson, 1978).

Geochronological information on both the country rock metasediments and the granitic intrusions in the Aylmer Lake field is limited. Aside from mafic and ultramafic dykes, the pegmatitic granitoids are the latest intrusions in the area. Van Breemen et al. (1987) and van Breemen and Henderson (1988) dated zircon and monazite from two-mica and pegmatitic leucogranites from near the southern border of the Aylmer Lake pegmatite field, around Healey Lake and Clinton-Colden Lake, at 2530-2600 Ma (U-Pb). Book muscovite in related pegmatitic phases yields somewhat younger Rb-Sr ages of around 2535 Ma.

The granite and pegmatite population of the Aylmer Lake field can be subdivided into five areas (see Fig. 3, 4, 5, 6, 7, below); the pegmatites in each display distinct local geochemical signatures:

Aylmer Lake - Be, Nb-Ta, (subordinate Li);
Reid Lake - Be, P, Li, (subordinate Nb-Ta);
Kirk Lake - P, B;
Nebbish Lake - Li, Nb-Ta, Be, P, B;
Thonokied Lake - Be, (subordinate P, B).

The fertile granites

Within the Aylmer Lake pegmatite field, fertile granites comprise broadly zoned plutons containing fine grained, typically foliated, biotite granite, two-mica granite and muscovite granite. These granitoids become coarser grained and richer in garnet, tourmaline, and apatite in the fine-grained leucogranites and ultimately become extremely coarse grained pegmatitic leucogranites, which commonly occupy the margins of individual plutons (e.g., Western and Northern Aylmer Lake granites, Fig. 3; Reid Lake granite, Fig. 4; Nebbish Lake granite, Fig. 6; Karhu intrusion, Fig. 7). Pegmatitic leucogranites are typified by potassic pegmatite and sodic aplite, commonly exhibiting layered textures (e.g., Aylmer Island granite, Fig. 3; Kirk Lake granite, Fig. 5)(Černý and Meintzer, 1988).

Besides microcline-perthite, plagioclase (commonly with An <10), quartz, biotite, and muscovite, the finer grained leucogranites contain accessory apatite, garnet, monazite, and zircon. Epidote and allanite are rare. The occurrence of tourmaline is highly variable, ranging from 0 to 5% of the modal minerals. Apatite and garnet are particularly abundant in the pegmatitic leucogranites.

The granitic rocks typically possess massive, undeformed fabrics (e.g., the Reid Lake granite, Fig. 4, Afridi Lake and Nebbish Lake granites, Fig. 6). This suggests generally quiescent, posttectonic emplacement; however, areas of weak to moderate alignment of micas, particularly in the chemically more primitive facies of granitic plutons, suggest that pluton emplacement was not strictly postkinematic. Chemically primitive, foliated parts of biotite granite plutons indicate emplacement from the mid/late kinematic to postkinematic stages.

There is considerable evidence for ductile response by host metasedimentary rocks to the emplacement of granitoids. For example, along the western arm of Aylmer Lake, granite exhibits lit-par-lit injection along planar fabric. Similarly, the granite body south of Thonokied Lake contains abundant micaceous schlieren which are relics of almost totally digested schist screens, as well as rafts of plastically deformed metasedimentary rock. The undulose and lenticular shapes of such inclusions imply ductile behavior during emplacement.

Within the Aylmer Lake field all fertile granites are peraluminous (molar A/CNK >1.0) and silicic (SiO_2 >69.7 wt.%), and are slightly more so depending on the degree of mineralogical, textural, and geochemical fractionation. The CIPW normative orthoclase:albite ratio is highly variable from compositions near the ternary minimum to strongly albitic (Fig. 8).

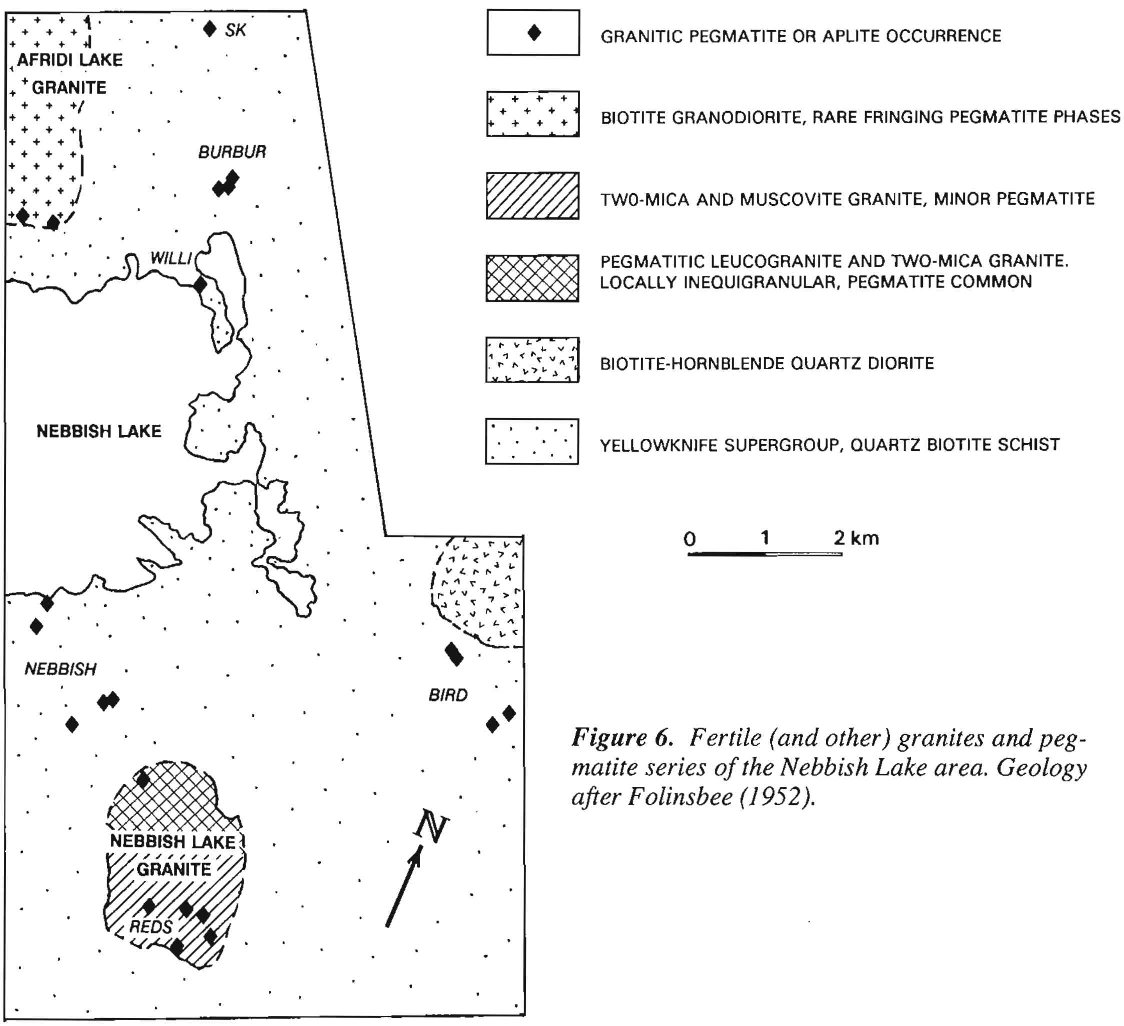


Figure 6. *Fertile (and other) granites and pegmatite series of the Nebbish Lake area. Geology after Folinsbee (1952).*

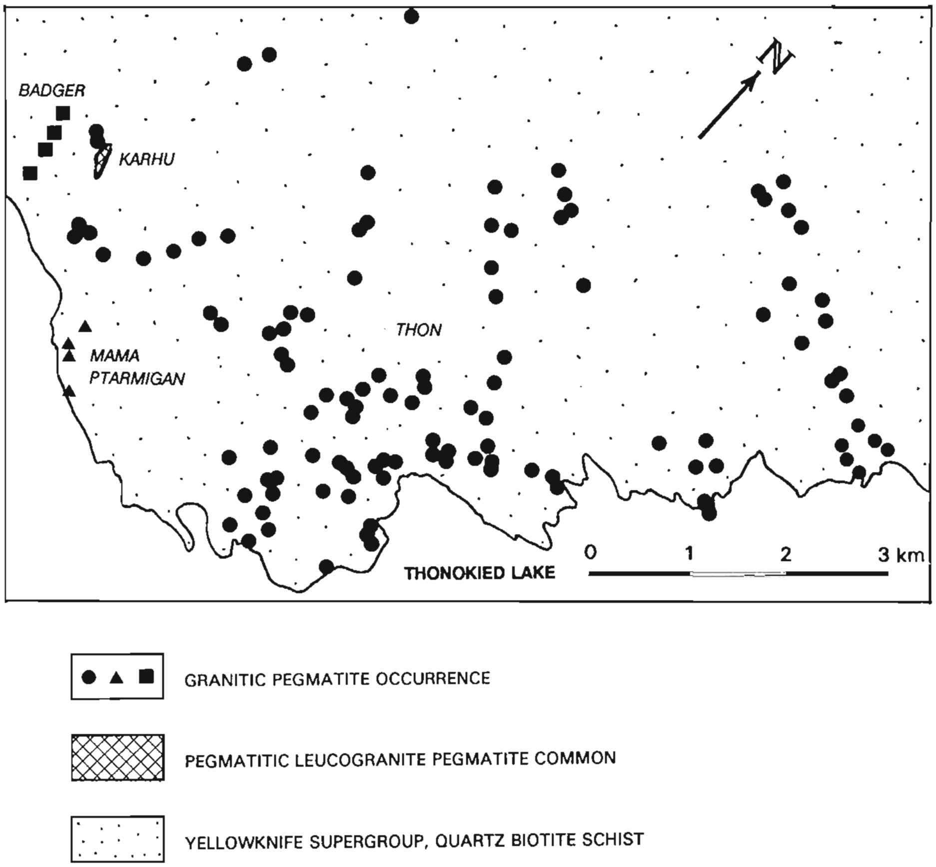


Figure 7. *Fertile granites and pegmatite populations of the Thonokied Lake area. Geology after Barnes (1950) and Lord and Barnes (1954).*

The P_2O_5 content of many fertile granites in the Aylmer Lake field is considerably higher than averages for fine grained and pegmatitic leucogranites examined by Černý and Meintzer (1988) (0.29 vs. 0.1 wt.%). The low CaO in Aylmer Lake field plutons rules out apatite as a control on extreme P_2O_5 fractionation. Some evidence suggests that, in general, P_2O_5 increases with increasing fractionation (Tomascak and Černý, 1992)(Fig. 9A).

The fertile granites of the Aylmer Lake field are enriched in Rb, with high Rb/Sr and low K/Rb (Fig. 9A, B), and, in general, low values of Zr/Y compared to nonfertile granites (Černý and Meintzer, 1988). Not all fertile granites have Sr and Ba depleted proportionally to enrichment in Rb, but correlation with Sr is better than with Ba. The fractionation of granites is demonstrated in the field by zoned plutons containing biotite granite, fine grained leucogranites (with muscovite or two micas), and pegmatitic leucogranites. This mineralogical fractionation is paralleled by chemical differentiation of fertile intrusions, as summarized in Table 1.

The pegmatite populations

The pegmatites of the Aylmer Lake field can be divided into five areas (Fig. 3, 4, 5, 6, and 7). Within each area, spatially associated and mineralogically related pegmatites with common geochemical features are termed a series (or a group, if a parent granitic intrusion can be identified with reasonable certainty).

The Aylmer Lake area contains six pegmatite series: GHIT, BOO-GA, SLOG, MACRO, AL, and NANNE (Fig. 3). All series contain primarily beryl-bearing pegmatites with minor columbite-tantalite. Apparent relics of spodumene crystals occur as woody-textured micaceous pseudomorphs and masses, although no indisputable evidence for the presence of spodumene can be presented. Montebrasite was found in one GHIT-series pegmatite and alluaudite is plentiful in the area. The Aylmer Lake area pegmatites are essentially all of the beryl-columbite subtype of Černý (1991a).

The Reid Lake area contains four pegmatite series: YES, OIG, FISHHEAD, and FINE, the last two of which are single dykes (Fig. 4). The SWEET pegmatite, which outcrops 12 km east of Reid Lake, will be discussed with other Reid Lake area dykes. Pegmatites are commonly beryl-bearing and the OIG series and SWEET pegmatite are rich in spodumene.

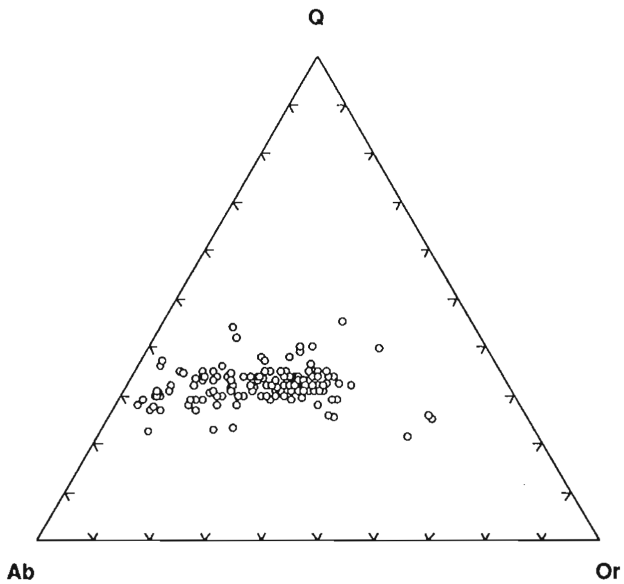


Figure 8. Mesonormative Ab-Or-Q variation of the fertile granites of the Aylmer Lake pegmatite field. Note the trend toward albite (i.e. enrichment in Na).

Phosphate minerals attain greatest abundance in pegmatites displaying diverse mineralogy and zonal character. Columbite-tantalite was only seen in the YES series. According to the classification of Černý (1991a), the Reid Lake area contains pegmatites of the beryl-columbite and beryl-columbite-phosphate subtypes (FINE, FISHHEAD, and YES) as well as those of the albite-spodumene type (OIG and SWEET).

The Kirk Lake area contains two pegmatite series: BORIS and BUGGER (Fig. 5). Rare-element mineralization of these pegmatites is the sparsest of the field, with triphylite-lithiophilite being the only rare-element mineral, which is present in the BUGGER series. That series, however, does contain a significant number of secondary phosphate minerals. In the nomenclature of Černý (1991a), the BORIS and BUGGER series belong mainly to the beryl-columbite subtype of rare-element pegmatites, although certain BUGGER dykes are part of the beryl-columbite-phosphate subtype.

The Nebbish Lake area contains six pegmatite series: SK, WILLI, BURBUR, NEBBISH, BIRD, and REDS (Fig. 6). The first two series are represented by single dykes. Members of the BIRD and REDS series represent the highest level of chemical fractionation in the field. These series, along with the NEBBISH series and the SK dyke, contain abundant spodumene. Blue tourmaline (indicolite) and niobian rutile are unique to the BIRD series. Montebrasite occurs in the REDS series and columbite-tantalite is plentiful in the WILLI dyke. Beryl is a common constituent of most of the series of this area. Using Černý's (1991a) classification, this area contains both beryl-columbite subtype pegmatites (BURBUR, WILLI) and those of the complex-spodumene type (BIRD, NEBBISH, SK, and REDS).

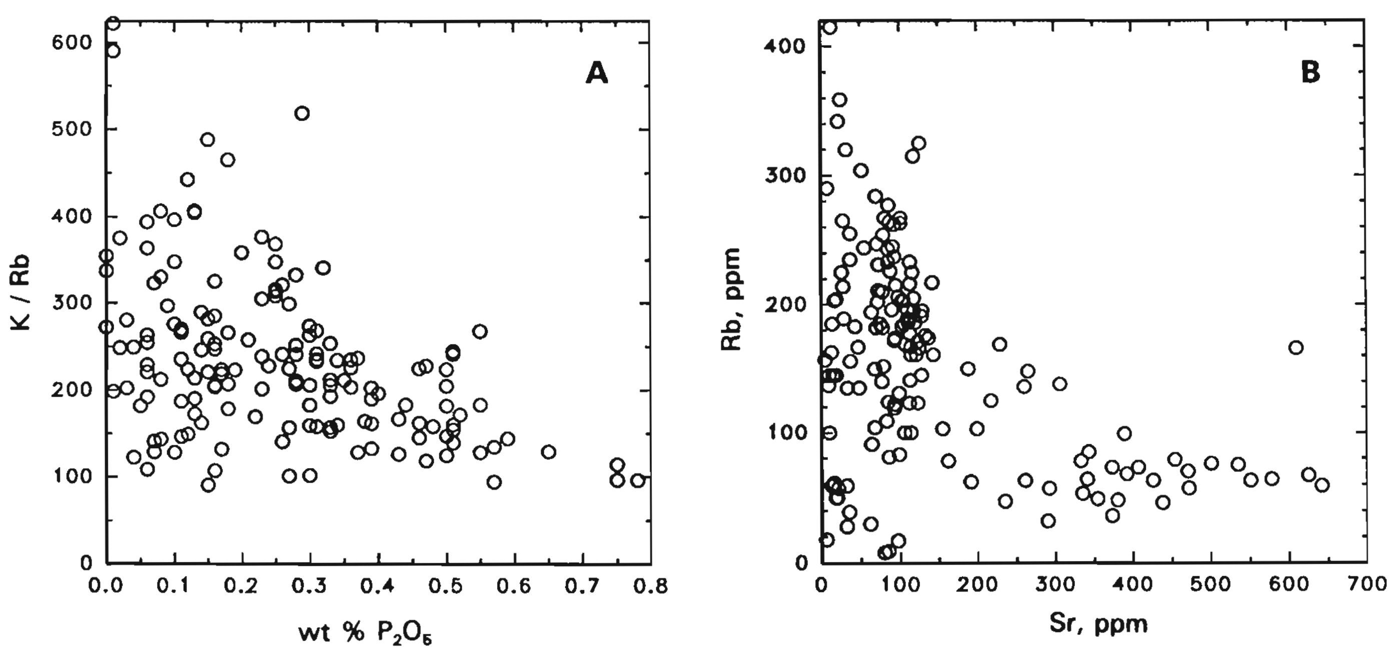


Figure 9. (A) Correlation of K/Rb and P_2O_5 in the granites of the Aylmer Lake pegmatite field; the highest P_2O_5 contents are typical of some of the most fractionated rocks. (B) Correlation of Rb and Sr in the granites of the Aylmer Lake pegmatite field. Note the distinctly antipathetic distribution between Rb and Sr.

Table 1. Average compositions of Aylmer Lake pegmatite field fertile granites

	biotite granites n=24	two-mica granites n=83	leucogranites n=40
SiO_2 (wt.%)	71.5	73.7	74.1
Al_2O_3(wt.%)	15.5	14.6	14.8
TiO_2 (wt.%)	0.78	0.14	0.04
$Fe_2O_3^*$(wt.%)	1.72	1.04	0.71
MnO (wt.%)	0.04	0.04	0.06
MgO (wt.%)	0.58	0.29	0.17
CaO (wt.%)	1.92	0.87	0.66
Na_2O (wt.%)	4.68	4.15	4.42
K_2O (wt.%)	2.89	3.99	3.93
P_2O_5 (wt.%)	0.15	0.27	0.32
total	**99.8**	**99.1**	**99.2**
Rb (ppm)	101	165	178
Sr (ppm)	313	122	79
Ba (ppm)	480	276	151
Zr (ppm)	90	58	29
A/CNK	1.08	1.15	1.16
K/Rb	237	201	183
Rb/Sr	0.32	1.35	2.25

**total Fe as Fe_2O_3*
A/CNK= molar $Al_2O_3/(Na_2O+K_2O+CaO)$

The main pegmatite group in the Thonokied Lake area (abbreviated THON in text that follows) is made up of more than 118 dykes (Fig. 7). Dykes of this group contain simple mineral assemblages (quartz+perthite+muscovite+schorl+garnet) and internal zonation. Most dykes in the THON group lack rare-element minerals, but may carry beryl and some contain lazulite-scorzalite. Located immediately west of the THON group are the MAMA PTARMIGAN, and BADGER series, which bear mineralogical similarities to the THON group pegmatites but are, in general, more primitive. According to Černý (1991a), these are dominantly beryl-columbite subtype pegmatites.

The Aylmer Lake field has only a few examples of regional zonation of a pegmatite series that are clearly supported by mineralogical and geochemical evidence. Regionally zoned pegmatite populations are most clearly displayed in the Reid and Nebbish Lake areas (Fig. 4, 6). This is in marked contrast to the well-developed zoning in many different parts of the Yellowknife pegmatite field (e.g., Meintzer, 1987), which is otherwise very similar to the Aylmer Lake field. Two explanations are favored for the absence of regional zonation of pegmatite groups in parts of the Aylmer Lake field: (1) erosion to a deeper crustal level has produced an area containing chemically primitive pegmatites of uniform mineralogy and geochemistry (e.g., the THON group, Fig. 7), and (2) a parent pluton with irregular (undulating) roof topography has yielded groups of chemically evolved pegmatites which are not accompanied by more chemically primitive pegmatites needed to define a pattern of regional zonation (e.g., the BIRD, NEBBISH, and REDS pegmatite series, Fig. 6).

Mineralogy and geochemistry

Because microcline-perthite serves as the most widespread, and most reliable, indicator of pegmatite fractionation, a total of 189 samples were partially analyzed for major and trace cations (e.g., Trueman and Černý, 1982; Černý, 1989, 1990). The fractionation trend in K-feldspar of the Aylmer Lake field is shown in Figure 10. The mean concentrations of alkalis in these K-feldspars are as follows: Li (mean = 32 ppm; range = <1 to 409 ppm), Rb (mean = 1119 ppm; range = 139 to 4192 ppm), Cs (mean = 87 ppm; range = 3 to 1900 ppm), Sr (mean = 68 ppm; range = <1 to 323 ppm), Ba (mean = 100 ppm; range = 5 to 2501 ppm); K/Rb ranges from 28 to

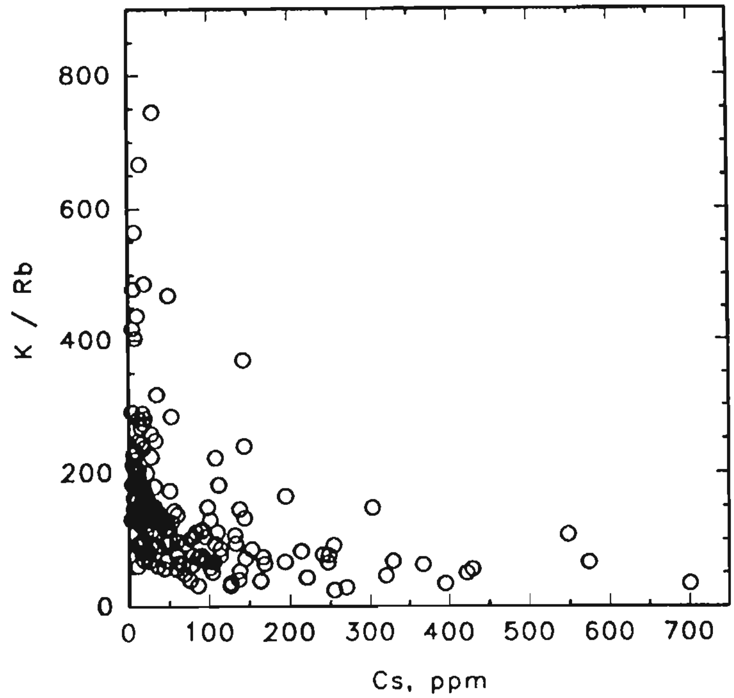


Figure 10. Correlation of K/Rb with Cs in blocky K-feldspar from pegmatites of the Aylmer Lake field. Note the prominent increase in Cs at the lowest levels of K/Rb.

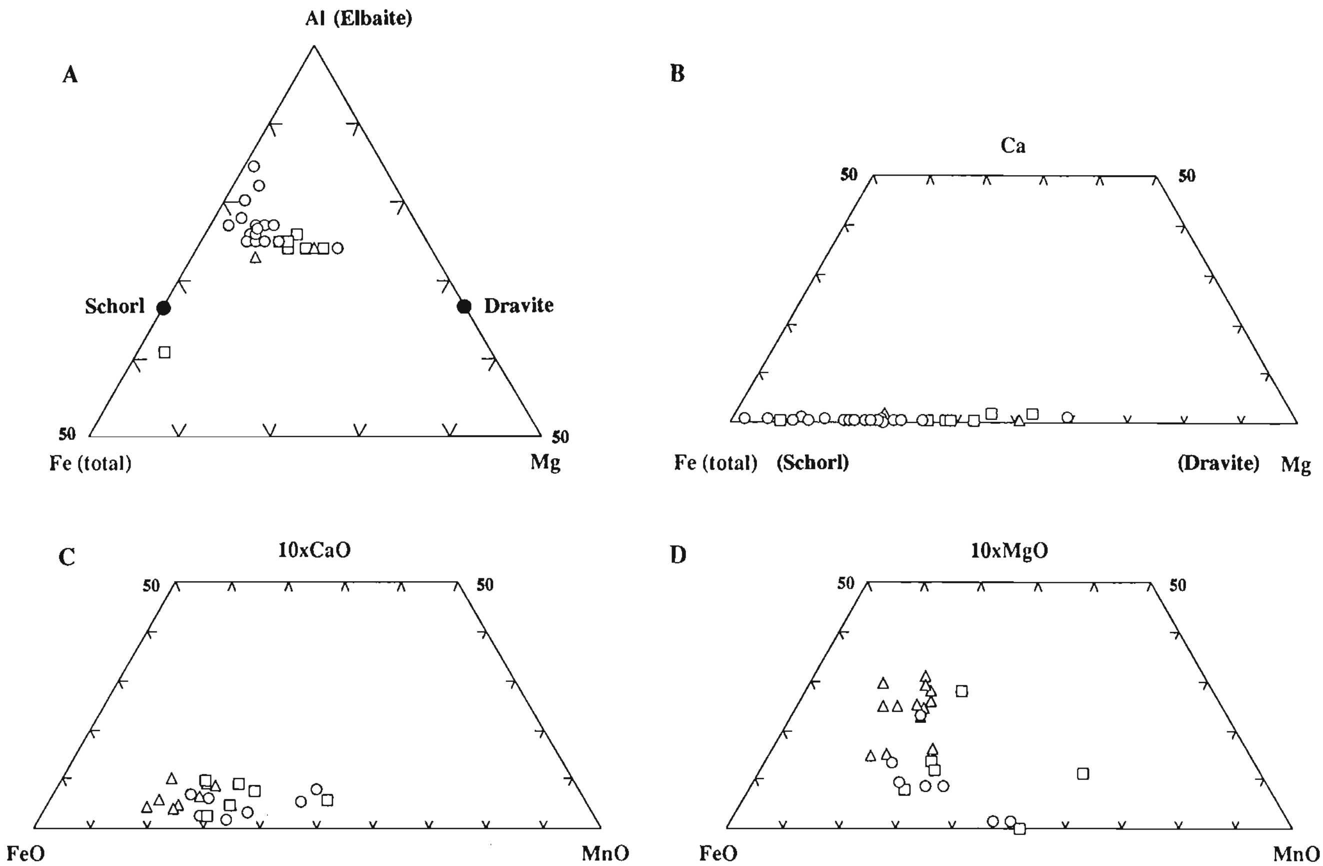


Figure 11. Tourmaline from the Aylmer Lake pegmatite field in the (A) Fe(total)-Mg-Al and (B) Fe(total)-Mg-Ca plots of Henry and Guidotti (1985; atomic ratios). On average, tourmaline from the fine grained leucogranites (squares) and from the potassic pegmatite facies of these granites (triangles) is Mg-enriched schorl and is more primative than the Al-enriched schorl from the pegmatites (circles), which trends toward elbaite. Garnet from the Aylmer Lake pegmatite field is shown in (C) FeO(for total Fe)-MnO-10xCaO and (D) FeO(for total Fe)-MnO-10xMgO plots (wt.% ratios). Garnet from the fine grained leucogranites (squares) and from the potassic pegmatite facies of these granites (triangles) has higher MgO contents than that from the pegmatites (open circles). The CaO content is generally low, and varies within about the same limits in all types.

745 (mean = 108). Anderson (1984) commented on the possible use of Pb as a geochemical indicator in pegmatites. The Pb contents of feldspars in the Aylmer Lake field tend to decrease slightly with increasing overall fractionation of the pegmatites (mean = 30 ppm; range = <1 to 89 ppm).

Trends in K/Rb versus Cs and K/Rb versus Li in 155 muscovite samples parallel the same trends revealed by K-feldspar. In addition, decreasing Fe and Mg accompany progressive fractionation: MgO (mean = 0.17 wt.%; range = <0.08 to 0.68 wt.%), ΣFe as Fe_2O_3 (mean = 0.92 wt.%; range = 1.74 to 0.33 wt.%).

Chemical fractionation of the K-feldspar and muscovite is accompanied by compositional changes in other pegmatite minerals, and closely reflects the general degree of mineralogical diversity of the individual pegmatite areas. The Nebbish Lake pegmatites are the most fractionated of the whole field, whereas the pegmatites of the Thonokied Lake and Kirk Lake areas are the most chemically primitive. The Aylmer Lake and Reid Lake areas show extensive internal diversity (spodumene-bearing pegmatites are the most evolved).

Spodumene shows only minor variations in Fe throughout most of the field (0.26 to 0.49 wt.% Fe_2O_3). No simple explanation is apparent for the distinctly elevated Fe_2O_3 in spodumene of the BIRD series (0.26 to 1.24 wt.%). The contents of Na_2O and K_2O are very low in carefully hand-picked fresh spodumene (0.05 to 0.27 and 0.01 to 0.24 wt.%, respectively).

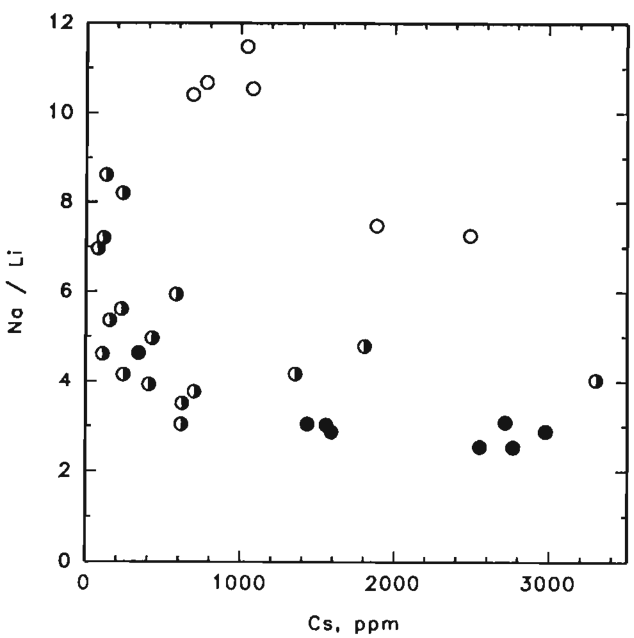


Figure 12. Correlation of Na/Li with Cs in beryl from central parts of the pegmatites in the Aylmer Lake field. The ratio Na/Li is lowest in samples from the spodumene-bearing pegmatite areas (half-filled circles) and particularly from spodumene-bearing series (solid dots); high Na/Li values are typical of samples from geochemically primitive populations represented by the THON group (open circles).

In the granites and pegmatitic leucogranites, tourmaline is considerably enriched in MgO (mean = 3.31 wt.%; range = 1.43 to 5.07 wt.%); however, in the pegmatites, particularly those containing spodumene, MgO-poor (mean = 1.57 wt.%; range = 0.10 to 6.03 wt.%), Li-Al-dominated compositions of elbaite in tourmaline are prevalent (Fig. 11A, B). The Mn contents of tourmalines examined is very low and Zn, Ca, and F concentrations are generally higher in tourmalines moderately enriched in Al.

Garnet is not widespread in pegmatites of the Aylmer Lake field; it is significantly more concentrated in the pegmatitic granites, especially in the potassic pegmatite. The garnet displays compositional features that typify much of the field's mineralogy (low Mn and dominance of low Mn/Fe). In most cases, pegmatitic garnet is richer in Mn than that of related granites, but this is not the case with garnet from pegmatites containing greater diversity of rare-element minerals, like those of the YES and BUGGER series. Average garnet compositions, computed from 1-5 point analyses per crystal by electron microprobe, are given for fine grained leucogranites, potassic pegmatites of these granites, and pegmatites (Fig. 11C, D). Fresh, euhedral garnet displays only minor chemical zonation, with MnO and FeO varying only 1 to 3 wt.% from core to rim. Many crystals have slightly Fe-enriched outer zones. The Mg/Ca generally exceeds one, but the sum of the pyrope and grossular components comprises less than 5 mol.% of any sample.

The morphological variation of beryl in the Aylmer Lake field is limited. Crystals are dominantly prismatic, although relatively "stumpy", short-prismatic beryl was noted in the MACRO series (Aylmer Lake area). Whereas most beryl is pale yellow to green, Cs-enriched beryl tends to be white to colorless. Beryl exhibiting strong enrichment in Li, Rb, and Cs is primarily found in the Nebbish Lake dykes and in those pegmatites containing spodumene. This beryl also is rich in sodium (twice the average content for beryl in the field), despite very low Na/Li. Figure 12 contrasts the geochemical signatures of beryls of different parageneses within the Aylmer Lake field.

Representative compositions of columbite-tantalite, tapiolite, and a single niobian rutile (Fig. 13, Table 2) reveal an extensive range in Nb/Ta, and more limited range in Fe/Mn, with Fe dominating. Back-scattered electron images of individual specimens show near-homogeneous to conspicuously zoned compositions. Oscillatory, irregular and complex crosscutting relationships between Ta- and Nb-enriched domains are all commonly observed in a single crystal.

The niobian rutile from BIRD-4 is an unique phase in the Aylmer Lake field. Whereas the BIRD series appears well-fractionated with respect to the rare-alkalis, it is poor in Ta and Nb relative to Ti and this may reflect the primary melt composition. Similarly, the REDS series lacks oxide minerals, suggesting a similar paucity of Ta and Nb.

Although largely decomposed into secondary phases (heterosite-purpurite, sicklerite-ferrisicklerite and alluaudite) triphylite-lithiophilite seems to be the most abundant phosphate mineral among Aylmer Lake field pegmatites.

Table 2. Chemical compositions of representative Nb, Ta oxide minerals from the Aylmer Lake pegmatite field.

	1	2	3	4	5	6
Ta_2O_5	15.31	34.95	48.08	60.90	75.31	6.13
Nb_2O_5	62.90	45.53	33.51	20.91	8.25	15.34
FeO*	16.32	13.16	13.03	7.93	14.06	7.69
MnO	3.13	4.79	3.37	7.55	0.24	0.09
WO_3	0.59	0.02	0.35	0.13	0.00	0.05
TiO_2	0.27	0.30	0.36	0.60	0.57	68.25
ZrO_2	0.00	0.00	0.00	0.78	0.00	0.00
SnO_2	0.04	0.11	0.03	0.25	0.32	2.69
UO_2	0.00	0.00	0.02	0.09	0.00	0.00
total	**98.56**	**98.86**	**98.75**	**99.14**	**98.75**	**100.24**

* *total Fe as FeO*
1= ferrocolumbite, WILLI pegmatite, Nebbish Lake area
2= ferrocolumbite, GHIT-7 pegmatite, Aylmer Lake area
3= ferrocolumbite, YES-1 pegmatite, Reid Lake area
4= ferrotantalite, WILLI pegmatite, Nebbish Lake area
5= ferrotapiolite, YES-1 pegmatite, Reid Lake area
6= niobian rutile, BIRD-4 pegmatite, Nebbish Lake area

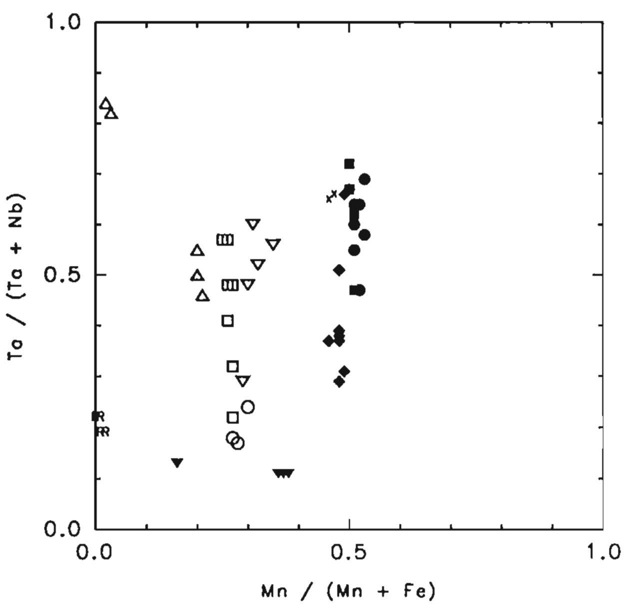


Figure 13. Compositions of the Nb-Ta oxide minerals from pegmatites of the Aylmer Lake field in the columbite quadrilateral (atomic ratios). R = niobian rutile from the BIRD-4 pegmatite. Columbite-tantalite locations: open circles - GHIT-2; open inverted triangles - GHIT-6; open squares - GHIT-7; solid dots - WILLI-2; solid inverted triangles - WILLI-5; solid diamonds - WILLI-6; solid squares - WILLI-7; X - MACRO-7; open triangles - YES-5. The two data points with the highest contents of Ta represent tapiolite.

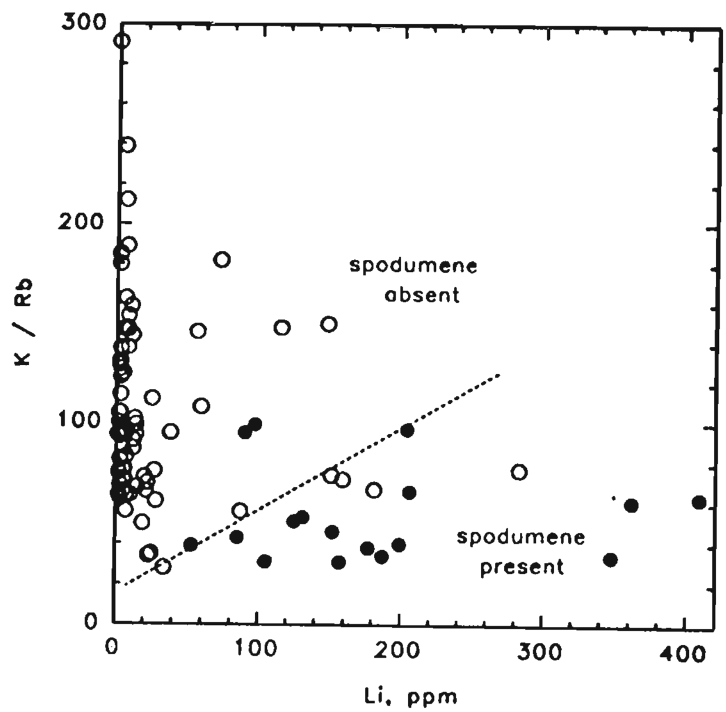


Figure 14. Correlation of K/Rb with Li in blocky K-feldspar from pegmatites of the Aylmer Lake field. Note the increase in Li in the feldspar from the spodumene-bearing pegmatites (solid dots) relative to beryl±columbite pegmatites (open circles).

Montebrasite contains ≤3 wt.% F. Lazulite-scorzalite ranges from Mg > Fe compositions of lazulite proper to intermediate compositions with Mg/Fe of ~1.0. Graftonite-beusite is relatively common, unlike its rare occurrences in most pegmatite populations elsewhere. Sarcopside is found only as lamellar intergrowths with other phosphates.

Exploration potential

The Aylmer Lake pegmatite field compares in many respects with the Yellowknife pegmatite field (Meintzer, 1987): regional rock units and metamorphic grade, the emplacement level, compositional range and internal zoning of the fertile granites, and the overall character of the pegmatite populations are very similar. However, distinct differences also exist. At Aylmer Lake: (1) many of the granite- pegmatite systems appear to be eroded to deeper, more primitive levels than in the Yellowknife field, (2) primary phosphate minerals are dispersed throughout all categories of pegmatites, and are not restricted to the beryl-columbite-phosphate subtype alone as at Yellowknife, (3) tourmaline is widespread, and not largely restricted to exomorphic assemblages, and (4) the whole parent granite-pegmatite population is distinctly poor in Nb and Ta.

Overall, the Aylmer Lake field has economic potential for Be and Li in spodumene-bearing pegmatites. The Reid Lake and particularly the Nebbish Lake areas have the best potential for economic mineralization in hidden pegmatites close to the parental pluton (Tomascak, 1991). As shown on Figure 14, rare alkali contents of K-feldspars (i.e., Rb and Li) can be used as an exploration tool for Li mineralization.

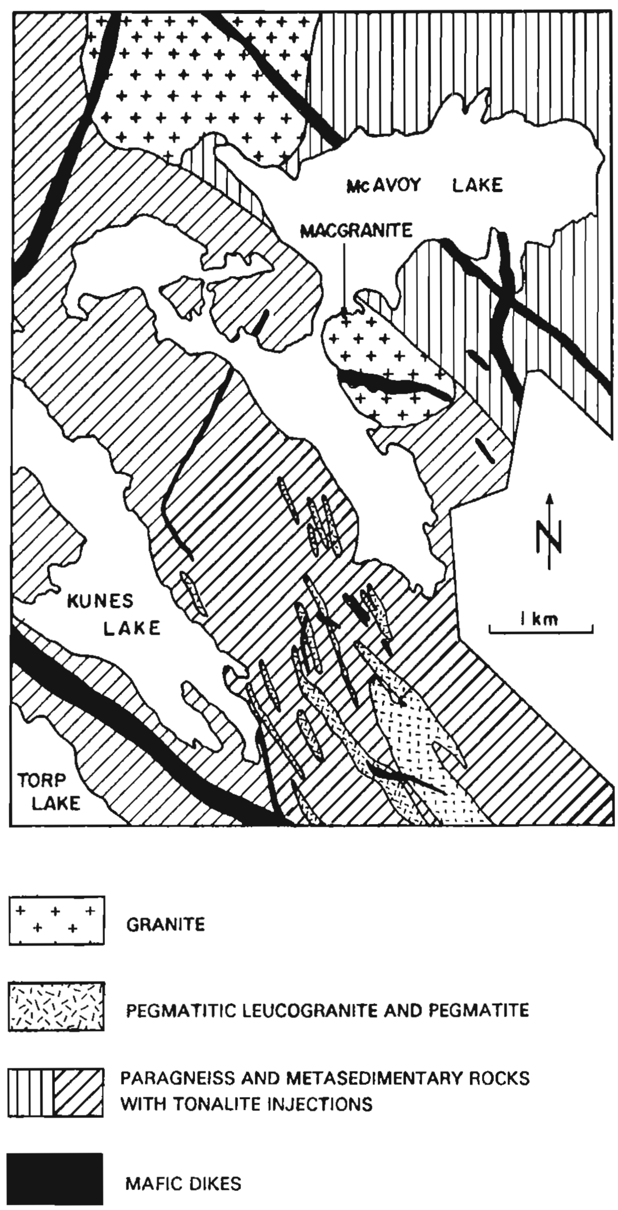


Figure 15. Schematic geology of the examined segment of the Torp Lake field, modified after Johnstone (1988).

Torp Lake pegmatite field, Bathurst Inlet

The Torp Lake pegmatite field is located in the northern Slave Province (Fig. 1). This 800 km^2 field comprises a series of granites, pegmatitic granites, and pegmatites that have perforated and permeated the Torp Lake greenstone belt and an adjacent gneiss belt.

The area examined around McAvoy Lake (Fig. 15) first attracted attention by the discovery of a spodumene-rich pegmatite in 1986 (S. Beaubien, INAC, pers. comm.). The northeastern part of this area is underlain by metaturbidites of the Yellowknife Supergroup, metamorphosed to a low-pressure, medium grade (cordierite-amphibolite facies with chiastolite; Johnstone, 1988). Toward the northeast, the metamorphic grade is greenschist facies. To the west and southwest, the Yellowknife Supergroup metasedimentary rocks grade into a gneiss belt, intruded by dykes of tonalite subparallel to bedding, and flanked farther to the west by extensive granodioritic to granitic intrusions. Dykes of Proterozoic diabase crosscut the Archean rock units in two orientations.

The fertile granites

Two types of granitic intrusions displaying different compositions, textures, and intrusive styles can be distinguished in the area. The first type occurs as small plugs of relatively homogeneous, massive, medium grained, two-mica leucogranite, not directly associated with pegmatite bodies (Macgranite plug, Fig. 15). The other type of granite appears in layered sheets of heterogeneous, very coarse grained, two-mica leucogranite that are largely pegmatitic with abundant graphic K-feldspar-quartz intergrowths, and reveal a gradual transition into internally zoned pegmatite veins (southeastern corner of Fig. 15).

Chemical composition of the poorly fractionated Macgranite plug is rather uniform (Table 3). The pegmatitic granites were not analyzed because of logistic difficulties (i.e., representative samples of these extremely coarse grained rocks were prohibitively large for the available means of transportation).

The pegmatite population

Pegmatites were examined in the area south of McAvoy Lake and east to southeast of Kunes Lake (Fig. 16). Field observations indicate a progressive increase in internal structural and mineralogical diversity in a northerly direction, from near-homogeneous and barren pegmatites through to dykes carrying beryl and phosphates to the aforementioned spodumene-bearing body. Some of the barren dykes attain considerable dimensions, but the beryl-phosphate pegmatites are rarely over 100 m in length and 10 m across.

The spodumene-rich dyke is traceable for 200 m, but discontinuous outcrops suggest that the dyke may extend for as much as 400 m along strike. It is concentrically zoned, with the outer zones best developed in the extremities of the body, which become very thin to absent along the flanks of the central part. The border zone is discontinuous, up to 5 cm wide, and consists of fine- to medium-grained quartz, muscovite, and albite (locally cleavelandite); the tonalitic country rock shows no tourmalinization. The wall zone contains medium grained K-feldspar and quartz, with minor cleavelandite, muscovite, and accessory garnet and schorl. The first intermediate zone is composed of medium grained quartz, muscovite, cleavelandite, and green elbaite, with minor altered phosphates. In contrast, the second intermediate zone lacks accessory minerals; it consists of medium grained quartz and cleavelandite with local saccharoidal albite. The third intermediate zone is characterized by minor albite, fine grained muscovite with accessory beryl, pink elbaite, and amblygonite-montebrasite, in addition to quartz dominating over K-feldspar. The core features quartz, K-feldspar, and columnar crystals of spodumene that attain 1.5 m in length (Fig. 17); cleavelandite and fine grained blue tourmaline are very minor constituents. Patches of pink to red lithium mica with saccharoidal albite and cleavelandite form a discontinuous unit along the contacts of the third intermediate zone with both the second intermediate zone and core. Whereas the bulk of the pegmatites in this area are beryl type (as defined by Černý, 1991a), the spodumene-bearing dyke belongs to the complex-spodumene type.

Table 3. Chemical compositions of representative samples from the Macgranite plug, Torp Lake pegmatite field.

	1	2	3	4
SiO_2 (wt.%)	72.28	72.14	71.95	71.67
Al_2O_3 (wt.%)	15.16	14.73	15.18	14.73
TiO_2 (wt.%)	0.26	0.24	0.24	0.29
$Fe_2O_3^*$ (wt.%)	1.65	1.62	1.62	1.72
MnO (wt.%)	0.02	0.02	0.02	0.02
MgO (wt.%)	0.55	0.51	0.57	0.60
CaO (wt.%)	0.52	0.75	0.58	0.62
Na_2O (wt.%)	3.55	3.49	3.61	3.22
K_2O (wt.%)	4.94	4.64	4.76	4.97
P_2O_5 (wt.%)	0.21	0.26	0.26	0.25
total	**99.14**	**98.40**	**98.79**	**98.09**
Rb (ppm)	310	268	288	303
Sr (ppm)	92	94	94	96
Ba (ppm)	392	413	429	391
Zr (ppm)	126	136	121	135
Zn (ppm)	67	62	62	66
A/CNK	1.25	1.21	1.25	1.25
K/Rb	132	144	137	136
Rb/Sr	3.37	2.85	3.06	3.16

**total Fe as Fe_2O_3*
A/CNK= molar $Al_2O_3/(Na_2O+K_2O+CaO)$
1, 2, 3, 4 are all medium grained two-mica granites

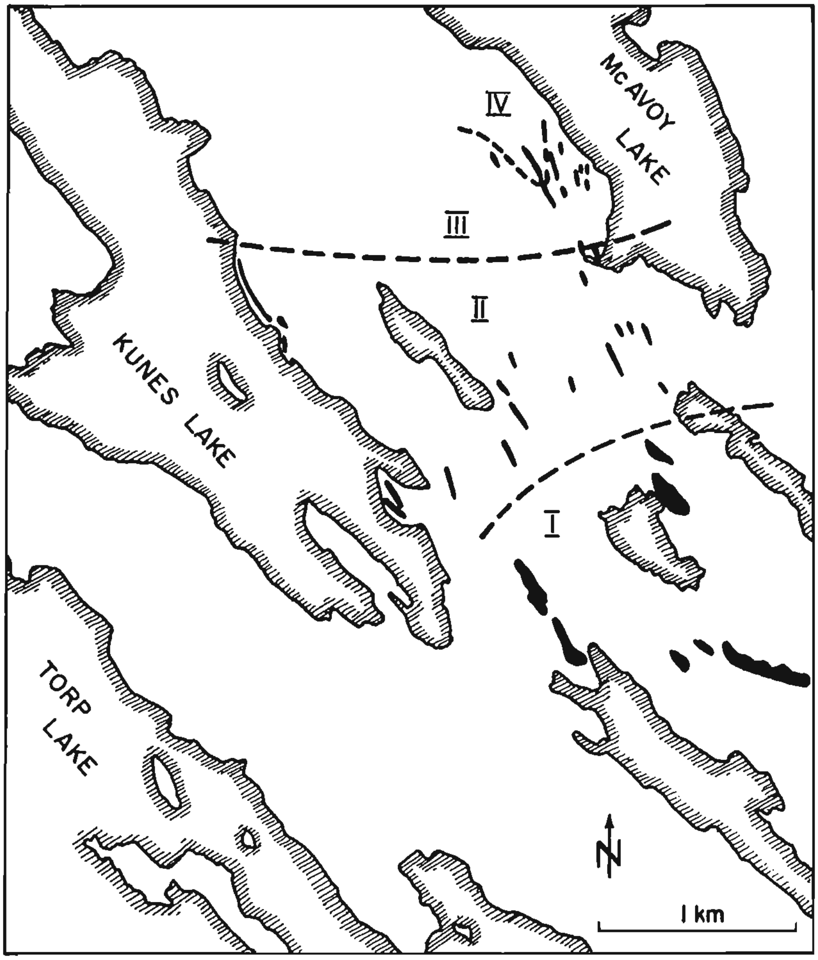


Figure 16. *Regional zoning of pegmatites between Kunes and McAvoy Lakes:*
I - barren pegmatites;
II - beryl-bearing pegmatites;
III - beryl+phosphate pegmatites;
IV - spodumene-bearing dyke.

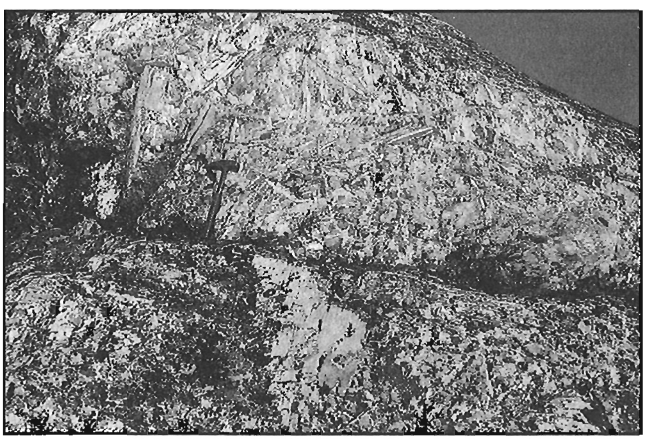


Figure 17. The spodumene-quartz core zone of the spodumene-bearing pegmatite at McAvoy Lake.

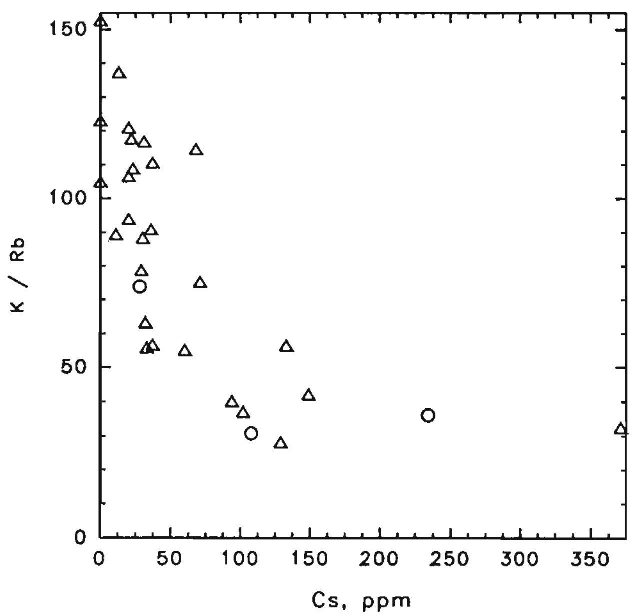


Figure 18. Correlation of K/Rb with Cs in blocky K-feldspar of the Torp Lake pegmatite field. Data from the spodumene-bearing pegmatite (circles) do not differ markedly from the other relatively fractionated pegmatites (triangles).

Mineralogy and geochemistry

In general, the geochemical evolution of individual minerals progresses in a northward direction, as indicated by textural and paragenetic diversification (Fig. 16). For example, blocky microcline-perthite shows a broad range of K/Rb, from 150 to 25. Contents of Cs also extend over a wide range, although most values are <100 ppm (Fig. 18). Muscovite displays a similar broad range of alkalis and their ratios, for example K/Rb = 72 to 21 and as much as 320 ppm Cs. A considerable concentration gap separates even the most fractionated samples of muscovite from those of Li-micas (Fig. 19A). The Li-micas are unique to the spodumene-bearing pegmatite, where they occur in three varieties: a brown fine grained mica that occurs locally in contact with semidigested xenoliths of the country rock; a pink mica that composes patches apparently replacing spodumene; and medium-flaked pods of red lepidolite. All three varieties are intergrown with minor muscovite. The dominant lepidolite phase of the brown mica is enriched in Fe (1.6 to 2.2 wt.% FeO) and contains ~4 wt.% Li_2O, 1.3 to 2.1 wt.% Rb_2O, and 0.1 to 1.0 wt.% Cs_2O. Lepidolite in the pink mica aggregates shows 0.5 to 0.8 wt.% Rb_2O and ~1.0 wt.% Cs_2O (rarely in microscopic patches up to 9.9 wt.%); this mica could not be analyzed for Li_2O because of its intimate intergrowth with spodumene. The red lepidolite has 4.9 wt.% Li_2O, 1.6 to 2.0 wt.% Rb_2O, and 0.2 to 0.9 wt.% Cs_2O. The associated muscovite is, as expected, relatively poor in Rb and Cs, and presumably in Li. Figure 19B shows the compositional characteristics of the muscovite-lepidolite aggregates, as established by electron microprobe analysis. Compositions representative of individual phases are listed in Table 4.

Tourmaline from the spodumene-bearing pegmatite is very low in Mg. It ranges from schorl to elbaite-dominant compositions (Fig. 20A, B). The pink tourmaline (rubellite), which was not chemically analyzed, would likely plot close to the elbaite apex of Figure 20A, as suggested by unit cell dimensions near those of end-member elbaite.

Accessory garnet, a primary phase of Zone III beryl-columbite-phosphate pegmatites #8 and #13, and garnet in digested xenoliths of the wall rock in the spodumene-bearing dyke were analyzed by electron microprobe. All crystals of garnet examined are virtually homogeneous, as most fall within a narrow range of ~30-40 mol.% spessartine (Fig. 20C, D). The garnet from the spodumene-bearing dyke, expected to be distinctly enriched in Mn if primary, is evidently contaminated by Fe, Mg, and Ca from the country rock. Hence, the lack of fractionation between garnet from the two pegmatite subtypes does not appear to be attributable to igneous fractionation.

Beryl was analyzed from three dykes in Zone II (Fig. 16), and from the spodumene-bearing pegmatite. The four samples from the latter show a greater spread of data than the others (Fig. 21). Overall, however, alkali fractionation in beryl is limited, particularly in terms of Cs_2O (maximum of 0.30 wt.% and 0.80 wt.% Li_2O).

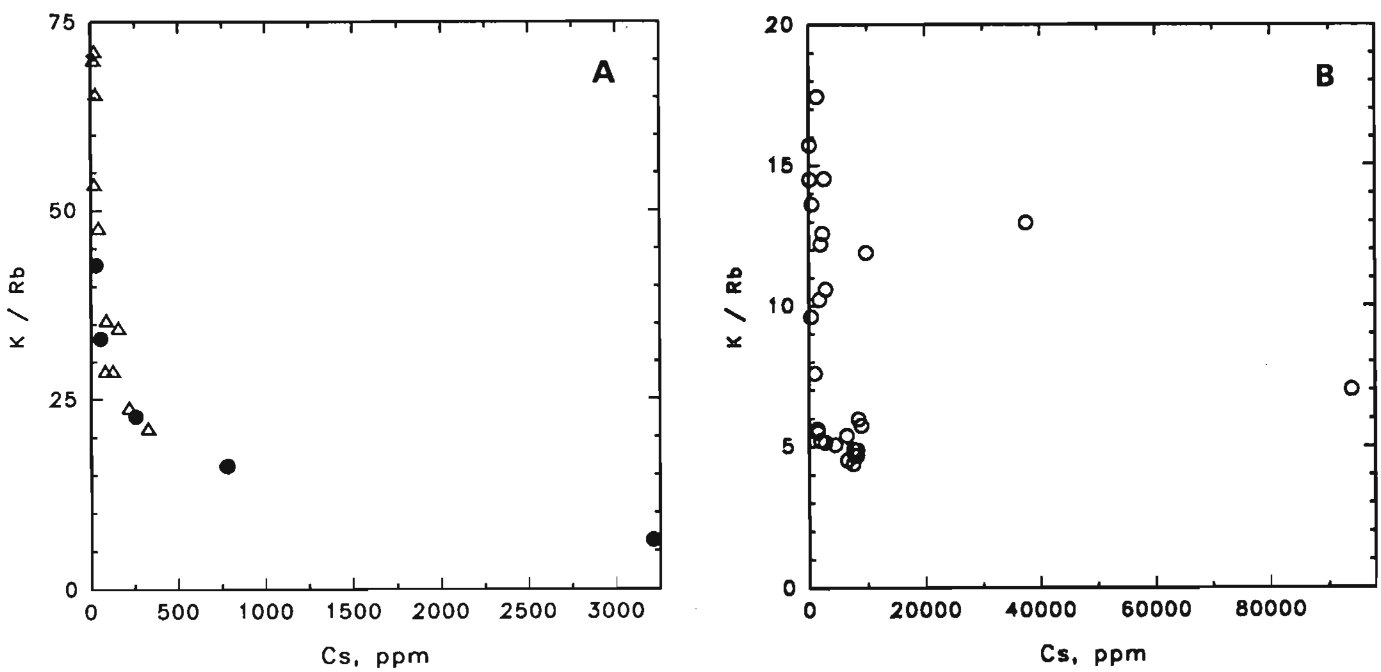


Figure 19. (A) Correlation of K/Rb with Cs in micas of the northwestern part of the Torp Lake pegmatite field, as analyzed by atomic absorption spectrometry. Solid dots mark compositions of micas from the spodumene-bearing dyke; triangles are muscovites from non-spodumene-bearing pegmatites. The extremely Cs-enriched point represents brownish, Fe-rich lepidolite. (B) Correlation of K/Rb with Cs in micas of the spodumene-bearing pegmatite at McAvoy Lake, as determined by electron microprobe. The extremely Cs-enriched data represent microscopic patches of lepidolite which are insignificant in volume relative to the bulk of the mineral.

Table 4. Chemical compositions of representative micas from the spodumene-bearing pegmatite at McAvoy Lake, Torp Lake pegmatite field.

	1	2	3	4	5	6	7	8	9	10
SiO_2	52.54	47.32	46.84	51.63	50.82	45.43	45.77	53.79	51.16	45.11
Al_2O_3	18.64	34.18	37.76	22.76	25.61	37.69	38.29	23.62	27.92	37.62
Fe_2O_3	0.17	0.05	0.09	2.15	1.69	0.24	0.16	0.00	0.00	0.00
MnO	0.25	0.08	0.03	0.59	0.43	0.02	0.05	0.21	0.22	0.04
MgO	1.57	0.01	0.00	0.07	0.08	0.02	0.00	0.00	0.00	0.00
ZnO	0.14	0.06	0.00	0.11	0.12	0.08	0.03	0.09	0.00	0.02
BaO	0.06	0.02	0.02	0.05	0.02	0.00	0.03	0.00	0.02	0.03
SrO	0.02	0.00	0.01	0.03	0.02	0.03	0.00	0.01	0.02	0.00
Na_2O	0.00	0.34	0.49	0.12	0.19	0.52	0.60	0.14	0.26	0.60
K_2O	4.48	10.13	10.47	10.25	10.75	10.39	9.89	10.13	9.81	9.94
Rb_2O	0.58	0.77	0.78	2.06	1.28	0.69	0.62	1.97	1.71	0.94
Cs_2O	9.97	1.05	0.22	0.70	0.11	0.06	0.02	0.87	0.21	0.04
F	4.53	2.25	0.25	7.88	6.39	0.51	0.40	8.89	6.11	0.52

total Fe as Fe_2O_3
1= cesian lepidolite intergrown with spodumene (~4.0 wt.% Li_2O)
2= lithian muscovite intergrown with spodumene (~4.0 wt.% Li_2O)
3= muscovite intergrown with spodumene (~4.0 wt.% Li_2O)
4,5= ferroan lepidolite
6,7= muscovite intergrown with 4 and 5
8,9= medium-flaky red lepidolite (~4.9 wt.% Li_2O)
10= muscovite intergrown with 8 and 9 (~4.9 wt.% Li_2O)
All compositions show TiO_2, CaO, and $P_2O_5 \leq$ 0.01 wt.% and $Sc_2O_3 \leq$ 0.02 wt.%.

Phosphate minerals include amblygonite-montebrasite, triphylite-lithiophilite and lazulite-scorzalite, and several unidentified secondary phosphates.

Exploration potential

The Torp Lake field is complex in distribution of potential parental granites and their pegmatitic progeny, and has only been examined over a small part of its total extent. The genetic relationships between massive intrusions of two-mica granites and the pervasively emplaced pegmatite dykes should be examined in the whole field, which may establish patterns of regional zoning of pegmatite populations. It is encouraging that some of the beryl-columbite-phosphate pegmatites attain a degree of fractionation in K-feldspar, muscovite, and beryl similar to that in the spodumene-bearing dyke. Pegmatites with substantial Be and Li may be expected in this field, but prospects for Nb-Ta and Cs are not encouraging on the basis of available data.

RAE PROVINCE

Chantrey Inlet pegmatite field

This pegmatite field is located along the eastern shore of Chantrey Inlet in the central part of the Rae Province (Fig. 1, 22). The area is underlain by a juvenile Archean metadiorite basement (T. Frisch, GSC, pers. comm., 1989), which hosts three metasedimentary belts of presumed Aphebian age: Chantrey belt in the south and Barclay plus Hay belts to the north (Fig. 22). The Chantrey belt is best exposed, and has been mapped in detail; the Barclay belt is poorly exposed, and the Hay belt is known only from limited shoreline outcrop. The Chantrey and Barclay belts were metamorphosed under low-pressure medium grade conditions that resulted in the appearance of andalusite, staurolite, and grunerite. The original synclinal form of these belts has been extremely disturbed by faulting, including local basement overthrusts (Frisch et al., 1985; Frisch, 1989).

Frisch et al. (1985) reported widespread granitic pegmatites throughout the Chantrey belt, with a muscovite K-Ar age of 1.68 Ga. A. Beaulieu (pers. comm., 1988) reported crystals of green beryl from pegmatites in the Barclay belt and outcrops of pegmatitic leucogranite from the Hay belt. This study concentrated on the pegmatites near the shore of the Barclay belt, as the lichen growth farther inland effectively obscures textural and compositional details.

Near the shoreline of Chantrey Inlet, the Barclay metasedimentary belt consists of dominantly subvertically-dipping, northeastward-striking metavolcanic rocks, metapelites (with andalusite and cordierite), chlorite schists grading into garnet-rich silicate ironstones, with subordinate quartz-eye schist, amphibolite, magnetite-bearing iron-formation, marble, quartzite, and metaconglomerate.

Fertile granites

Two granitic intrusions are observed in the Barclay belt (Fig. 23): the Orange granite and the Southeastern granite. The Orange granite in the north is a medium grained leucogranite with abundant patches of pegmatitic texture, in places cut by fracture-filling pegmatite dykes. Its contacts are covered by overburden, except at the southeastern margin which seems to be faulted against mica schists (or possibly mylonitized metasedimentary rocks). No rare-element minerals were observed in this intrusion.

The Southeastern granite is largely composed of pegmatitic leucogranite typical of fertile intrusions that have generated rare-element pegmatites (cf. Černý and Meintzer, 1988; Černý, 1991b). Layers of medium grained leucogranite and sodic aplite are rare. Pods of potassic pegmatite containing

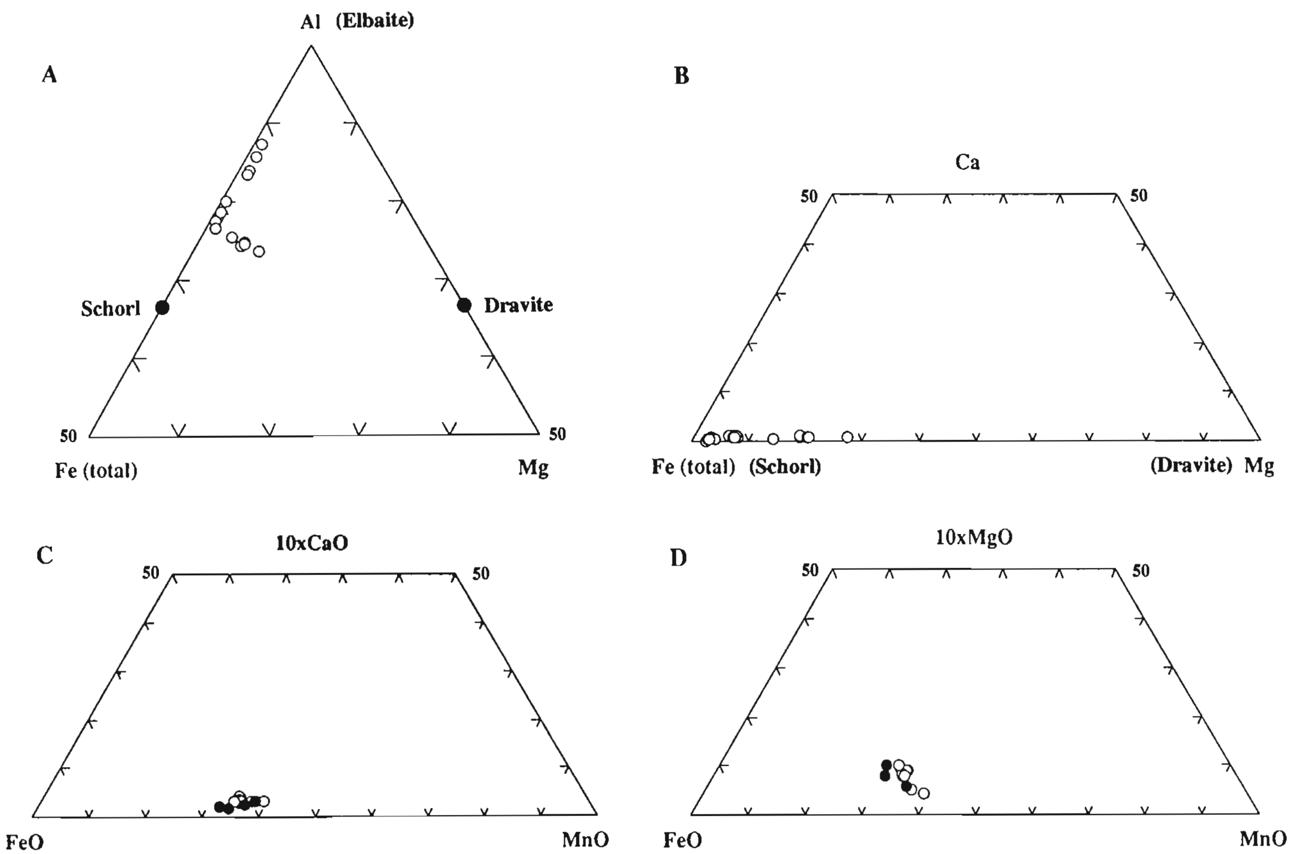


Figure 20. Tourmaline from pegmatites of the northwestern part of the Torp Lake pegmatite field in the (A) Fe(total)-Mg-Al and (B) Fe(total)-Mg-Ca diagrams of Henry and Guidotti (1985; atomic ratios). Note the low content of Mg in schorl, and the well-expressed trend to about 50% elbaite content. Garnet from pegmatites #8 and #13 (beryl-columbite-phosphate subtype; open circles) and from the spodumene-bearing pegmatite (solid dots) at McAvoy Lake in the (C) FeO(for total Fe)-MnO-10xCaO and (D) FeO(for total Fe)-MnO-10xMgO plots (wt.% ratios). Note the tight clustering of garnet data from the less evolved dykes between ~30 and ~40% of the spessartine component; garnet from the spodumene-bearing dyke, generated by digestion of xenoliths of the country rocks, shows a similar range of spessartine content combined with elevated contents of CaO and particularly MgO.

garnet, intergrowths of garnet and quartz, and local beryl crystals (up to 3 by 15 cm) are found primarily on Beryl Island and the peninsula south of Camp Alex (Fig. 23).

Exposures of the two major intrusions of the Southeastern granite (Fig. 23) show only very limited contacts with host-rocks, but dykes of this granite to the southwest crosscut regional foliation, especially in the vicinity of Camp Alex and on the nearby islands. Pristine, undeformed igneous texture is typical of these bodies (Fig. 24); however, an early generation of fine grained leucogranite is present as extensively mylonitized, sill-like injections that parallel the foliation of the host rocks (Fig. 25).

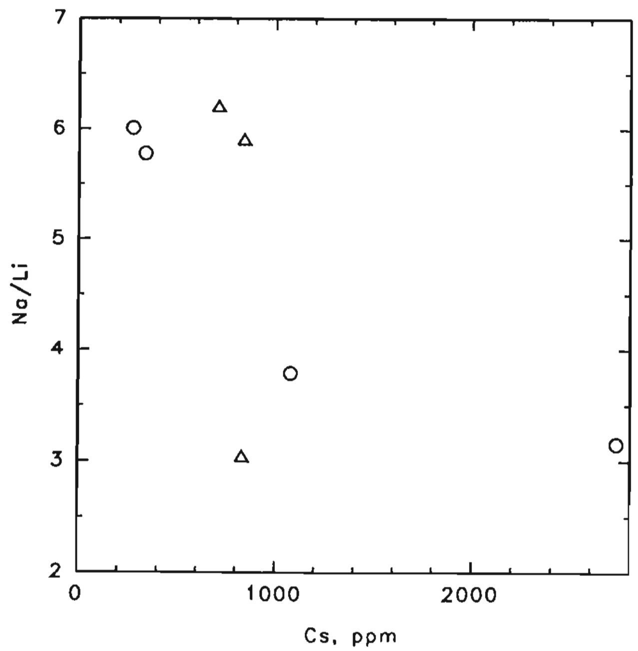


Figure 21. Correlation of Na/Li with Cs in beryl from the northwestern part of the Torp Lake pegmatite field. Circles = spodumene-bearing pegmatite; triangles = Zone II pegmatites.

Table 5 presents the chemical composition of three granite types. These rocks are silicic, slightly peraluminous, with low Ca, Rb, Sr, Mg, and Fe. Despite the advanced textural evolution and local showings of beryl, the geochemical signature of the granites seems to be rather primitive (e.g., low Rb contents).

The pegmatite population

Pegmatites are found in three areas: immediately northwest of Camp Alex, approximately halfway between Camp Alex and Columbite Bay, and in a narrow series trending northeast from Columbite Bay (Fig. 23). Subvertical pegmatites adjacent to Camp Alex are relatively simple, largely unzoned, and in part transitional from the pegmatitic leucogranite of the Southeastern intrusion. Garnet and beryl are the only known accessory minerals. Muscovite is subordinate, and medium grained albite is locally abundant within the central parts of individual dykes, which commonly carry pods of quartz.

Pegmatites, sparsely distributed between Camp Alex and Columbite Bay, contain cleavelandite and scant beryl in one dyke. The northeastern pair of these pegmatites resembles those in the northeastern extremity of the Columbite Bay area, in terms of textures and rock-forming minerals.

The largest pegmatite series extends northeast of Columbite Bay and is the most enriched in rare-element minerals. The pegmatites are subvertical, and are essentially parallel to the foliation of the host schists (Fig. 26); discordance could be established only locally. Internal structure within this group of pegmatites ranges from homogeneous through to local development of blocky pods in the interior, to distinct internal zonation. Exomorphic tourmalinization is rare.

Mineralogy and geochemistry

Muscovite forms as many as three generations in some pegmatites, but it is generally scarce or entirely absent. Potassium feldspar is ubiquitous in the form of microcline-perthite. Samples of blocky K-feldspar from cores of pegmatite pods and dykes show poor to moderate degrees of fractionation of rare alkali elements (i.e., Rb and Cs)(Fig. 27).

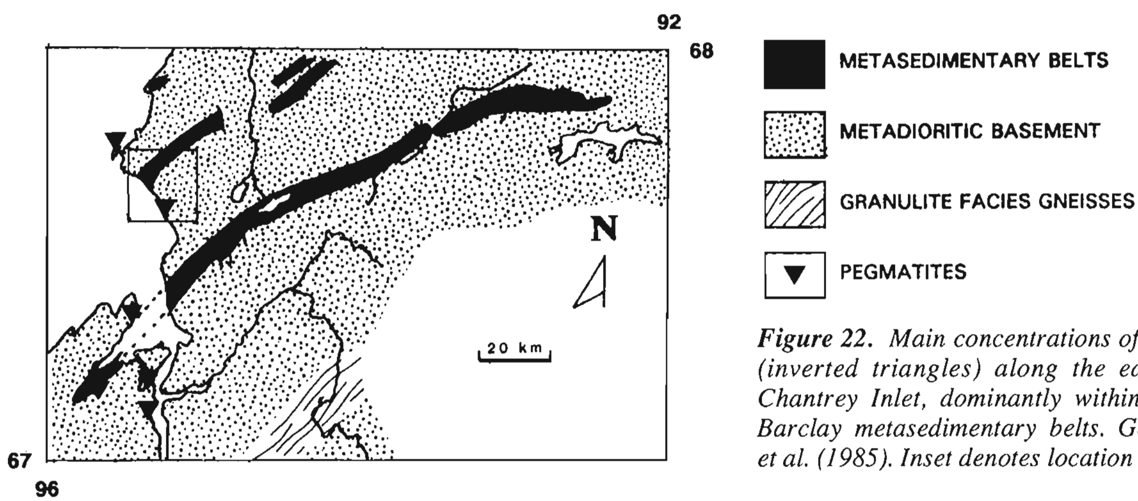


Figure 22. Main concentrations of granitic pegmatites (inverted triangles) along the eastern shoreline of Chantrey Inlet, dominantly within the Chantrey and Barclay metasedimentary belts. Geology after Frisch et al. (1985). Inset denotes location of Figure 23.

Tourmaline (schorl) is locally present in exocontacts of the pegmatitic leucogranites and pegmatite dykes. Within the pegmatites, it is not abundant except in the Columbite Bay series. Composition of the tourmaline is relatively primitive, considerably enriched in Mg and poor in Al (Fig. 28A, B).

Garnet is a widespread accessory. Its composition corresponds to almandine with ~8 to ~38 mol.% spessartine component. Distinct but generally low CaO and MgO are typical for most garnet samples (Fig. 28C, D).

Beryl is widespread, particularly in the Columbite Bay series, but only a few samples of greenish to yellow beryl were chemically analyzed. This beryl is chemically primitive with maximum alkali contents of 0.98 wt.% Na_2O, 900 ppm Li, and 1200 ppm Cs.

Columbite-tantalite was identified in a single pegmatite at the head of Columbite Bay, where its black subhedral crystals attain 8 cm in maximum dimension. Four mineral aggregates were analyzed by electron microprobe (Table 6). Three are ferrocolumbite and the fourth consists of ferrotantalite and tapiolite (Fig. 29).

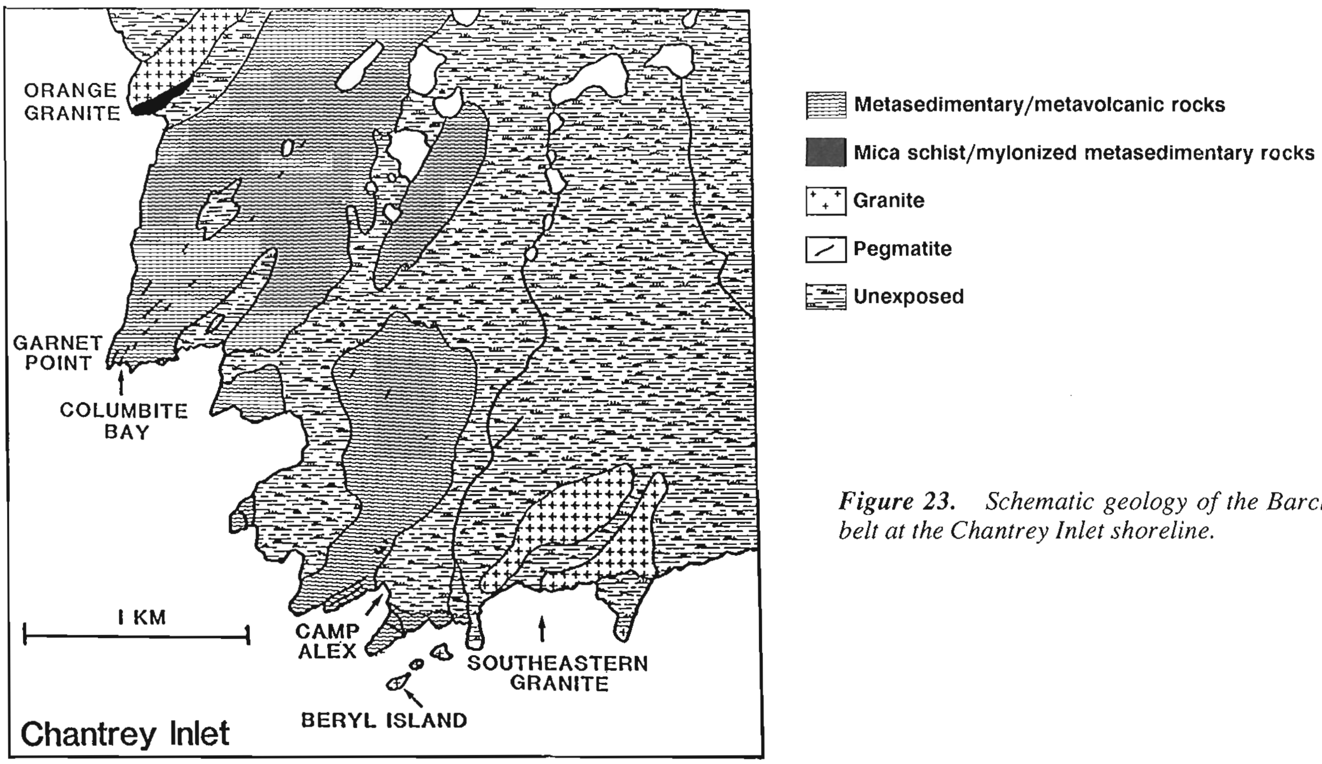


Figure 23. Schematic geology of the Barclay belt at the Chantrey Inlet shoreline.

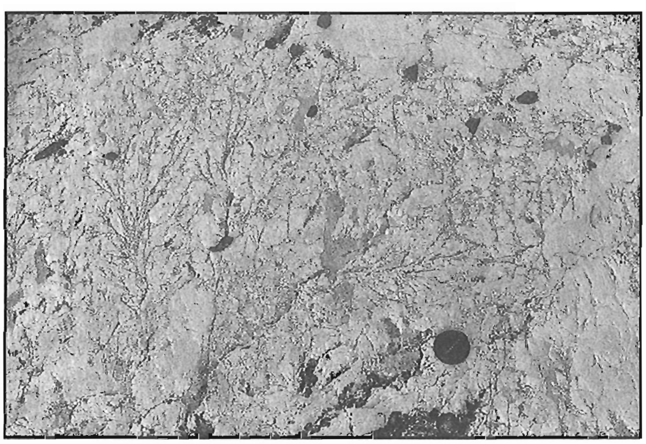


Figure 24. Pegmatitic leucogranite, in part graphic, with typical crowfoot patterns of branching mica aggregates; Camp Alex.

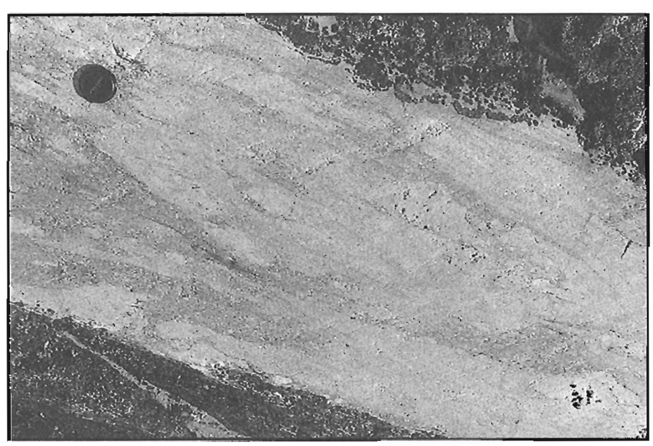


Figure 25. Sheared pegmatitic leucogranite at Camp Alex.

Besides the above minerals, unidentified rusty-brown grains of a metamict mineral, possibly zircon, were found associated with the Nb,Ta oxide minerals at Columbite Bay. Weathered, in part oxidized, triphylite (in crystals up to 5 cm in size) and its alteration products were found in a pegmatite dyke immediately east of Columbite Bay, associated with beryl and apatite.

According to Černý's (1991a) classification, the pegmatite population of the Barclay belt belongs to the beryl type of rare-element pegmatites, which locally advances into more evolved beryl-columbite and beryl-columbite-phosphate subtypes. The overall level of fractionation in the granite-pegmatite system is rather low.

Exploration potential

An extensive pegmatite-generating magmatic event in the Chantrey Inlet field is indicated by the abundance of leucogranite and pegmatitic granite intrusions from the Barclay belt southward, and pegmatite dykes reported in large numbers. The occurrences of abundant beryl, local concentrations of Nb,Ta oxide minerals, and the Li, Fe, Mn phosphate (triphylite) indicate advanced fractionation in some parts of the field, trending toward enrichment in Li that suggests the presence of complex pegmatites. Although these data demonstrate that rare-element mineralization in pegmatites can easily be overlooked during regional mapping surveys, the generally low levels of fractionation in the examined granites and pegmatites imply a low mineral exploration potential.

Table 5. Chemical compositions of representative samples of granites from the Chantrey Inlet pegmatite field.

	1	2	3
SiO_2 (wt.%)	75.30	73.63	76.52
Al_2O_3 (wt.%)	13.19	14.76	12.68
TiO_2 (wt.%)	0.01	0.01	0.07
$Fe_2O_3^*$ (wt.%)	0.48	0.59	0.88
MnO (wt.%)	0.03	0.02	0.05
MgO (wt.%)	0.01	0.01	0.01
CaO (wt.%)	0.54	0.86	0.52
Na_2O (wt.%)	3.84	4.25	3.77
K_2O (wt.%)	5.32	3.75	4.90
P_2O_5 (wt.%)	0.10	0.17	0.01
total	**98.82**	**98.05**	**99.41**
Rb (ppm)	101	165	178
Sr (ppm)	313	122	79
Ba (ppm)	480	276	151
Zr (ppm)	90	58	29
A/CNK	1.01	1.17	1.02
K/Rb	437	189	228
Rb/Sr	0.32	1.35	2.25

total Fe as Fe_2O_3
A/CNK= molar $Al_2O_3/(Na_2O+K_2O+CaO)$
1= Southeastern granite, sheared pegmatitic leucogranite
2= Southeastern granite, coarse grained pink leucogranite
3= Orange granite, medium grained leucogranite

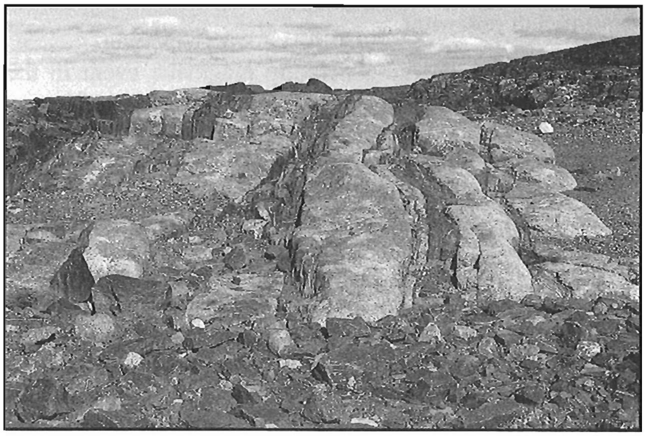


***Figure 26.** A swarm of beryl-bearing pegmatites, subparallel to the subvertical foliation of host metasedimentary rocks northeast of Columbite Bay.*

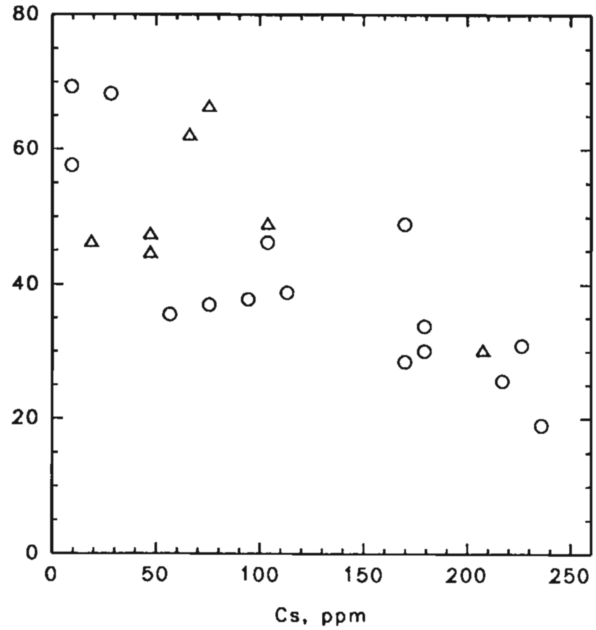


***Figure 27.** Correlation of K/Rb with Cs in blocky K-feldspar from potassic pegmatite pods in pegmatitic leucogranites (triangles) and pegmatites (circles) of the near-shore Chantrey Inlet-Barclay belt.*

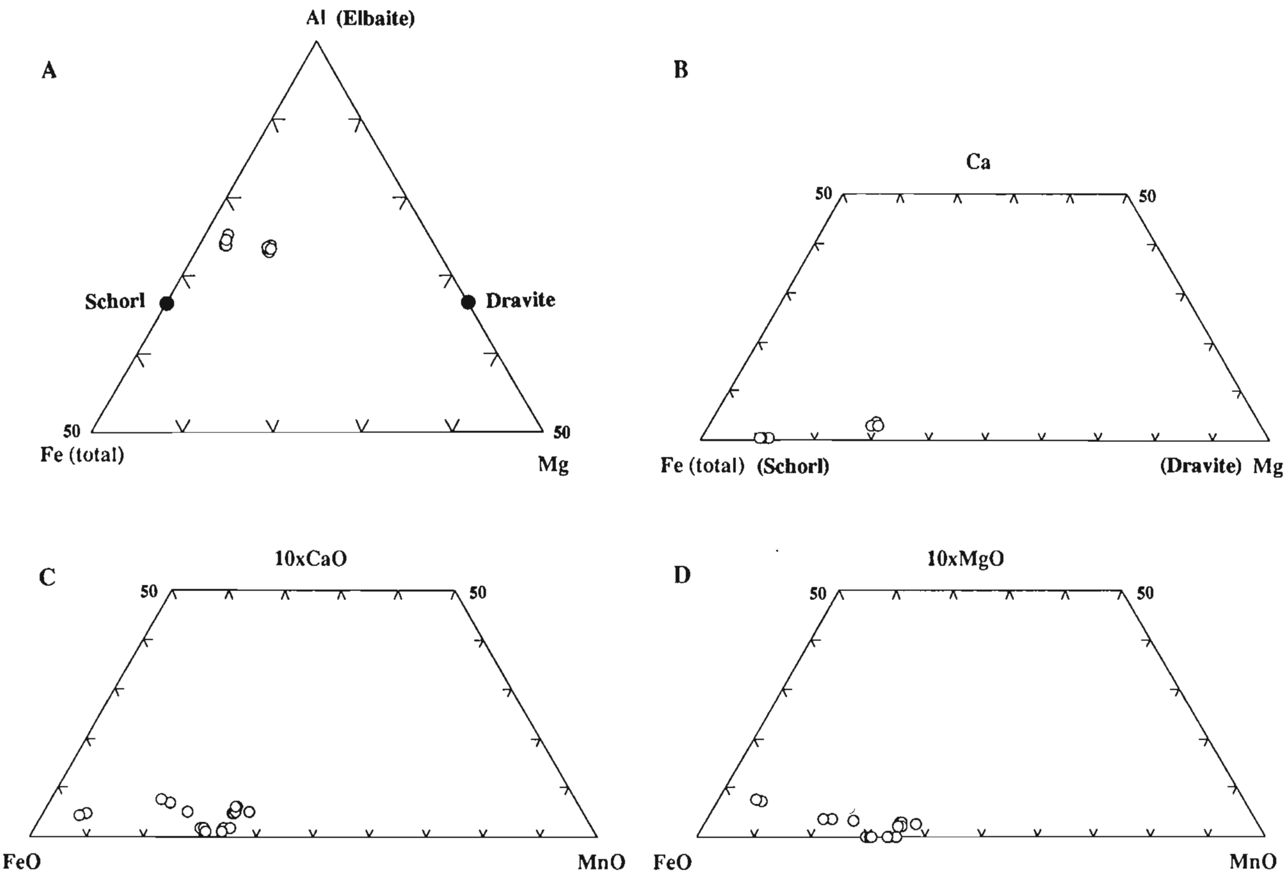


***Figure 28.** Tourmaline from the pegmatites of the near-shore Barclay belt in the (A) Fe(total)-Mg-Al and (B) Fe(total)-Mg-Ca plots of Henry and Guidotti (1985; atomic ratios). Note the prominent enrichment in Mg, but generally negligible contents of Ca. Composition of garnet from the pegmatitic leucogranites and pegmatites of the near-shore Barclay belt, in the (C) FeO(for total Fe)-MnO-10xCaO and (D) FeO(for total Fe)-MnO-10xMgO plots (wt.% ratios). Note the restriction of the spessartine component in garnet <40% and the generally very low MgO and CaO contents.*

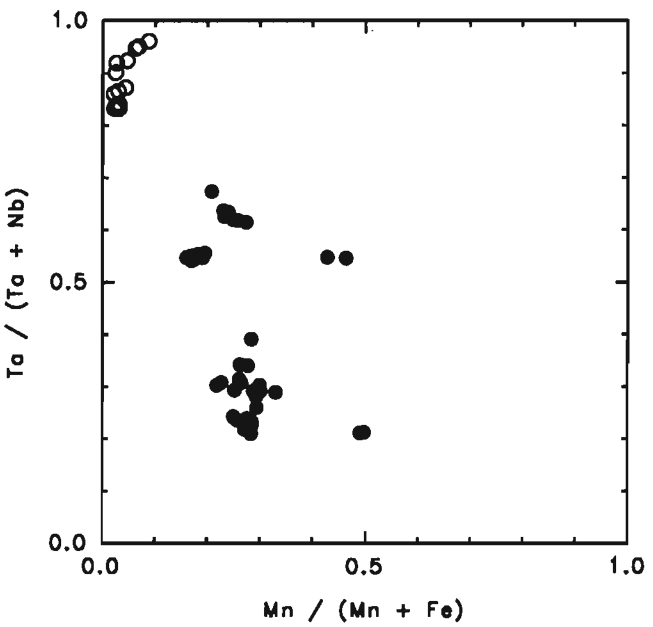


Figure 29. Compositions of tapiolite (open circles) and columbite-tantalite (solid dots) from the GP-1 pegmatite at Columbite Bay, Barclay belt, in the columbite quadrilateral (atomic ratios).

Foxe pegmatite field, Baffin Island

This field, in the northeastern segment of the Foxe fold belt of the eastern Rae Province, extends from the heads of the Itirbilung and McBeth fiords westward, to the southeastern tip of the Barnes Icefield (Fig. 1, 30). The field is hosted by Early Proterozoic metasedimentary rocks in the northern margin of the Piling Group, which overlies Archean gneissic basement that is characterized by gneiss domes along the pegmatite field. The Piling Group rocks underwent multiple folding events, some episodes of which accompanied low-pressure, high-temperature metamorphism and also involved the Archean basement (Jackson and Morgan, 1978; Tippet and Morgan, 1981; Grocott, 1989). The pegmatite field is confined to metasedimentary rocks of amphibolite facies metamorphism (sillimanite-almandine-muscovite subfacies), which surround a greenschist facies core of the fold belt. Metamorphic grades advance into granulite facies along the belt margins which are perforated by charnockites in the south (Fig. 30).

Fertile granites

The only granitic intrusions within this pegmatite field are sheets, dykes, and large pods or lenses (<1000 by 500 m) of two-mica, garnet-bearing granite, with local development

Table 6. Chemical compositions of representative Nb, Ta oxide minerals from the GP-1 pegmatite, Chantrey Inlet pegmatite field

	1	2	3	4	5	6
Ta_2O_5	24.45	33.08	55.34	62.66	75.80	83.23
Nb_2O_5	55.35	47.94	28.14	21.72	8.94	2.76
FeO^*	13.60	13.64	13.62	11.97	14.10	12.99
MnO	5.31	4.53	2.75	3.73	0.35	0.86
WO_3	0.41	0.11	0.18	0.00	0.00	0.05
Bi_2O_3	0.02	0.00	0.00	0.00	0.01	0.00
Y_2O_3	0.04	0.04	0.02	0.00	0.00	0.00
Sb_2O_3	0.02	0.00	0.01	0.00	0.00	0.00
TiO_2	0.00	0.00	0.05	0.04	0.22	0.00
SnO_2	0.06	0.00	0.00	0.00	0.07	0.05
UO_2	0.02	0.10	0.00	0.00	0.03	0.00
MgO	0.01	0.01	0.09	0.01	0.00	0.00
CaO	0.03	0.02	0.01	0.02	0.02	0.01
total	**99.32**	**99.47**	**100.21**	**100.15**	**99.54**	**99.95**

* *total Fe as FeO*
1,2= ferrocolumbite
3,4= ferrotantalite
5,6= ferrotapiolite

of pegmatitic leucogranite, west of Iturbilung fiord (P.C. LeCouteur, pers. comm., 1982). The granite bodies are particularly abundant along the contacts of the gneissic basement with the metasedimentary rocks. The granites crosscut the basement contacts, both of which are in turn crosscut by pegmatites. However, the granite-pegmatite assemblage is locally confined to the gneiss, leaving the metasedimentary cover intact.

Although no geochemical data are available for the granites, they seem to be suitable candidates for fertile intrusions generating rare-element pegmatites. Their biotite-muscovite-garnet mineralogy attests to a distinctly peraluminous composition, and the presence of pegmatitic leucogranite indicates differentiation into pegmatitic rocks.

The pegmatite population

The pegmatites that carry tourmaline and beryl occur west of Itirbilung fiord, and bodies with garnet, hornblende, tourmaline, and beryl are found west of McBeth fiord (Kranck 1951, 1955; P.C. LeCouteur, pers. comm., 1982). Biotite and muscovite are widespread. Individual dykes and lenses of pegmatites are up to 50 m long and a few metres across, but they are locally concentrated in large numbers.

The PLEX pegmatite

The only pegmatite examined in appreciable detail is located 2.5 km south of the southern shore of the proglacial Generator Lake, at the southeastern termination of the Barnes ice sheet (Fig. 30). The PLEX pegmatite was first described by Kranck (1951, 1955) who recognized the main rock-forming and accessory minerals. Later documentation was by Henderson (1980) and Henderson and Tippett (1980). The pegmatite was staked by Cominco in the summer of 1979, and, under a joint-venture agreement with the Tantalum Mining Corporation of Canada Ltd., examined by D.L Trueman and P. Černý.

The PLEX pegmatite was emplaced along a shallowly-dipping contact between metasedimentary rocks and overlying metabasalts. Two pegmatites can be distinguished (Fig. 31): an upper, main sill-like body and a lower, more poorly-exposed appendage. The metasedimentary rocks are represented by biotite-quartz-garnet paragneiss, locally containing staurolite. Near the pegmatite, this paragneiss contains abundant porphyroblasts of exomorphic black tourmaline. Exocontact effects are limited to a narrow biotite-rich seam; tourmaline or other reaction products were not observed. The pegmatite is exposed over 90 by 400 m and generally dips shallowly to the southwest (20-25°) with a maximum dip of 50°. Thickness varies from about 1.2 m in the northeasternmost exposure to a minimum of 2.5 m (possibly as much as 5 m) in the central parts.

The lower pegmatite is poorly exposed below the central parts of the upper pegmatite outcrop. It may be connected with two small pegmatite outcrops to the northeast and southwest, forming a thin lens subparallel to the main pegmatite (Fig. 31). This pegmatite was not examined in detail because of its restricted exposure and apparent lack of rare-element minerals. The following sections deal exclusively with the main pegmatite.

Internal structure

The main pegmatite consists of four units: a wall zone, a lower intermediate zone, a core-margin zone, and a core. The wall zone consists of albite, quartz, and muscovite, with subordinate garnet and tourmaline. In the northeasternmost exposure of the main pegmatite, the wall zone is the exclusive constituent of the pegmatite over its entire width. It is poor in muscovite but enriched in garnet and tourmaline. Both these minerals are intergrown with quartz in a quasi-graphic pattern. In the central parts of the pegmatite, the wall zone is relatively thin, enriched in plumose and platy muscovite, poor in garnet, and locally lacking tourmaline.

The lower intermediate zone consists of medium- to coarse-flaked, green-yellow muscovite with small local patches of quartz, albite, and garnet. In its lower part, accessory columbite is disseminated throughout the muscovite-rich matrix.

The core-margin zone consists of grey to milky quartz, white blocky K-feldspar, subordinate to accessory book muscovite and columnar tourmaline. Feldspar and mica are relatively abundant along the footwall contact. Pods of loellingite also occur in this unit.

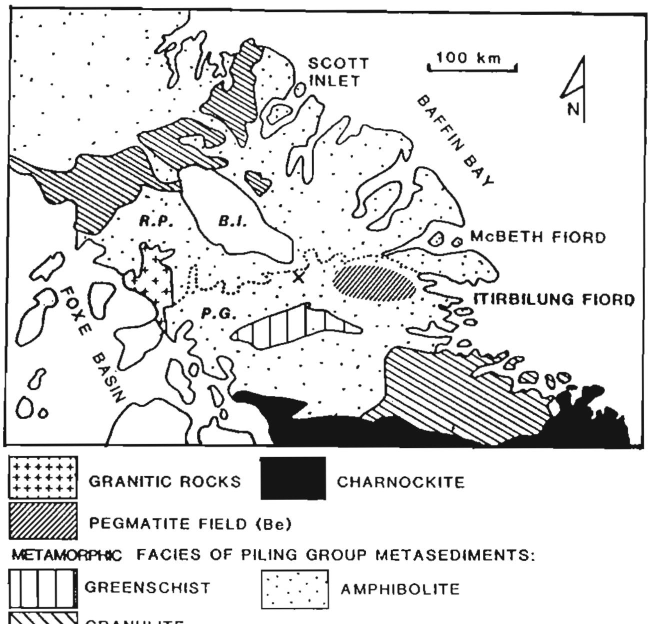


Figure 30. *Location of the Foxe pegmatite field in the central part of Baffin Island (geology generalized from Jackson and Morgan, 1978 and Hoffman, 1988). P.G. = Piling Group of the Foxe fold belt; R.P. = northeastern arm of the Rae Province; B.I. = Barnes Icefield; X = the PLEX (Nb-Ta) pegmatite at Eskimo Hill.*

The core consists predominantly of milky quartz but also contains very large columns of black tourmaline (as large as 0.15 by 1.5 m), that have zircon and columbite crystals on their surfaces. Locally, in the vicinity of columbite and zircon, the quartz is brown to black, with a gradual transition into the milky type.

Mineralogy and geochemistry

Albite is present dominantly as cleavelandite; saccharoidal albite is rare. In the wall zone, albite near contacts with wallrocks shows optical properties corresponding to An_{5-7}; in the internal parts of the wall zone and in the core-margin, the composition is close to An_{2-3}.

White microcline-perthite intergrowths possess near-maximum values of triclinicity (0.88-0.95). These feldspars are sodic (2.48 to 3.28 wt.% Na_2O), and indicators of rare-alkali fractionation are moderate (K/Rb = 54 to 24, K/Cs = 1100 to 3200; Fig. 32).

Muscovite belongs to the common $2M_1$ polytype. In the wall zone, muscovite chemistry is relatively primitive, as indicated by poor rare-alkali fractionation (K/Rb = 25 to 35, K/Cs = 1300 to 2700), low Li content (0.25 to 0.27 wt.% Li_2O) and high Fe (total Fe content as Fe_2O_3 is 2.2 to 2.8 wt.%). In contrast, the medium-flaked muscovite from the lower intermediate zone is more chemically evolved (K/Rb = 10 to 18, K/Cs = 170 to 680; 0.24 to 0.27 wt.% Li_2O); Fe is high but the Fe/Mn is distinctly lower than that of the wall zone muscovite.

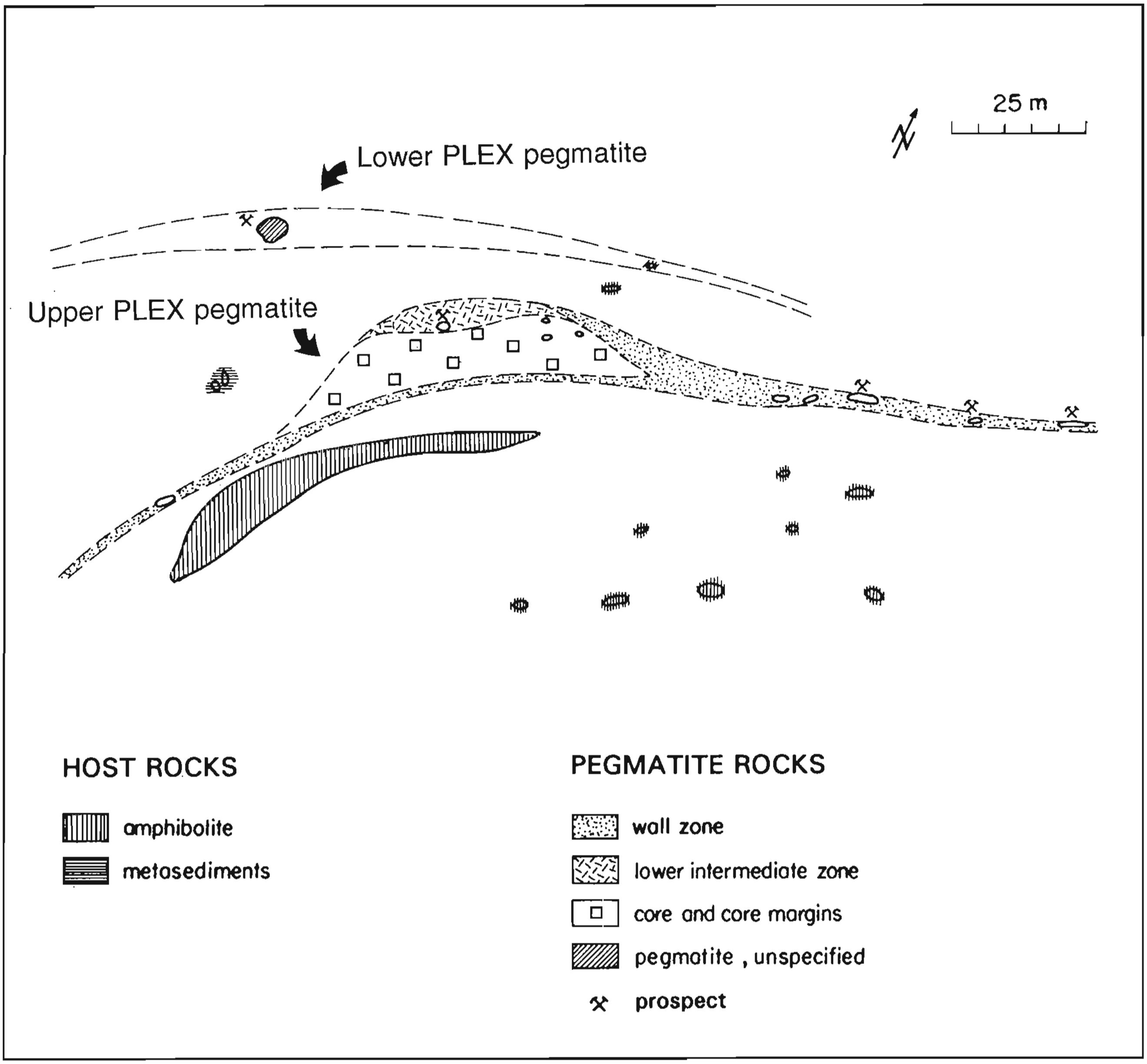


Figure 31. Outcrop map and internal structure of the PLEX pegmatite.

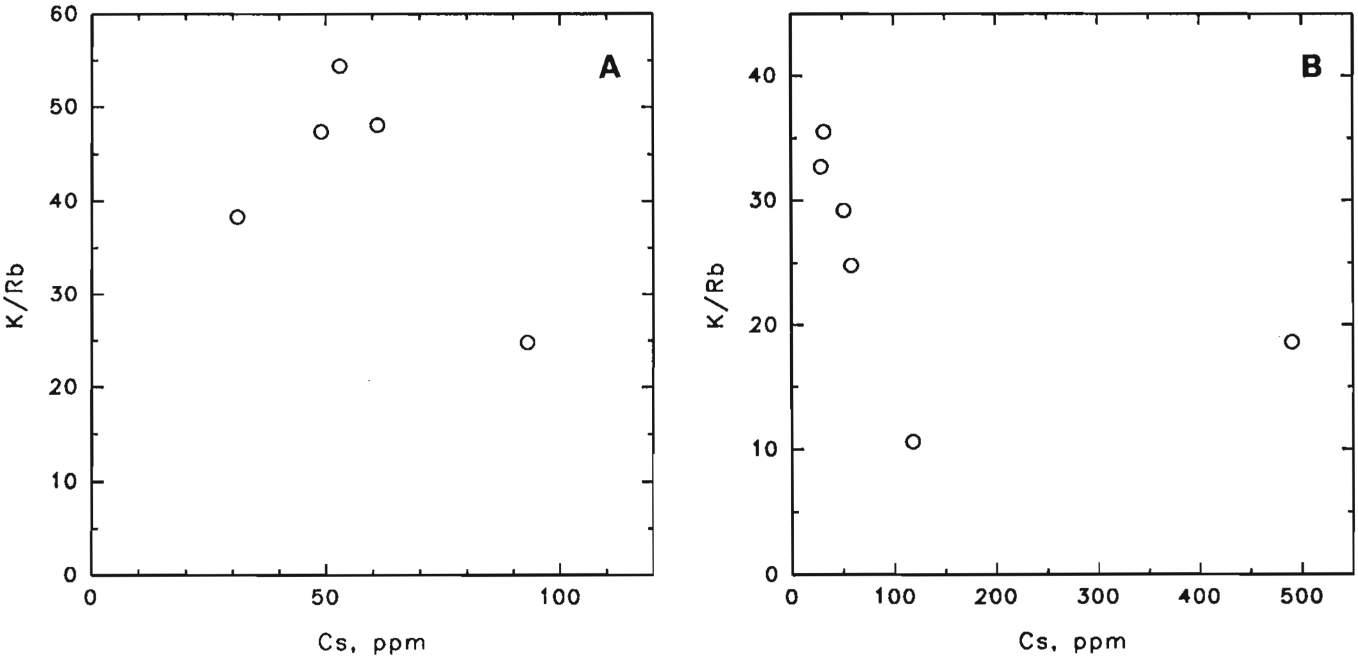


Figure 32. *Correlation of K/Rb with Cs in (A) blocky K-feldspar and (B) muscovite of the upper PLEX pegmatite.*

Tourmaline (schorl) appears as dendritic aggregates finely intergrown with albite and coarse-grained intergrowths with quartz, as well as the aforementioned gigantic columnar crystals in the core zone. Its composition varies slightly within individual crystals, showing oscillatory concentric zoning. In contrast to coexisting garnet, the tourmaline preferentially incorporates Fe, and is very poor in Mn relative to garnet. Magnesium oxide is variable, being highest along the wall rock contacts (3.4 wt.%) but low in the internal units (0.0 to 0.6 wt.%). The black tourmaline from the footwall paragneiss is, however, Mg- and Ti-rich with elevated Ca. Dravite is the dominant component of this tourmaline (Fig. 33A, B).

Garnet of the wall zone forms dark red crystals as much as 3 cm in size, or quasi-graphic intergrowths with quartz that reach 12 cm across. The composition is largely close to Alm_{50} $Spess_{50}$, with only minor Ca and Mg (<ca. 0.10 wt.% MgO). Garnet from the lower intermediate zone is distinctly more fractionated. Its red-orange grains, found with albite in clusters within the medium-flaked muscovite masses, range from $Spess_{59-78}$. Garnet that occurs in minor quantities with muscovite in the core-margin of the pegmatite also reaches the composition of Alm_{22} $Spess_{78}$. Garnet compositions enriched in Mn carry distinctly elevated but still minor Ca (Fig. 33C, D).

A single 2.5 by 10 cm beryl crystal, associated with cleavelandite and garnet, was found on the talus slope beneath the upper pegmatite but above the lower dyke. It is considerably altered and stained by manganese oxides and consequently was not analyzed; however, identification was confirmed by X-ray powder diffraction.

Columbite crystals in the core zone are flat, columnar and average 1 by 3 by 7 cm but in places reach 5 by 10 by 16 cm. Embedded in otherwise milky quartz, the columbite crystals developed a smoky-black halo in the host, as much as 15 cm wide. The mineral corresponds to ferrocolumbite with narrow ranges of Fe-Mn and Nb-Ta substitutions (Fig. 34). In contrast, columbite of the lower intermediate zone forms anhedral to brick-shaped subhedral grains that average 1 cm in size and are slightly enriched in Ta and distinctly enriched in Mn relative to ferrocolumbite in the core zone. Columbites from the lower intermediate zone are limited in composition to the manganocolumbite quadrant of the columbite quadrilateral (Fig. 33). Representative compositions of ferrocolumbite and manganocolumbite are given in Table 7.

Structurally, columbite from both zones displays intermediate to high degrees of cation disorder, with a peculiar, inexplicable bimodal distribution of structural states. All heated specimens appear to develop an ordered structure.

Zircon, as radial aggregates of columnar crystals averaging 0.6 cm in length, occur on the surfaces of tourmaline crystals in the core-margin unit and in the core. It is metamict but the structure can be reasonably restored by heating. Metamictization, caused by 0.3 wt.% UO_2 (see below), is expressed in the electron microprobe analysis by low totals and deviations from stoichiometry. The HfO_2 is relatively low (3.6 wt.%).

Uranophane occurs as an alteration product of zircon, and forms pale yellow powdery coatings on the surfaces of, and within fractures in, zircon. No compositional data are available but X-ray powder diffraction data yielded a reliable identification.

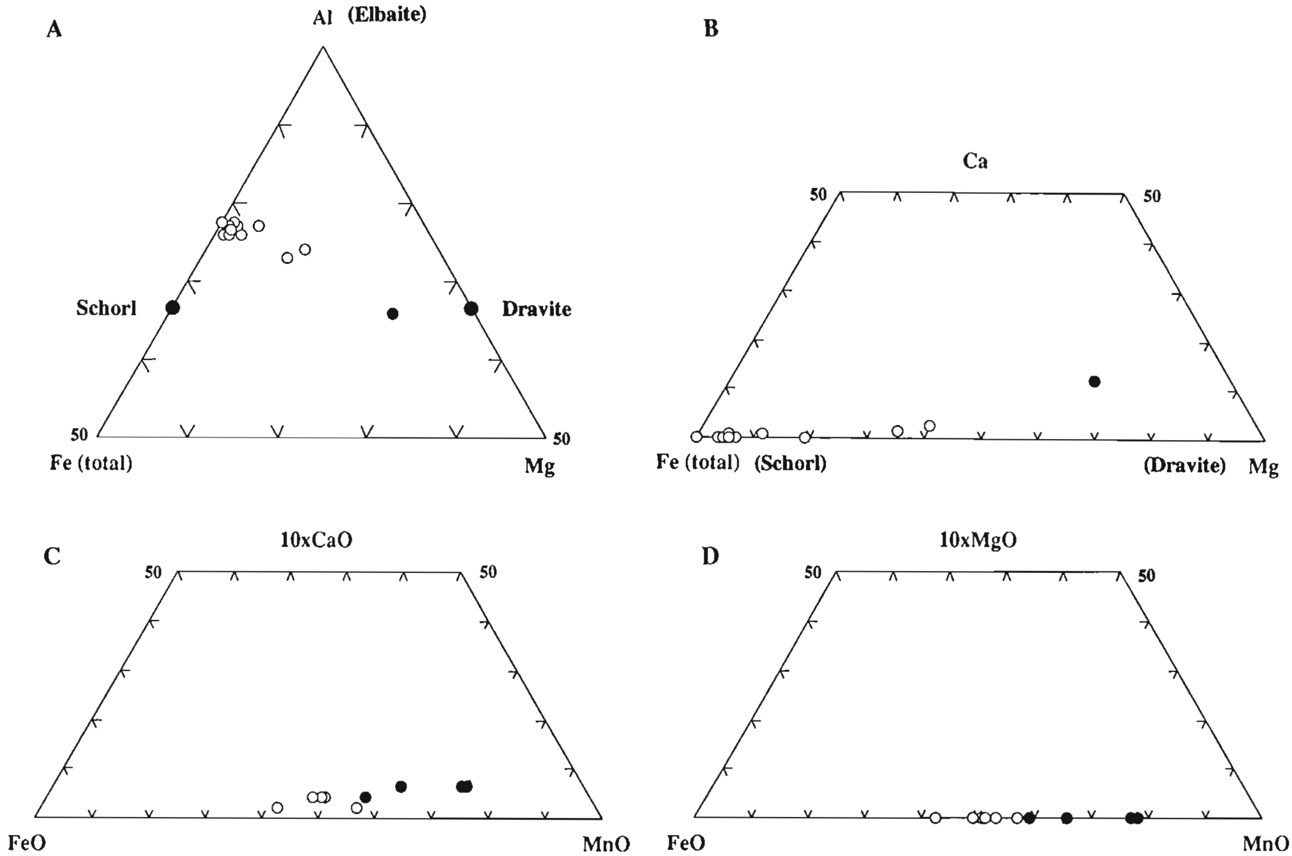


Figure 33. Tourmaline of the upper PLEX pegmatite in the (A) Fe(total)-Mg-Al and (B) Fe(total)-Mg-Ca diagrams of Henry and Guidotti (1985; atomic ratios). Internal schorl with subordinate Mg contrasts with the Mg-rich exomorphic tourmaline from the adjacent metasedimentary schist (marked by solid dot). Garnet of the upper PLEX pegmatite in the (C) FeO(for total Fe)-MnO-10xCaO and (D) FeO(for total Fe)-MnO-10xMgO diagrams (wt.% ratios). Compositions of garnet from the lower intermediate zone are marked by solid dots; those from the wall zone are represented by open circles. Note the slight enrichment in CaO with increasing MnO.

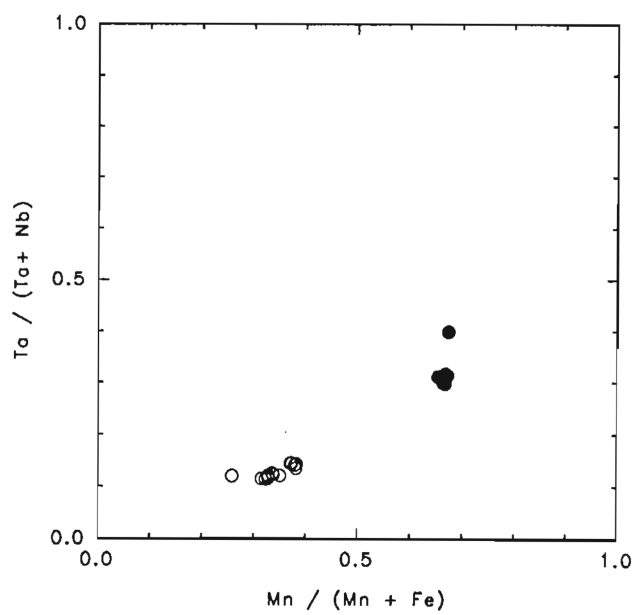


Figure 34. Composition of columbite from the upper PLEX pegmatite in the columbite quadrilateral (atomic ratios). Note the marked difference between the Ta and Mn contents of ferrocolumbite from the core-margin and core (open circles) and manganocolumbite from the lower intermediate zone (solid dots).

Table 7. Chemical compositions of columbite-tantalites from the PLEX pegmatite, Foxe pegmatite field, Baffin Island.

	1	2	3	4	5	6
Ta_2O_5	15.0	14.8	17.6	33.5	35.3	43.8
Nb_2O_5	64.9	64.8	62.6	47.8	46.7	39.5
FeO^*	13.3	13.3	12.5	6.1	6.1	5.8
MnO	6.5	6.4	7.3	12.1	12.3	11.8
TiO_2	0.9	0.6	0.6	0.3	0.2	0.0
SnO_2	0.3	0.0	0.0	0.0	0.3	0.0
total	**100.9**	**99.9**	**100.6**	**99.8**	**100.9**	**100.9**

* *total Fe as FeO*
1,2,3= core margin
4,5,6= lower intermediate zone

Loellingite, unequivocally identified by X-ray powder diffraction, was found in the southern end of the main exposure of the Upper pegmatite. It forms a pod at least 20 cm across, in quartz and K-feldspar of the core-margin zone.

Scorodite is an abundant alteration product of loellingite. The green microcrystalline material is contaminated by relics of loellingite and is too soft for mounting; consequently, no chemical analysis was possible, however, X-ray diffraction provided a positive identification.

Exploration potential

Using Černý's (1991a) classification of pegmatites of the rare-element class, and based upon the internal structure, rock-forming minerals and the assemblage of accessory phases, the main PLEX pegmatite belongs to the beryl-columbite subtype of the beryl type of rare-element granitic pegmatites. If the mineralogy at the present level of exposure is characteristic of the whole pegmatite, the pegmatite is rather anomalous, with abundant columbite dominant over rare beryl. A reverse ratio is normally the "rule" in pegmatites of this type. The geochemical signature of this pegmatite is typical of the beryl-columbite subtype, and is comparable to other occurrences (Černý et al. 1981; Meintzer 1987). The chemical fractionation of muscovite, columbite and, to a lesser degree garnet, is distinctly more advanced in the muscovite-rich lower intermediate zone than in the core-margin and core. The lower intermediate zone may actually be a metasomatic unit which postdates the concentric succession of primary zones.

The Foxe pegmatite field has not been well explored. The present data indicate poor chemical fractionation in the most evolved pegmatite. A larger number of Nb,Ta-bearing pegmatites can be expected in this field, as columbite-tantalite commonly forms inconspicuous grains dispersed in the silicate matrix and can easily be missed on cursory examination. The size of columbite crystals in the main PLEX pegmatite is exceptional. However, there are no indications that fractionation of granitic melts in the Foxe field evolved beyond the beryl-columbite subtype of the rare-element pegmatite class.

PEGMATITES IN OTHER PARTS OF THE SLAVE AND RAE PROVINCES

The potential for further discoveries of rare-element pegmatites in the Slave Province is particularly good. Pegmatite populations deserving closer examination include: (1) the Russell Lake area northwest of Yellowknife (Jackson, 1988); (2) MacKay Lake, west of the Aylmer Lake field (Henderson, 1941); (3) Benjamin Lake basin on the northernmost shore of Great Slave Lake (Heywood and Davidson, 1969); (4) two areas in the vicinity of Clinton-Colden and Healey lakes (van Breemen et al., 1987; van Breemen and Henderson, 1988); (5) the Regan intrusive suite in the northeast of the province (Frith and Fryer, 1985); (6) the area east of Bathurst Inlet (W.A. Padgham, INAC, pers. comm., 1990); and (7) south of the Lupin Mine, near Contwoyto Lake (King et al., 1988).

Regions with known pegmatite potential are not as numerous in the Rae Province. However, an apparently isolated occurrence of lepidolite was reported from the easternmost Dorset belt, in the southeastern extremity of Baffin Island (R. Mulligan, pers. comm. in Bell, 1978).

CONCLUDING REMARKS

This paper describes geological, mineralogical, and chemical attributes of four pegmatite populations in Northwest Territories, previously known only from field observations of mapping geologists or local inhabitants:

1) The Aylmer Lake pegmatite field in the southeastern Slave Province is dominated by mineralogically simple beryl type pegmatites; however, many pegmatite series are enriched in spodumene and there is potential for economic mineralization in unexposed pegmatites.

2) The majority of Torp Lake field pegmatites (Bathurst Inlet, northwestern Northwest Territories) are geochemically simple. A minority of the dykes in this field are complex, and one large intrusion is rich in spodumene, lepidolite, cleavelandite, and elbaite. The potential for undiscovered pegmatites with substantial Be and Li is good.

3) The Chantrey Inlet field on the Arctic coast contains abundant evolved granites and granitic pegmatites, the most highly fractionated of which contain columbite-tantalite and Li-Fe-Mn phosphate minerals. Pegmatite-granite relations in this field are complex and exploration potential for rare elements is limited.

4) The Foxe field on Baffin Island contains a series of beryl-bearing pegmatites. The one dyke which was examined in detail (the PLEX pegmatite) carries columbite-tantalite, spessartine-rich garnet, beryl, and tourmaline. This field has minor potential for containing further pegmatites enriched in Nb,Ta-oxides.

The results presented here have upgraded the existing qualitative and quantitative information on three of these populations, and the M.Sc. thesis research of Tomascak (1991) generated a comprehensive evaluation of the Aylmer Lake pegmatite field. These studies document the widespread distribution of granitic pegmatites with rare-element concentrations in regions of Northwest Territories where pegmatites were either virutally unknown, or their number, distribution, and mineralization were recorded in a cursory fashion. All of these localities should receive closer examination to characterize their geology and economic prospects more fully. The potential for further discoveries is also good in other segments of the Slave Structural Province.

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REFERENCES

Anderson, A.J.
1984: Geochemistry, mineralogy and petrology of the Cross Lake pegmatite field, Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 251 p.

Barnes, F.Q.
1950: Second preliminary map, Aylmer Lake, Northwest Territories (descriptive notes); Geological Survey of Canada, Paper 50-10, 8 p.

Bell, C.K.
1978: Geology, Wekusko Lake map area; Geological Survey of Canada, Memoir 384.

Černý, P.
1989: Exploration strategy and methods for pegmatite deposits of tantalum; in Lanthanides, Tantalum and Niobium, (ed.) P. Möller, P. Černý, and F. Saupé; Springer-Verlag, p. 271-299.
1990: Distribution, affiliation and derivation of rare-element granitic pegmatites in the Canadian Shield; Geologische Rundschau, v. 79, p. 183-226.
1991a: Rare-element granitic pegmatites, Part I: Anatomy and internal evolution of pegmatitic deposits; Geoscience Canada, v. 18, p. 49-67.
1991b: Rare-element granitic pegmatites, Part II: Regional to global environments and petrogenesis; Geoscience Canada, v. 18, p. 68-81.

Černý, P. and Meintzer, R.E.
1988: Fertile granites in the Archean and Proterozoic fields of rare-element pegmatites: crustal environment, geochemistry and petrogenetic relationships; in Recent Advances in the Geology of Granite-Related Mineral Deposits, (ed.) R.P. Taylor and D.F. Strong; The Canadian Institute of Mining and Metallurgy, Special Volume 39, p. 170-207.

Černý, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E., and Paul, B.J.
1981: The Cat Lake-Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Department of Energy and Mines, Mineral Resources Division, Economic Geology Report ER80-1, 234 p.

Folinsbee, R.E.
1952: Walmsley Lake, District of Mackenzie, Northwest Territories; Geological Survey of Canada Map 1013A, scale 1:253 440.

Frisch, T.
1989: Metamorphism of the Aphebian Chantrey Group, northern district of Keewatin, Northwest Territories; Geological Association of Canada-Mineralogical Association of Canada, Annual Meeting, Montreal, Program with Abstracts, v. 14, p. A7.

Frisch, T., Annesley, I.R., and Gittins, C.A.
1985: Geology of the Chantrey Belt and its environs, Lower Hayes River and Darby Lake map areas, Northern District of Keewatin; in Current Research, Part A; Geological Survey of Canada, Paper 85-1A, p. 259-266.

Frith, R.A. and Fryer, B.J.
1985: Geochemistry and origin of the Regan Intrusive Suite and other granitoids in the northeastern Slave Province, northwest Canadian Shield; Canadian Journal of Earth Sciences, v. 22, p. 1048-1065.

Fyson, W.R. and Helmstaedt, H.
1988: Structural pattern and evolution of supracrustal domains in the Archean Slave Province, Canada; Canadian Journal of Earth Sciences, v. 25, p. 301-315.

Grocott, J.
1989: Structural constraints on Early Proterozoic assembly of NE Laurentia: evidence from Baffin Island and West Greenland; Geological Association of Canada-Mineralogical Association of Canada Annual Meeting, Montreal, Program with Abstracts, v. 14, p. A10.

Henderson, J.F.
1941: Preliminary Report, MacKay Lake Area, Northwest Territories; Department of Mineral Resources, Mines and Geology Branch, Geological Survey Paper 41-1, 6 p.

Henderson, J.R.
1980: MacBeth Fiord Sheet; (NTS 27C/12) Geological Survey of Canada, Open File 705.

Henderson, J.R. and Tippett, C.R.
1980: Foxe Fold Belt in Eastern Baffin Island, District of Franklin; in Current Research, Part A; Geological Survey of Canada, Paper 80-1A, p. 147-152.

Henry, D.J. and Guidotti, C.V.
1985: Tourmaline as a petrogenetic indicator mineral: an example from the staurolite-grade metapelites of NW Maine; American Mineralogist, v. 70, p. 1-15.

Heywood, W.W. and Davidson, A.
1969: Geology of Benjamin Lake map area, District of Mackenzie; Geological Survey of Canada, Memoir 361, 35 p.

Hoffman, P.F.
1988: United plates of America, the birth of a craton: Early Proterozic assembly and growth of Laurentia; Annual Reviews of Earth and Planetary Sciences, v. 16, p. 543-603.

Hutchinson, R.W.
1955: Regional zonation of pegmatites near Ross Lake, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Bulletin 34, 50 p.

Jackson, G.D. and Morgan, W.C.
1978: Precambrian metamorphism on Baffin and Bylot Islands; in Metamorphism in the Canadian Shield, (ed.) J.A. Fraser and W.W. Heywood; Geological Survey of Canada, Paper 78-10, p. 249-267.

Jackson, V.A.
1988: Geology of the Russell-Slemon Lakes area; Open File Report EGS1988-11, Indian and Northern Affairs Canada, Yellowknife, 1 map with marginal notes.

Johnstone, R.M.
1988: Preliminary geology of the Torp Lake area, Torp Lake metasedimentary belt, NWT; Open File Report EGS1989-7, Indian and Northern Affairs Canada, Yellowknife (1 map and marginal notes).

Jolliffe, A.W.
1943: Tin and tantalum deposits, Sproul Lake, Ross Lake area, Northwest Territories; Unpublished Report, Geological Survey of Canada, 3 p.
1944: Rare-element minerals in pegmatites, Yellowknife-Beaulieu area, Northwest Territories; Geological Survey of Canada, Paper 44-12, 17 p.

King, J.E., Davis, W.J., Relf, C., and Avery, R.W.
1988: Deformation and plutonism in the western Contwoyto Lake map area, central Slave Province, District of Mackenzie, N.W.T.; in Current Research, Part C; Geological Survey of Canada, Paper 88-1C, p. 161-176.

Kranck, E.H.
1951: Mineral possibilities of Baffin Island; Canadian Mining and Metallurgical Bulletin, v. 44, p. 682-683.
1955: The bedrock geology of the Clyde area in northeastern Baffin Island; Acta Geographica, v. 14, p. 226-248.

Kretz, R.
1968: Study of pegmatite bodies and enclosing rocks, Yellowknife-Beaulieu Region, District of Mackenzie; Geological Survey of Canada, Bulletin 159, 109 p.
1970: Variation in the composition of muscovite and albite in a pegmatite dike near Yellowknife; Canadian Journal of Earth Sciences, v. 7, p. 1219-1235.
1985: Chemical composition of the Sparrow pluton and associated pegmatite dikes; Contributions to the Geology of the Northwest Territories, v. 2, p. 1-13.

Lord, C.S. and Barnes, F.Q.
1954: Aylmer Lake, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1031A, scale 1:235 440.

Meintzer, R.E.
1987: The mineralogy and geochemistry of the granitoid rocks and related pegmatites of the Yellowknife pegmatite field, Northwest Territories; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 708 p.

Meintzer, R.E. and Černý, P.
1988: Evolution of late Archean granitoid rocks and pegmatites of the Yellowknife basin, Northwest Territories; The Geochemical Society, V.M. Goldschmidt conference, Baltimore 1988, Program and Abstracts, p. 6.

Meintzer, R.E. and Wise, M.A.
1987: Granitoids and Pegmatites of the Yellowknife Area, N.W.T.; in Yellowknife Guide Book, (ed.) W.A. Padgham; Geological Association of Canada, Mineral Deposits Division, p. 123-134.

Meintzer, R.E., Černý, P., and Clark, G.S.
1988a: The Buckham granite, a highly fractionated pluton of the Prosperous Granite in the Yellowknife pegmatite field, Northwest Territories; Geological Association of Canada-Mineralogical Association of Canada Annual Meeting, St. John's, Newfoundland, Program with Abstracts, v. 13, p. A83.

Meintzer, R.E., Černý, P., Longstaffe, F.J., and Fryer, B.J.
in press: Geochemical variations and petrogenesis of the Defeat Plutonic Suite, Northwest Territories; Canadian Journal of Earth Sciences.

Meintzer, R.E., Černý, P., and Wise, M.A.
1988b: Variations in mineralogical and geochemical regional zonation in rare-element pegmatites of the Yellowknife pegmatite field, Northwest Territories; Geological Society of America Annual Meeting Denver, Colorado, Abstracts with Program, v. 20, no. 7, p. A313.

Meintzer, R.E., Wise, M.A., and Černý, P.
1984: Distribution and structural setting of fertile granites and related pegmatites in the Yellowknife pegmatite field, District of Mackenzie; in Current Research, Part A; Geological Survey of Canada, Paper 84-1A, p. 373-381.

Rowe, R.B.
1952: Pegmatitic mineral deposits of the Yellowknife-Beaulieu region, Northwest Territories; Geological Survey of Canada, Paper 52-8, 22 p.

Thompson, P.H.
1978: Archean regional metamorphism in the Slave structural province - A new perspective on some old rocks; in Metamorphism in the Canadian Shield, (ed.) J.A. Fraser and W.W. Heywood; Geological Survey of Canada, Paper 78-10, p. 85-102.

Tippett, C.R. and Morgan, W.C.
1981: Tectonic evolution of the southern margin of the Foxe fold belt, Baffin Island and implications for models of Early Proterozoic mobile belts; Geological Association of Canada-Mineralogical Association of Canada Annual Meeting, Calgary, Alberta, Program and Abstracts, v. 6, p. A56.

Tomascak, P.B.
1991: Granites and rare-element pegmatites of the Aylmer Lake pegmatite field, Slave Structural Province, N.W.T.: petrochemistry, mineralogy and exploration guidelines; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 215 p.

Tomascak, P.B. and Černý, P.
1992: Mineralogy and geochemistry of phosphorus in the Aylmer Lake pegmatite field, N.W.T.; Geological Association of Canada-Mineralogical Association of Canada Annual Meeting, Wolfville, Nova Scotia, Abstracts with Programs, v. 17, p. A110.

Trueman, D.L. and Černý, P.
1982: Exploration for rare-element granitic pegmatites; in Granitic Pegmatites in Science and Industry, Mineralogical Association of Canada Short Course Handbook 8, (ed.) P. Černý, p. 463-494.

van Breemen, O. and Henderson, J.B.
1988: U-Pb zircon and monazite ages from the eastern Slave Province and Thelon Tectonic zone, Artillery Lake area, N.W.T.; in Radiogenic Age and Isotopic Studies: Report 2, Geological Survey of Canada, Paper 88-2, p. 73-83.

van Breemen, O., Henderson, J.B., Sullivan, R.W., and Thompson, P.H.
1987: U-Pb zircon and monazite ages from the eastern Slave Province, Healey Lake area, N.W.T.; in Radiogenic and Age Isotopic Studies: Report 1, Geological Survey of Canada, Paper 87-2, p. 101-110.

Wise, M.A.
1987: Geochemistry and crystal chemistry of Nb, Ta and Sn minerals from the Yellowknife pegmatite field, N.W.T.; Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, 368 p.

Wise, M.A. and Černý, P.
1990a: Primary compositional range and alteration trends of microlite from the Yellowknife pegmatite field, Northwest Territories, Canada; Mineralogy and Petrology, v. 43, p. 83-98.
1990b: Beusite-triphylite intergrowths from the Yellowknife pegmatite field, N.W.T.; Canadian Mineralogist, v. 28, p. 133-139.

Wise, M.A., Meintzer, R.E., and Černý, P.
1985: The Yellowknife pegmatite field: mineralogy and geochemistry of Nb-Ta-Sn oxide minerals; Contribution to the Geology of the Northwest Territories, v. 2, p. 15-25.
1988: Phosphate mineralogy of the Yellowknife pegmatite filed; Contributions to the Geology of the Northwest Territories, v. 3, p. 123-129

Geological setting and genetic aspects of mineral occurrences in the southern Great Bear magmatic zone, Northwest Territories[1]

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Gandhi, S.S., 1994: Geological setting and genetic aspects of mineral occurrences in the southern Great Bear magmatic zone, Northwest Territories; in Studies of Rare-Metal Deposits in the Northwest Territories, (ed.) W.D. Sinclair and D.G. Richardson; Geological Survey of Canada, Bulletin 475, p. 63-96.

Abstract: The southern part of the Great Bear magmatic zone is characterized by abundant continental felsic volcanic rocks and related plutons, which were emplaced 1870-1840 Ma ago. The basement rocks include remnants of an early Proterozoic metamorphosed platform-shelf sequence and granitic plutons intrusive into the sequence.

Mineral occurrences and deposits in the area are of six distinct metallogenic types. The argillaceous and silty beds of the Proterozoic metasedimetary sequence host synsedimentary/diagenetic sulphide and magnetite concentrations, some of which also served as favourable host rocks for later epigenetic mineralization. Occurrences genetically related to the Great Bear magmatic activity are of four types: felsic volcanic-associated uranium occurrences; monometallic and polymetallic iron oxide-rich veins and breccia-fillings exemplified by the magnetite-apatite-actinolite veins of Kiruna-type and the copper-uranium-gold-silver-rare-earth-bearing breccia zones of Olympic Dam-type; granite-related molybdenum-uranium±copper occurrences; and bismuth-cobalt-copper-gold-bearing hydrothermal arsenopyrite-pyrite veins and disseminations. The occurrences that postdate the Great Bear magmatic activity are the fracture-fillings and quartz veins containing pitchblende and copper sulphides, and include those in a giant quartz vein at the Rayrock mine that produced uranium in the 1950s. The most attractive targets from the standpoint of present exploration are the polymetallic Olympic Dam-type deposits.

Evolution of the magmatic zone and the geological setting of the selected occurrences of each metallogenic type are described. Their genetic aspects are discussed and some comments on the resource potential and guides to exploration are provided.

Résumé : La partie sud de la zone magmatique du Grand lac de l'Ours est caractérisée par une quantité abondante de roches volcaniques felsiques de caractère continental et de plutons apparentés qui se sont formés à environ 1 870-1 840 Ma. Les roches du socle comportent des lambeaux d'une séquence de plate-forme continentale métamorphisée du Protérozoïque précoce recoupée de plutons granitiques.

Les indices minéralisés et les gisements dans la région appartiennent à six types métallogéniques distincts. Les couches argileuses et silteuses de la séquence métasédimentaire du Protérozoïque renferment des concentrations synsédimentaires/diagénétiques de sulfures et de magnétite, dont quelques-unes servent aussi de roches encaissantes favorables à des minéralisations épigénétiques ultérieures. Les indices

[1] Contribution to Canada-Northwest Territories Mineral Development subsidiary Agreement 1987-1991, and the 1991-1996 Canada-Northwest Territories Minerals Initiatives Program.
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génétiquement rattachés à l'activité magmatique de la zone du Grand lac de l'Ours sont de quatre types : des indices d'uranium associés à des roches volcaniques felsiques; des filons monométalliques et polymétalliques et des matériaux de remplissage de brèche riches en oxyde de fer dont des exemples sont fournis par des filons d'apatite-actinote à magnétite de type Kiruna et des zones bréchiques à cuivre-uranium-or-argent-terres rares de type Olympic Dam; des indices de molybdène-uranium cuivre reliés à des granites; enfin des filons et des disséminations d'arsénopyrite-pyrite d'origine hydrothermale à concentrations de bismuth-cobalt-cuivre-or. Les indices qui sont postérieurs à l'activité magmatique de la zone du Grand lac de l'Ours sont les matériaux de remplissage des fractures et les filons de quartz qui renferment de la pechblende et des sulfures de cuivre, et comportent ceux qui se trouvent dans le filon géant de quartz de la mine Rayrock qui a produit de l'uranium dans les années 50. Les cibles les plus attrayantes du point de vue de l'exploration actuelle sont les gisements polymétalliques de type Olympic Dam.

Sont décrits l'évolution de la zone magmatique et le milieu géologique d'indices choisis pour chaque type métallogénique. Leurs aspects génétiques sont discutés et les auteurs apportent quelques observations sur les ressources potentielles et fournissent des guides à l'exploration.

INTRODUCTION

The southern part of the Great Bear magmatic zone (GBmz) is noted for several promising prospects of uranium, copper, gold, bismuth, and cobalt, and for one past producer of uranium, namely the Rayrock mine (Fig. 1, 2). The region has been explored intermittently since the 1930s, but geological and metallogenic studies of the area lagged behind the exploration activities. Recent studies elsewhere in the northwestern Canadian Shield have led to a better understanding of the Proterozoic evolution of this part of the Shield, which can be applied to further assist exploration and mineral resource assessment of the southern Great Bear magmatic zone. In view of these studies, a regional metallogenic study of the area was undertaken by the author as a part of the 1987-1991 Canada-Northwest Territories Mineral Development Subsidiary Agreement (MDA).

The project involved documentation of the geological settings and deposit characteristics of selected mineral occurrences, and metallogenic research to develop insights into their genesis and potential for additional resources. A significant outcome of this work has been the recognition of a type of mineralization comparable to that of the giant breccia-hosted Olympic Dam copper-uranium-gold-silver-rare-earth element deposit in South Australia, which indicates a potential for large polymetallic deposits in the region. This in turn provided an incentive to continue and intensify the metallogenic study of the southern Great Bear magmatic zone under the 1991-1996 Canada-Northwest Territories Mineral Initiatives Program that followed the first MDA.

This report presents an overview of the results obtained from the studies conducted under the two projects up to 1992. It is the first attempt to synthesize the regional metallogeny of the southern Great Bear magmatic zone.

PREVIOUS WORK

The southern part of the Great Bear magmatic zone has been explored intermittently since the 1930s. Pitchblende was first reported near the Rayrock mine in 1934 by a field party of the Geological Survey of Canada (GSC) (Lang et al., 1962). Intensive prospecting in the mid-1950s for uranium led to the discovery of numerous occurrences, but most of these were too small to be economic except for the Rayrock deposit, which produced 150 tonnes of uranium during the period 1957 to 1959. Sporadic exploration in the 1960s by prospectors and exploration companies (i.e., Precambrian Mining Services, Giant Yellowknife Mines Limited, New Athona Mines Limited, Shield Resources Limited, Angus Petroleum Consultants Limited, and Westrim Mining Corporation Limited) led to the discovery of the bismuth-cobalt-copper-gold occurrences of the Gar prospects near Lou Lake and the molybdenum-uranium±copper occurrences at DeVries Lake, and a number of other smaller occurrences (Gandhi and Lentz, 1990; Gandhi and Prasad, 1993). The prospects at Lou Lake and DeVries Lake were explored by trenching and drilling.

The uranium boom in the 1970s led to renewed exploration by Uranerz Mining and Exploration Company, Esso Minerals, Noranda Exploration Company, and Eldorado Nuclear Corporation. Exploration was greatly assisted by the GSC's 1974 airborne radiometric survey, which led to the discovery of the Sue-Dianne deposit (Charbonneau, 1988; Gandhi, 1989). The Sue-Dianne property was optioned by Noranda Exploration Company, who drilled the deposit and also conducted exploration for similar deposits elsewhere in the southern Great Bear magmatic zone. This work led to the discovery of the Fab, Mar, and Nod prospects (Gandhi, 1988, 1992a). Exploration activity declined in the early 1980s, but over the last few years, Aber Resources Limited has been actively exploring for stratiform base metal deposits in the DeVries Lake area, and Cominco Limited has explored for polymetallic Olympic Dam-type deposits on the west shore of the Great Slave Lake. The most recent staking in the area has been for diamonds, in the wake of the major staking rush in the Archean Slave Province to the east.

Geological mapping of the area at a scale of 1 inch to 4 miles was done more than 50 years ago (Kidd, 1936; Lord, 1942). Since then, additional regional and detailed mapping have been restricted to selected parts of the area (Fraser, 1967; McGlynn, 1968, 1979). Property-scale mapping has been completed by various exploration companies. A regional lake sediment geochemical survey (Allan and Cameron, 1973), a lithogeochemical survey of felsic volcanic rocks of the Great Bear magmatic zone for base metals (Garrett, 1975), and the previously mentioned airborne gamma-ray spectrometer survey (Richardson et al., 1973; McGlynn et al., 1974), were conducted by the Geological Survey of Canada. A geochronological study of uranium occurrences in the magmatic zone by Miller (1982a, b) included some of the occurrences in the southern part of the magmatic zone.

Results of the work done under the 1987-1991 MDA, on the Fab, Sue-Dianne, Mar, Nod, Gar, and Hump Lake prospects were previously reported by Gandhi (1988, 1989, 1992a, b) and Gandhi and Lentz (1990), and have been briefly summarized in Gandhi (1992c). Additional work done in 1991 and 1992 in the DeVries Lake area and on the Sue-Dianne deposit, under the subsequent 1991-1996 MDA, was reported by Gandhi and Prasad (1993) and Gandhi and Halliday (1993).

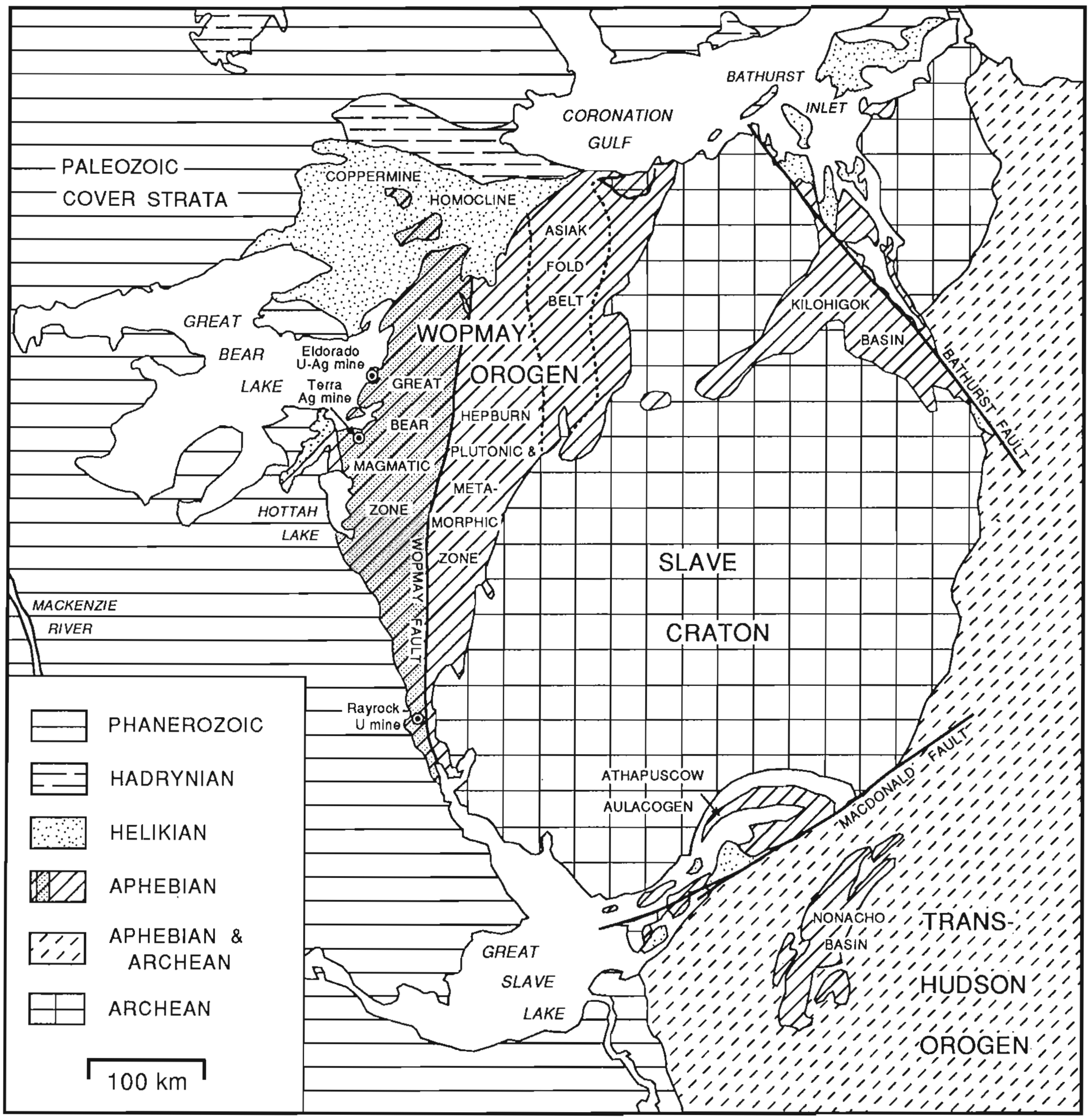

Figure 1. General geology of the northwestern Canadian Shield, and location of magnetite-rich veins and breccia zones related to the Great Bear magmatic zone.

GENERAL GEOLOGY

The Great Bear magmatic zone is a continental, dominantly felsic volcano-plutonic zone, formed 1870-1840 Ma ago on the west side of the early Proterozoic Wopmay Orogen (Fig. 1). It is posttectonic with respect to the Calderian orogeny, which culminated ca. 1900 Ma ago, and formed the Hepburn metamorphic and plutonic zone and a fold and thrust belt to the east. The Wopmay Orogen was interpreted by Hoffman (1980, 1984) to be a product of a Wilson cycle that affected the western margin of the Archean Slave craton. Badham (1973, 1978b) and Reichenbach (1991), however, interpret the plate margin as being of Andean-type. The boundary between the magmatic zone and the Hepburn metamorphic plutonic zone is marked by the north-trending Wopmay fault zone (Easton, 1981), which is recognized from recent work as a complex fold and fault zone, referred to as the 'median zone' (Hildebrand et al., 1990, 1991). The fault zone is covered at some places in the north by volcanic rocks of the Great Bear magmatic zone. Mylonites and ultramylonites were observed during the present study in the fault zone south-southeast of DeVries Lake. The magmatic zone is concealed in the north, west, and south by nearly flat-lying younger Proterozoic and Paleozoic strata (Douglas et al., 1974; McGlynn, 1977; Hoffman, 1984, 1988; Ross and Kerans, 1989; Pugh, 1993). Continuity of the north-trending magmatic zone beneath these strata is, however, reflected in regional magnetic patterns. A linear belt of quartz monzonitic intrusions forms an eastern extension of the magmatic zone in the Great Slave Lake area (Fig. 1).

The basement rocks on which the extrusive units of the magmatic zone were deposited in the main, north-trending part are considered to be early Proterozoic in age. These older rocks are well exposed in the Hottah Lake region, near Great Bear Lake (Fig. 1). They include metamorphosed sedimentary and volcanic rocks intruded by granitic plutons that are 1914-1902 Ma old (Hildebrand et al., 1987; Reichenbach, 1991). This assemblage comprises the 'Hottah terrane', which is interpreted as a continental magmatic arc originally located on the western edge of the Slave craton. Following this arc magmatism, a short lived period of extension led to the formation of a basin east of the arc and extrusion of a bimodal volcanic sequence that is overlain by a 2 km thick west-facing continental margin prism. This prism is comprised of the siliciclastic and carbonate rocks of the Coronation Supergroup, which lapped well onto the Slave craton. The basin fill was then shortened during the Calderian orogeny, and intruded by 1896-1878 Ma old granitic plutons, collectively known as the Hepburn intrusive suite (Hildebrand et al., 1987). The shortening culminated in the detachment and thin-skinned eastward thrusting of the imbricate basinal rocks, and the transport and emplacement of Hepburn plutons onto the Slave craton. Emplacement of hot plutons in this manner resulted in the inverted metamorphic isograds that cut across the basal décollement (St-Onge et al., 1984).

The basement rocks in the southern part of the Great Bear magmatic zone are relatively less well known, and include isolated remnants of metasedimentary rocks and granites that may be equivalents of those of the Hottah terrane or of the Snare Group east of the Wopmay fault zone. These rocks, in turn, correlate with the Coronation Supergroup (Lord, 1942; Frith, 1993). In the east arm of Great Slave Lake, the quartz monzonite intrusions have been emplaced into the Great Slave Supergroup, which is approximately coeval with the Coronation Supergroup. They are situated in a zone that trends northeasterly along, or close to, the boundary between the Archean Slave craton and the early Proterozoic (ca. 1950 Ma) Trans-Hudson Orogen to the south (Hoffman et al., 1977; Hoffman, 1980, 1988). The Great Slave Supergroup was deposited in a basin covering this boundary zone, and was folded along a belt lying southeast of the quartz monzonite intrusions.

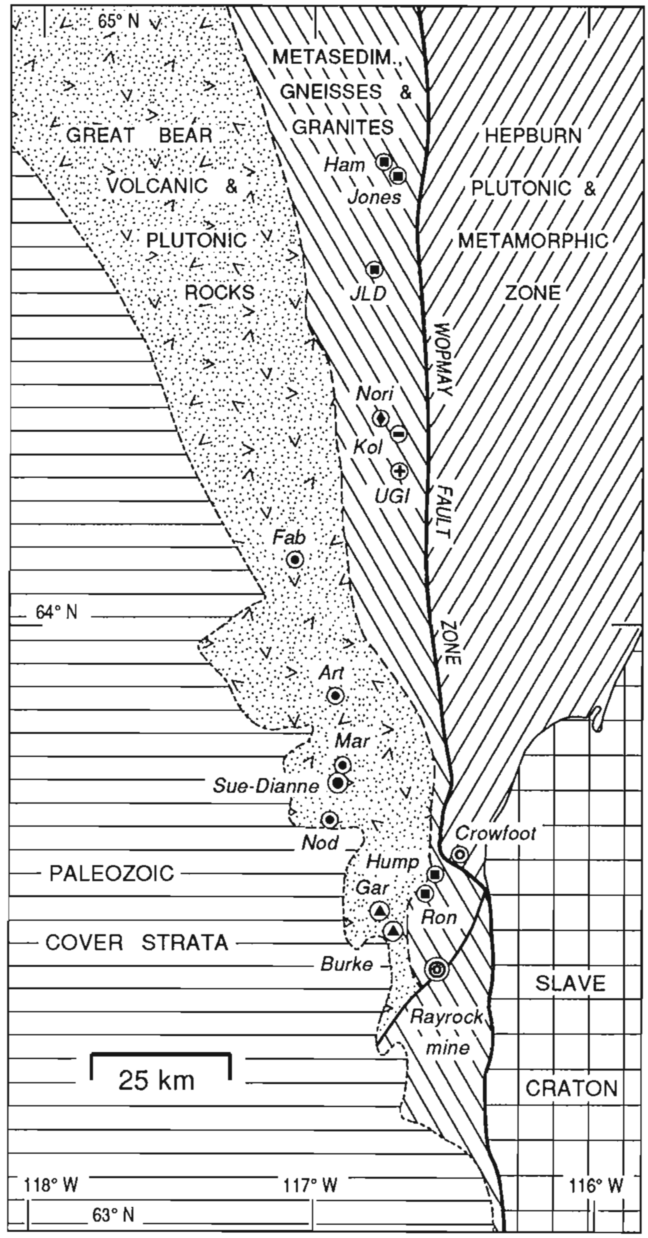

Figure 2. Geology and selected mineral occurrences of the southern Great Bear magmatic zone.

In the northern part of the Great Bear magmatic zone the volcanic rocks and associated volcaniclastic sediments have an aggregate thickness in the order of 10 km. They are divided into three groups: LaBine Group in the west, Sloan Group in the central part, and Dumas Group in the east (Baragar, 1977; Hoffman and McGlynn, 1977; Hoffman, 1980, 1984; Hildebrand et al., 1987). The LaBine Group consists mainly of basalts and rhyolites in the lower part, and is dominated by andesites in the upper part (Hildebrand, 1981, 1984). The andesites are geographically restricted to the Echo Bay-Camsell River mining camp, which is well known for the younger (<1400 Ma) vein-type polymetallic uranium and silver deposits (Lang et al., 1962). The LaBine Group was gently folded about northwest-trending axes, and intruded by quartz monzonitic plutons (Hildebrand, 1981; Hildebrand et al., 1987). Similar plutons also occur in the southern part of the magmatic zone (Fig. 2), and also in the east arm of Great Slave Lake, where they form a series of elongate laccoliths (Hoffman et al., 1977; Hoffman, 1988). These quartz monzonitic intrusions are characterized by numerous magnetite-apatite-actinolite veins on their margins and in the roof zones. The Sloan Group is younger than these plutons, and consists dominantly of dacite-rhyodacite-rhyolite flows and ignimbrites, and of a small proportion of mafic volcanic rocks, and numerous dacitic porphyritic dykes and subvolcanic intrusions. The Dumas Group is bimodal, and rhyolites dominate over basalts. Recent geochronological studies suggest that it is coeval with the LaBine Group (Hildebrand et al., 1987).

Uranium-lead zircon ages for volcanic and plutonic rocks in the northern part of the Great Bear magmatic zone near Great Bear Lake, and for the intrusions along the east arm of Great Slave Lake, have been reported by Van Schmus and Bowring (1984), Bowring (1984), and Bowring et al. (1984). More recently, Gandhi and Mortensen (1992) dated the volcanic and related dacite and quartz monzonite intrusions in the southern part of the magmatic zone by the U-Pb zircon method. These geochronological data show that the volcanic rocks and subvolcanic intrusions, including quartz monzonite plutons, were emplaced between 1870 and 1860 Ma, and were followed by the intrusion of younger granite batholiths during the period 1860 to 1840 Ma. This sequence of events was interpreted by Hildebrand et al. (1987) to be the result of eastward subduction of oceanic lithosphere, followed by ridge subduction that caused dextral transpression, crustal thickening, and generation of large, late granites.

Petrochemistry of the volcanic rocks of the three groups in the northern Great Bear magmatic zone indicates a calc-alkaline to subalkaline character, and the rocks have been regarded as a typical subduction-related calc-alkaline suite (Badham and Morton, 1976; Hoffman, 1980; Hildebrand et al., 1987). It must be noted, however, that the proportion of andesites is small (<10%) and their distribution is geographically restricted to an area near Great Bear Lake. Andesitic flows have not been found in the southern part of the magmatic zone. Here, rhyodacite-rhyolite flows and ignimbrites form a more than 3 km thick sequence, informally known as the Faber group, which is cut by numerous dacitic porphyry dykes and subvolcanic intrusions (Fig. 2; Gandhi, 1988, 1989; Gandhi and Lentz, 1990). The chemical characteristics of Faber group volcanic and intrusive rocks are discussed in a latter section. The voluminous continental felsic volcanism of the Great Bear magmatic zone is comparable in many respects, including its geologically short time span and metallogenic features, with that of the Gawler Ranges of South Australia (ca. 1600 Ma) (Wyborn, 1988); northern and central Sweden (ca. 1890 Ma)(Gaäl and Gorbatschev, 1987); and the St. Francois Mountains in Missouri, U.S.A. (ca. 1500 Ma) (Kisvarsanyi and Kisvarsanyi, 1989). In these cratonic regions the volcanic activity followed after the main phase of early Proterozoic orogeny, and as much as 200 to 300 million years later in the cases of the Australian and American areas. Hildebrand et al. (1987) have suggested that Great Bear volcanism occurred during active subduction. However, it is likely that crustal extension due to underplating, as suggested by Wyborn (1988) for the Gawler Ranges, rather than the compression inherent in the subduction model, was the primary cause of continental volcanism in all these regions, including the Great Bear magmatic zone.

Following the intrusion of late granites, there were movements along the Wopmay fault zone, and development of a set of northeast-trending right-lateral faults. Some of these faults are marked by giant quartz veins. The region has been tectonically stable since. It was partly or wholly covered by little disturbed younger Proterozoic and Phanerozoic strata, and is traversed by several diabase dykes and sheets of middle and late Proterozoic age (Fahrig and West, 1986). The most prominent of these dykes are the northwest-trending Mackenzie dykes in the north (ca. 1270 Ma) and east-north-east-trending sheets (ca. 780 Ma). The topography of the magmatic zone is characterized by low relief in granitic areas and hills as high as 150 m in volcanic terrain. The area has been glaciated, with evidence of east-to-west ice movement.

GEOLOGY OF THE SOUTHERN GREAT BEAR MAGMATIC ZONE

In regional mapping of the Great Bear magmatic zone south of latitude 65°N, Lord (1942) and Fraser (1967) recognized little deformed volcanic and intrusive porphyritic rocks, remnants of deformed metasedimentary rocks and abundant undifferentiated granites on the west side of the Wopmay fault zone (Fig. 1). East of the fault zone, the Archean Slave craton is overlain unconformably by a sequence of platform sedimentary rocks (conglomerate, sandstone, siltstone, shale, and dolomite) of the Aphebian Snare Group (Lord, 1942). These strata, similar to some of the units of the Coronation Supergroup in the northern part of the Wopmay Orogen (Hoffman, 1984; Frith, 1993), include some mafic to intermediate volcanic rocks (McGlynn, 1964; Easton, 1981). Unconformable contacts with Archean rocks are preserved at several places, but most of the strata of this group have been affected by deformation and metamorphism that accompanied the emplacement of the Hepburn suite of granitic plutons (Frith et al., 1977; Hildebrand et al., 1987; Frith, 1993).

Lithologically comparable metasedimentary rocks that occur as isolated remnants in the granitic areas of southern Great Bear magmatic zone have been regarded as equivalents of the Snare Group by Lord (1942), and this nomenclature has been followed by McGlynn (1968, 1977, 1979), and Gandhi and Lentz (1990). It is possible, however, that some of them may be older than the Snare Group (or Coronation Supergroup) and that they are equivalents of the metasediments of the Hottah terrane, as mentioned earlier. More detailed mapping and geochronological data are needed to define their stratigraphic relations more clearly and to differentiate the granitic plutons in the area. The volcanic and volcaniclastic rocks of the southern Great Bear magmatic zone show gentle to moderate dips in many places. They dip steeply in some places, but are not affected by tight folding and lack penetrative fabric. Much of the tilting and gentle folding is attributable to structural adjustment during the volcanic activity and subsequent intrusion of granitic plutons. Although northeasterly dips are common, northwest-trending folds, as seen in the equivalent rocks in the northern part of the Great Bear magmatic zone, are not evident from the mapping done to date. The rocks, however, have been affected by prominent northeast-trending, right lateral faults common throughout the magmatic zone, and by a few north-south faults. The rocks have been intruded by large northeast-trending gabbroic sheets, and smaller diabase dykes that are commonly less than a metre thick and are oriented randomly, except for some that suggest a northeast-trending swarm. Paleozoic sedimentary strata cover the southern Great Bear magmatic zone to the west and south, and dip very gently to the west. Progressively greater thickness of these is preserved towards the west, to as much as 500 m (Douglas et al., 1974).

Metasedimentary rocks

The metasedimentary rocks west of the Wopmay fault zone consist mostly of quartzofeldspathic siltstones, some argillaceous quartzite and calcareous beds, iron oxide-rich beds and lenses and a few garnetiferous amphibolitic lenses. The calcareous beds have been metamorphosed to calc-silicate rocks of variable composition. The metasedimentary assemblage occurs as remnants in granitic terrain. The largest remnant is in the area of the Rayrock mine (Fig. 2), where aggregate thickness of the beds is in the order of 1000 m (McGlynn, 1968). These beds strike northwest, and dip moderately to steeply to the northeast. Crossbedding in the southwestern part indicates that the beds here are right-side up, and may form one limb of a large synclinal structure. At DeVries Lake the beds are folded into a broad open syncline plunging gently to the northwest (see Fig. 6, below). The beds at most other places in the southern Great Bear magmatic zone have a general northwesterly trend, and their dips are usually steep, with local variations due to tight folding. Minor folds commonly plunge gently or moderately to the southeast or northwest. A well developed foliation is present in some beds. This foliation trends northwesterly and commonly dips steeply to the northeast. The metasedimentary rocks are migmatized along boundary zones with some of the granitic plutons, e.g., near the Rayrock mine, and at Hump and DeVries lakes (McGlynn, 1968; Gandhi, 1992a; Gandhi and Prasad, 1993). Although these metasedimentary rocks are lithologically similar to those on the east side of the Wopmay fault zone, no detailed stratigraphic correlations between the sedimentary rocks on the two sides of the fault zone have yet been made.

Older Aphebian intrusions

A large area south of the Rayrock mine is underlain by gneissic granodiorite that contains coarse feldspar phenocrysts or porphyroblasts (McGlynn, 1968). Foliation in this granodiorite, defined by the alignment of feldspar crystals and hornblende-biotite aggregates, varies in trend from north to northwest. The gneissic granodiorite, which appears to have intruded the metasedimentary rocks, contains numerous inclusions of these rocks, and locally grades into them. The gneissic granodiorite has been intruded in the north by an even grained, hornblende-biotite granite of variable composition. The contact between the two is locally gradational, and it appears that they are interrelated (McGlynn, 1968). Both are cut by quartz feldspar porphyry dykes and larger bodies, which were intruded during the Great Bear magmatic activity.

Gneissic granite-granodiorite bodies, commonly having a northwest-trending foliation, also occur to the north in the vicinity of the Wopmay fault zone. They are regarded here as synkinematic intrusions that accompanied deformation and metamorphism of the metasedimentary rocks. Additional bodies may occur in this little studied areas of 'undifferentiated granites'.

A large dacitic porphyry body near Hump Lake, mapped by Lord (1942) as intrusive, has well developed penetrative foliation, parallel to the regional northwesterly trend. Its contact with the siltstone observed south of Hump Lake is sharp and at places tightly folded. It is probably intrusive, and is distinguished as older than other porphyritic volcanic rocks of the Great Bear magmatic zone, which do not display penetrative foliation (Gandhi, 1992a).

Great Bear volcanic and intrusive rocks

Volcanic and volcaniclastic rocks

Extrusive rocks and associated tuffaceous sedimentary rocks of the southern Great Bear magmatic zone form a discontinuous north-northwest-trending belt (Gandhi, 1989). The basal unconformity of this sequence with the metasedimentary rocks is exposed at Lou Lake (Gandhi and Lentz, 1990). The Faber group volcanic sequence is 3 to 5 km thick in the Mazenod Lake area, and more than 2 km thick in the Fab Lake area to the north (Gandhi, 1988, 1989). Thick sections of it are well exposed at Mazenod Lake, where several cooling units have been recognized (see Fig. 10, below). Dips of the units, as indicated by flow contacts, flow banding, ignimbritic textures, and bedding in associated volcaniclastic siltstones, range from nearly horizontal to moderate, and in some places are steep to the northeast and north. Minor folds, including flow folds, are common, and larger scale folds are open to moderately tight. There is, however, no development of penetrative fabric in the rocks. Tops have been determined at many places from the flow top features in extrusive units, and from graded bedding and crossbedding in siltstones and fragmental units. The stratigraphic sequence is locally well established (Gandhi, 1988, 1989; Gandhi and Lentz, 1990), however, regional correlations are difficult because of variations and discontinuities in the units, and complexities due to folding, faulting, and intrusions, and inadequate mapping in intervening areas. The main volcanic units are thick and areally extensive rhyodacitic flows and ignimbrites that range in texture from massive porphyritic to streaky fiamme-rich to flow laminated. Early regional mapping by Lord (1942) did not distinguish between porphyritic flows and subvolcanic intrusions of porphyritic dacite and quartz feldspar porphyry. Subsequent detailed mapping of this 'porphyry' area, has revealed the presence of a large proportion of volcanic rocks (McGlynn, 1979; Gandhi, 1988, 1989; Gandhi and Lentz, 1990). Further mapping is likely to show an even greater relative abundance of volcanic rocks in the 'porphyry' area.

Intrusive rocks

The volcanic rocks of the Faber group have been intruded by related plutons and dykes of dacite, quartz feldspar and feldspar porphyries, diorite, quartz monzonite, and granite. Dacitic porphyries are common and areally extensive. They are regarded as subvolcanic intrusions. They typically have coarse phenocrysts of plagioclase, and smaller ones of hornblende and quartz, in an aphanitic matrix. Quartz feldspar porphyritic and feldspar porphyritic dykes may be related to dacite and quartz monzonitic intrusions. Small bodies and dykes of diorite are sparsely distributed in the region. In some

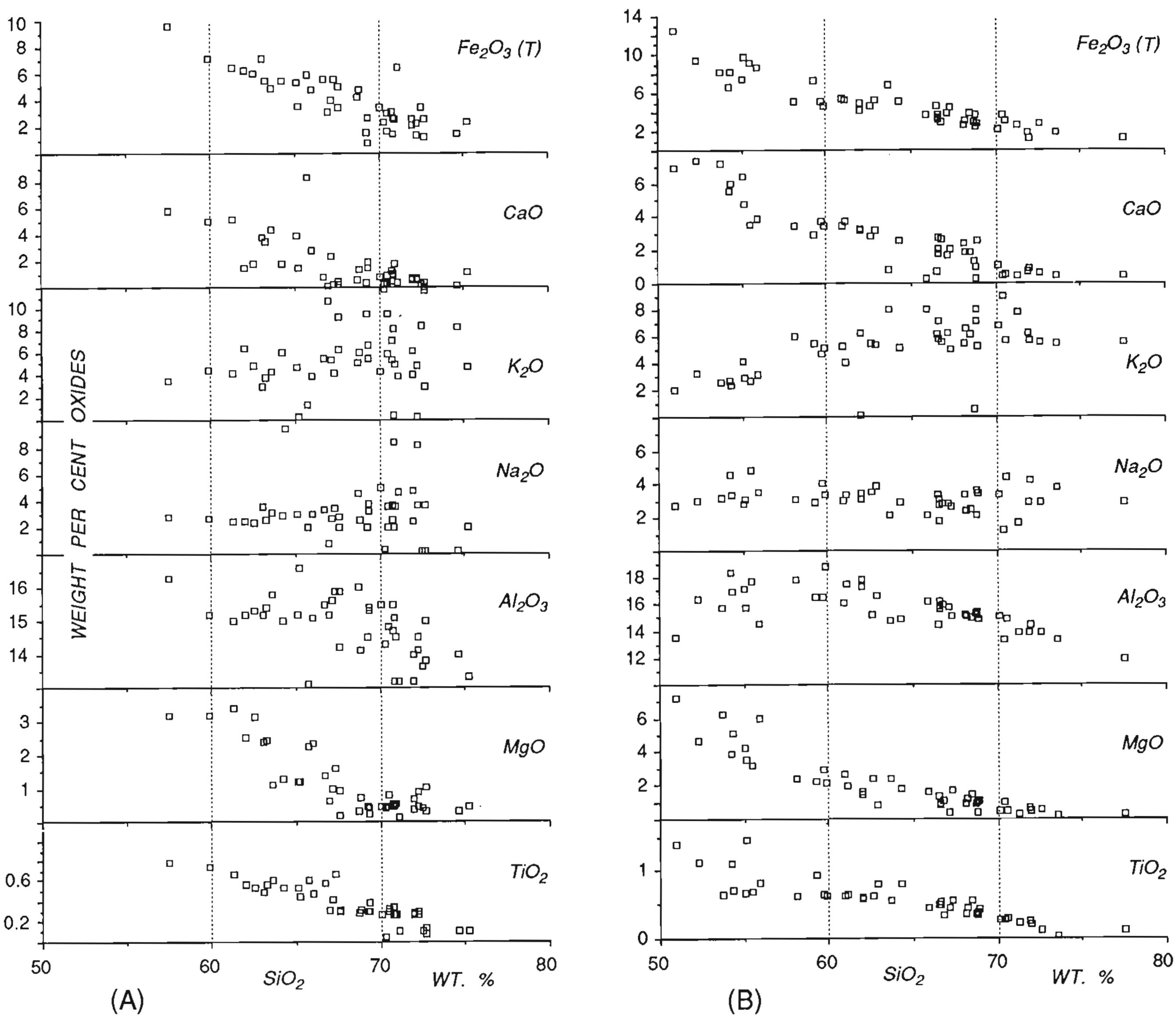

Figure 3. Harker diagrams for (A) volcanic and (B) intrusive rocks of the southern Great Bear magmatic zone.

cases, their age relative to other intrusives is uncertain, but in general they postdate the quartz monzonites and predate the granites. Quartz monzonitic intrusions in the southern Great Bear magmatic zone have only recently been recognized, and are significant in that they are comparable to those in the northern part of the magmatic zone, and in the east arm of Great Slave Lake, and have associated magnetite-apatite-actinolite veins. They range in composition from monzodiorite to granodiorite and contain well developed feldspar crystals with hornblende as the dominant mafic mineral. Associated dykes are common in the Lou Lake area (Gandhi and Lentz, 1990). In the Hump Lake area, a quartz monzonite has intruded metasedimentary rocks and contains numerous xenoliths of these rocks (Gandhi, 1992a).

Granites are among the youngest intrusions, and occur as small bodies of leucogranite and large plutons of granite-granodiorite. Only marginal parts of a few of these plutons are well mapped to date. The southern Great Bear magmatic zone is probably dominated by these granites, but also includes some of the previously mentioned older granitic rocks. Small bodies of diorite and numerous dioritic dykes are also present. Some of them are appinitic, characterized by hornblende phenocrysts, as seen at DeVries Lake (see Fig. 6, below). Relative ages of the diorites and other intrusions in the southern Great Bear magmatic zone are not certain. It appears that the diorites were intruded at different times, and some of them may be younger than the granites.

Petrochemistry of the volcanic and intrusive rocks

The major and minor element geochemistry of 43 volcanic rocks of the Faber group and 44 related intrusive rocks are displayed in Harker diagrams (Fig. 3A, B), AFM diagrams (Fig. 4A, B), and in plots of silica versus Na_2O+K_2O (Fig. 5A, B). The samples are from the areas around the Sue-Dianne and Mar deposits, Fab Lake and Lou Lake (see Fig. 9 and 11 to 13, below). Complete analytical data have been previously reported in Gandhi (1988, 1989, 1992b) and Gandhi and Lentz (1990). The samples of the volcanic rocks are considered fairly representative of the Faber group. However, in the case of the related intrusive rocks, the large plutons of younger granite are not adequately represented in the sample population. The samples also include diorites and some mafic varieties of the quartz monzonites that are volumetrically not significant. The most mafic sample is a magnetite-rich flow in the Fab Lake area. One rock from the Mazenod Lake area, previously regarded as a probable andesitic flow (Gandhi, 1989, p. 265, 267), is now considered to be an altered diorite based on its similarity with a dioritic dyke at the Mar prospect 5 km to the north (Gandhi, 1992b).

The volcanic sequence displays a rather narrow range in silica content (i.e., most samples plot in the range from 62 to 72 wt.% SiO_2). A relatively greater range in silica contents for the intrusive rocks reflects the inclusion of diorites and mafic varieties of quartz monzonite. For both volcanic and intrusive

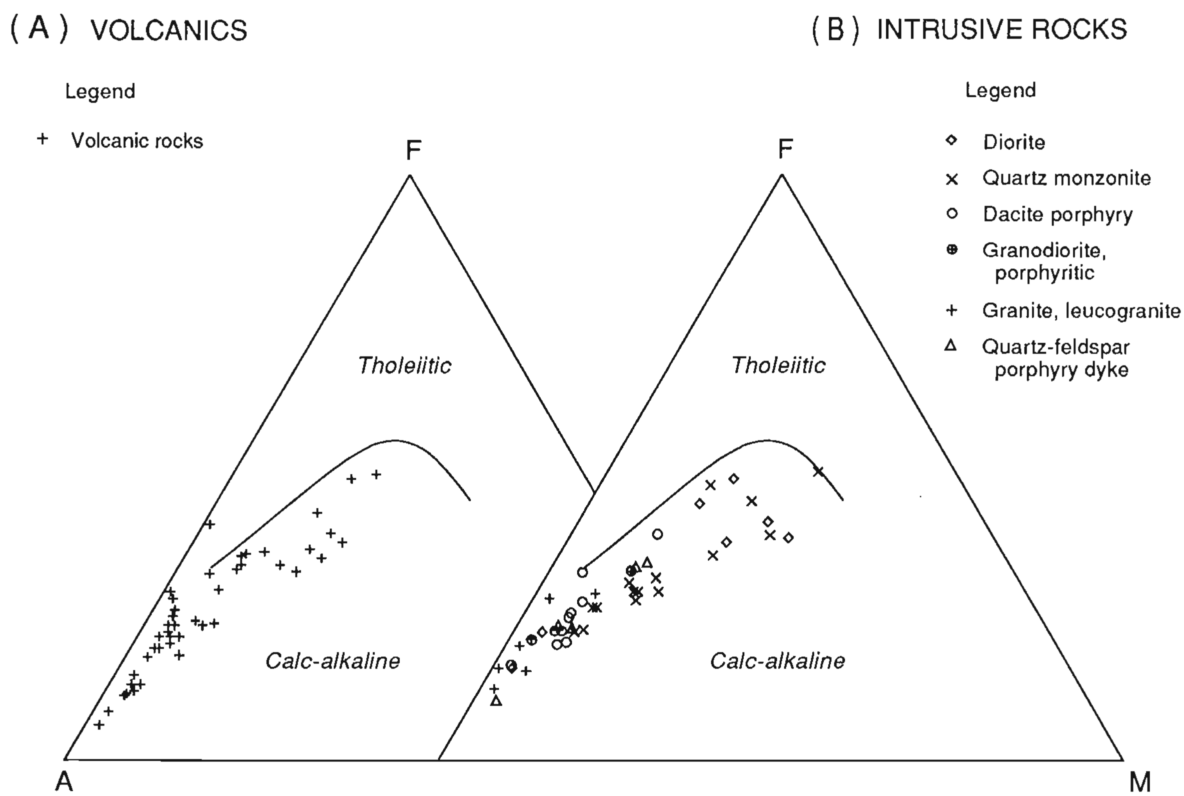

Figure 4. *AFM plots for (A) volcanic and (B) intrusive rocks of the southern Great Bear magmatic zone. Dividing line between the calc-alkaline and tholeiitic fields is from Irvine and Baragar (1971).*

rocks, the contents of total Fe_2O_3, CaO, MgO, and TiO_2 show smooth declines as silica content increases (Fig. 3). The Na_2O, K_2O, and Al_2O_3 contents show considerable scatter in the volcanic rock population (Fig. 3A), and less so in the intrusive rock population (Fig. 3B). The total alkalies range between 6 and 12%, and in general potassium dominates over sodium. The data indicate that some of the volcanic rocks have undergone alkali metasomatism and hydrothermal alteration.

The AFM plots, shown in Figure 4, reveal that data for both volcanic and intrusive rocks plot in the 'very felsic' region of the diagram, where the distinction between the tholeiitic and calc-alkaline fields is poorly defined (Fig. 4); however, relatively more mafic rocks in each sample group/population display a definite calc-alkaline character. In the silica versus total alkalies plots (Fig. 5), both groups straddle the boundary between the alkaline and subalkaline fields. These data suggest that the southern Great Bear magmatic zone volcano-plutonic assemblage has an overall calc-alkaline character that borders on the alkaline field.

Similar to the LaBine Group in the northern Great Bear magmatic zone, the Faber group has been intruded by quartz monzonites. Recent geochronological investigation of these quartz monzonites suggest that the two volcanic sequences, as well as the Dumas Group, are approximately coeval (Gandhi and Mortensen, 1992; Hildebrand et al., 1987), however, basalts and andesites that characterize the LaBine Group are not seen in the Faber group rocks, which lithologically more closely resemble Sloan Group rocks. The Faber group is texturally and chemically comparable with the felsic dominated intracratonic volcanic sequences formed in extensional regimes such as those in the southeast Missouri granite-rhyolite terrane (Kisvarsanyi and Kisvarsanyi, 1989) and the Gawler Ranges of South Australia (Giles, 1988; Creaser and White, 1991). Andesites, typically characteristic of subduction related calc-alkaline sequences, are scarce in these anorogenic volcanic sequences which are commonly bimodal or dominantly felsic. As previously noted, the overall proportion of andesites in the northern Great Bear sequence is less than 10% and the basalt/andesite ratio is high (Hoffman and McGlynn, 1977).

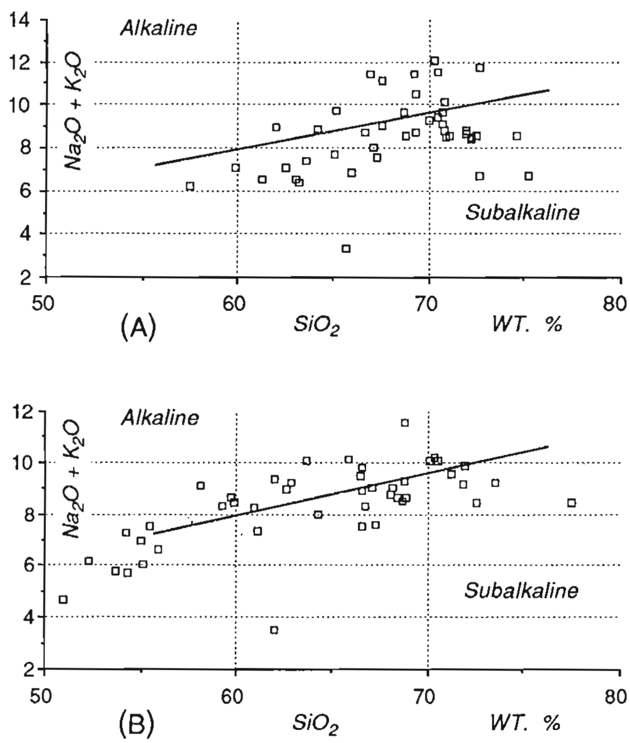

Figure 5. *Silica versus alkalis plot for (A) volcanic and (B) intrusive rocks of the southern Great Bear magmatic zone. Dividing line between the alkaline and subalkaline fields is from Irvine and Baragar (1971).*

Diabase dykes and sheets

Two main groups of diabase intrusions are found in the southern Great Bear magmatic zone: a group of small (<1 m thick), northeast-trending, massive and feldspar porphyritic dykes, and a few large, northeast- to east-northeast-trending sheets (Fahrig and West, 1986). Recent geochronological studies show that the sheets were intruded 780 Ma ago (K. Buchans, GSC, pers. comm., 1993). Dykes of the large northwest-trending Mackenzie swarm (ca. 1270 Ma old), which occur in the northern part of the magmatic zone, are not found in the southern part.

MINERAL OCCURRENCES

Mineral deposits and occurrences in the southern part of the Great Bear magmatic zone are numerous and varied. They are broadly grouped here into six main types to facilitate discussion of their general features, genetic aspects, resource potential, and guides to exploration. The descriptions are based on the data from assessment files, and from field and laboratory investigations. The six deposit types represent different stages of metallogenic evolution of this part of the Great Bear magmatic zone:

i) Synsedimentary/diagenetic sulphide and iron oxide concentrations in metasedimentary rocks (e.g., Kol, Jones, Hump Lake, and Ron showings);

ii) Felsic volcanic-associated uranium occurrences (UGI/DV prospect and FXO showings);

iii) Monometallic and polymetallic magnetite-rich veins and breccia-fillings, related to the Great Bear magmatic activity, comprised of two subgroups:

   a) Magnetite-apatite-actinolite±uranium±copper veins of Kiruna-type (Fab north, Tan, and Honk prospects);

   b) Breccia zones with magnetite matrix containing copper, uranium, and gold of Olympic Dam-type (Sue-Dianne and Mar deposits; Fab showings);

iv) Granite-related uranium±copper±molybdenum mineralization, locally superimposed on the iron oxide concentrations in metasedimentary rocks (e.g., Nori/RA showings);

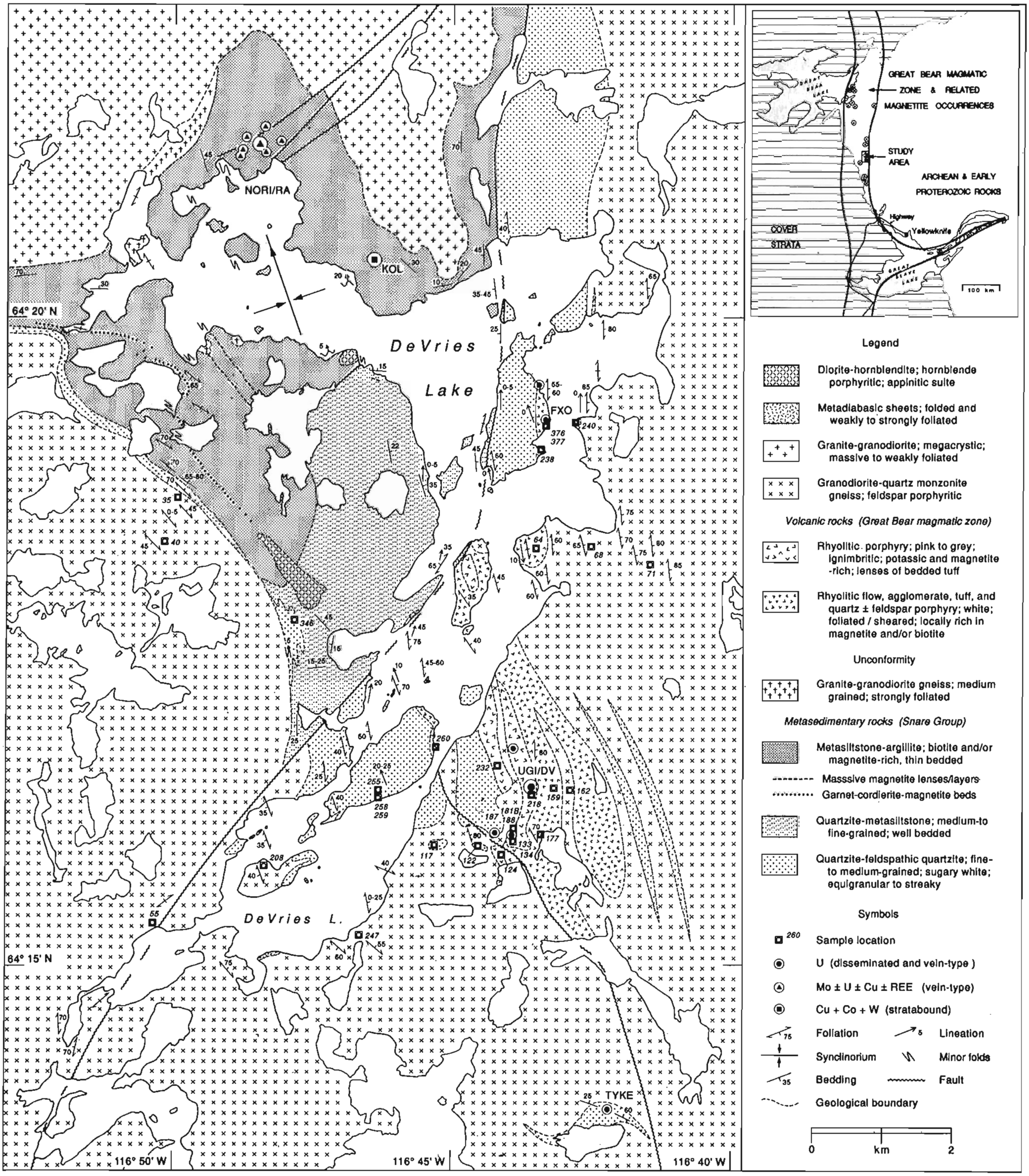

Figure 6. *General geology and mineral occurrences of the DeVries Lake area, southern Great Bear magmatic zone, Northwest Territories (after Gandhi and Prasad, 1993).*

v) Bismuth-cobalt-copper-gold-bearing arsenopyrite-pyrite hydrothermal veins and disseminations related to the Great Bear magmatic activity (Gar prospects and Burke Lake showings);

vi) Vein-type uranium±copper occurrences in brittle fractures that postdate the Great Bear magmatic activity, including giant quartz veins (Rayrock mine and numerous small occurrences).

Synsedimentary/diagenetic sulphide and iron oxide concentrations

The metasedimentary rocks contain some argillaceous beds and lenses that have disseminated and stratiform concentrations of pyrite±chalcopyrite±magnetite, and many siltstone beds that have significant concentrations of magnetite± hematite, but little or no sulphides. These occurrences have undergone folding and metamorphism that affected the host strata.

Sulphide concentrations

Sulphides are widely distributed in some argillaceous and associated metasediments. Locally, these sulphides are found in concentrations having significant contents of base metals and other metals. The main occurrences of this type are the Kol and Jones showings.

Kol copper showing

This is a chalcopyrite-pyrite-magnetite showing in metasiltstones on the north shore of DeVries Lake (Fig. 2, 6). Pyrite and chalcopyrite occur as thin stratiform layers and lenses, as much as 0.5 cm thick, interbedded with biotitic siltstone (Gandhi and Prasad, 1993). They are folded into a small synclinorium plunging gently to the north. Most of the sulphides are along conformable layers and lenses, but a small proportion of the sulphides also occurs as discordant veins. Sparsely distributed granitic veinlets, some of them ptygmatic, postdate the sulphides. Magnetite is present in the sulphide-rich layers and is coarser than the magnetite in the associated siltstones.

Jones copper-uranium showing

This showing is located south of Hailstone Lake, 45 km north of the Kol prospect, in deformed and metamorphosed siltstones containing stratiform concentrations of magnetite (Gandhi et al., 1992). Pyrite and chalcopyrite occur locally as aggregates associated with magnetite lenses as much as 0.5 m thick. Uranium is associated with the magnetite as pitchblende veins and disseminations. It is more widely distributed than the sulphides.

Other occurrences of sulphide-bearing chloritic argillaceous rocks are near Lou Lake (Gandhi and Lentz, 1990), and some have been reported at several other localities in the region of the Rayrock mine (Shegelski and Thorpe, 1972). Magnetite-rich layers are associated with them, and are a few millimetres to a few centimetres thick. Magnetite and pyrite are generally fine grained in these beds, and form layered aggregates and disseminations. At Lou Lake, they appear to be the preferred hosts of the epigenetic polymetallic arsenopyrite veins and disseminations described later.

Known occurrences of this deposit type are too small to be economically significant. However, it should be noted that the favourable argillaceous metasediments are poorly exposed in the study area due to differential erosion, and may be more abundant than appears to be the case. There has been little exploration to assess their mineral resource potential. It is relevant that east of the southern Great Bear magmatic zone, the Snare Group shales also contain sulphides. The best example is the Norris showing located approximately 45 km east of the Wopmay fault zone at latitude 64°26′30″N; longitude 11°54′530″W. Here, grey to black shale-siltstone beds, associated with dolomite and sandstone in a synclinal structure, host stratiform and disseminated concentrations of pyrrhotite, arsenopyrite, and graphite. Sphalerite, galena, and pyrite also occur in some beds, but these minerals occur more abundantly in seams, lenses, and veins of quartz, as much as 65 cm wide, which also contain gold and silver (Lord, 1951, p. 138; McConnell, 1970; Harris and Ryznar, 1984, Dobek, 1985). Trenching and drilling done in the 1940s and 1960s outlined a zone containing 73 500 tonnes of resources with an average grade of 0.228 oz/ton (10.1 g/t) gold. Among the better grade trench assays reported are 5.06% Pb, 4.70% Zn, 2.70 oz/ton (92.46 g/t) Ag, and traces of Au across a width of 1.8 m, and 1.04 oz/ton (35.6 g/t) Au, 1.2 oz/ton (41.08 g/t) Ag, 2.54% Pb, and 0.37% Zn across a width of 3 m.

Iron oxide concentrations

Magnetite and some associated hematite are widely distributed through the metasiltstones in concentrations ranging from a few per cent to a few tens of per cent. Locally, magnetite forms massive iron oxide beds and lenses. Their presence is reflected as regional airborne magnetic anomalies in an area near the Wopmay fault zone, which seems to broaden to the north. Two showings at Hump Lake which have been studied in detail (Gandhi, 1992a), are briefly described below. These were discovered in the 1970s during the search for polymetallic magnetite deposits that occur as veins and breccia fillings. Stratiform magnetite concentrations also occur at many other localities in the southern Great Bear magmatic zone, and some of them host notable amounts of copper sulphides, pyrite, and pitchblende, e.g., the Kol and Nori/RA showings at DeVries Lake (Fig. 6), and the Jones, Ham, and JLD showings near Hailstone Lake, 45 km to the north (Gandhi and Prasad, 1993; Gandhi et al., 1992).

Hump Lake North deposit

This deposit is in a tightly folded stratigraphic zone which is more than 300m long, and in some outcrops, more than 20 m wide (Fig. 7) (Gandhi, 1992a). It is comprised of thin iron oxide-rich beds and lamellae interlayered with oxide-poor quartzofeldspathic beds. The boundary of the deposit with adjacent siltstone is marked by interbedding and is abrupt to gradational over a metre or so. The siltstones and the deposit are tightly folded, as seen from V-shaped minor folds on the scale of metres. More open minor folds occur in the middle part of the deposit where there is a change in strike from a general north-northwest direction to the southwest. The plunge of these folds is moderate to the southeast. The deposit is cut by a few leucogranite dykelets.

Petrographic study revealed a granoblastic texture, with well preserved bedding and lamination. Magnetite predominates over hematite, but in some layers hematite is predominant. Twin lamellae are seen in many hematite crystals. Some thicker beds of iron oxides contain layers of relatively coarser crystals parallel to bedding. In such coarser beds, hematite is generally more abundant than magnetite. Coarse aggregates and veinlets in disrupted parts of beds contain mostly hematite. Replacement of magnetite by hematite along margins and cracks is seen in a few grains. Feldspar is more abundant than quartz, and it is mainly potassium feldspar and perthite. Apatite and zircon are sparsely distributed. Epidote and clinopyroxene occur in some layers close to the boundary with siltstone. Spectrometer readings indicated less than 5 ppm equivalent U and 15 ppm equivalent Th. No other metallic minerals were found. Although traces of copper minerals were reported by prospectors, it is likely that iridescent colours developed on iron oxide aggregates exposed to weathering may have been mistakenly attributed to the presence of copper minerals.

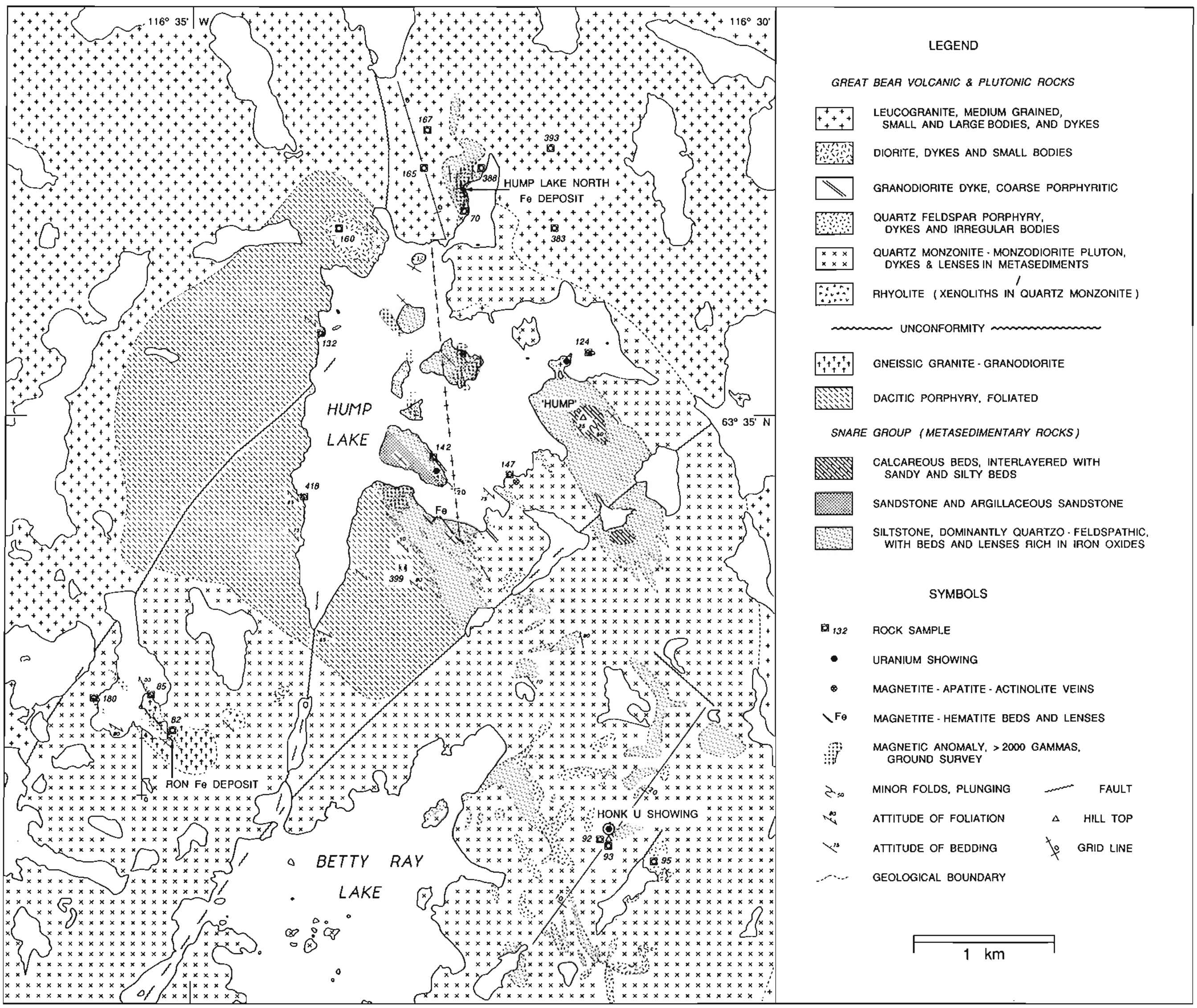

Figure 7. *Geology and stratiform iron oxide occurrences of the Hump Lake area, southern Great Bear magmatic zone (after Gandhi, 1992a).*

Ron deposit

This deposit is poorly exposed, and magnetic data indicate a strike length of greater than 200 m, most of it under a small lake (Fig. 7) (Gandhi, 1992a). The main exposure at the southeast end of the lake is as much as 22 m wide and contains more than 50% magnetite. On the west shore of the lake, a few smaller exposures have bands and disrupted patches of massive magnetite, ranging from 0.5 m to a few metres in width. A thin-bedded siltstone occurs adjacent to the magnetite zone. It has a northwest trend, steep dips, and locally minor folds that plunge moderately to the southeast. The lighter coloured beds in the siltstone contain lamellar twinned plagioclase, untwinned feldspar, diopside and/or amphibole, and scattered magnetite. The darker beds and aggregates contain relatively more magnetite (>25%) and some apatite. At the southeastern shore of the lake, a quartz monzonite intrusion truncates the boundary between the magnetite zone and siltstone. On the west shore of the lake, the quartz monzonite contains xenoliths of magnetite. Paragenetically late epidote, found occurring as veins and irregular patches in magnetite that predates the quartz monzonite, is common at both localities. In addition, there are epidote veins younger than the quartz monzonite.

Magnetite is the predominant iron oxide, and has been replaced by hematite along the margins of grains and cracks. A few crystals have been completely replaced by hematite. The proportion of hematite is, however, small in contrast to that in the Hump Lake North deposit. In the southeastern exposure of the Ron deposit, the central part of the magnetite zone has prismatic crystals of altered pyroxene as long as 5 cm. X-ray diffraction of the unaltered core and altered zone showed them to be clinopyroxene and talc, respectively. Microprobe analyses gave the following composition range for the pyroxene from three separate spots in terms of mole per cent wollastonite (Wo), enstatite (En), and ferrosilite (Fo): i) Wo 47.02, En 43.86, Fs 3.04; ii) Wo 46.76, En 39.90, Fs 6.98; and iii) Wo 43.78, En 28.89, Fs 17.01. In addition to talc, the presence of tremolite is suggested from petrographic observations. The rock contains trace amounts of apatite and chlorite, and veinlets containing actinolite and some sphene.

Elsewhere in the Hump Lake area, magnetite and hematite, in lenses and beds that are as much as a metre thick and several tens to a few hundred metres long, are found in metasiltstones. They constitute more than 50% of the rock in granoblastic aggregates with quartz, feldspar, diopside, amphibole, and epidote. Iron oxide-rich layers alternate with quartzofeldspathic layers. The bedding is well preserved even in tight minor folds.

Felsic volcanic-associated uranium occurrences

Anomalously high concentrations of uranium and a few pitchblende stringers and aggregates occur in a northerly trending, moderately to steeply east-dipping, felsic volcanic assemblage found on the east side of DeVries Lake (Fig. 6). Main occurrences of this deposit type include the UGI/DV prospect and the relatively smaller and less explored FXO showings (Gandhi and Prasad, 1993).

UGI/DV prospect

Anomalously high radioactivity occurs discontinuously on a ridge top in a zone more than 1 km long and 50 m wide. The prospect was explored by 4 trenches and 8 drill holes totalling 450 m. Exploration data show that high grade mineralization is found in lenses that are only a few centimetres wide and a few metres long (Legagneur, 1969; Paterson, 1974, 1975a, b; Male, 1978). These mineralized lenses trend northerly and dip moderately to steeply to the east. The best intersection obtained was from drill hole DV-2 at about 10 m depth, which averaged 0.07% U over a core length of 1.5 m (Male, 1978).

Anomalous radioactivity coincides with strongly magnetic zones in the host rhyolitic volcanic and volcaniclastic assemblage, which is locally mylonitized and sheared. Most of these zones are in a pink to grey, potassium-rich feldspar porphyritic unit. Spectrometer readings indicate the presence of 20 to 100 ppm equivalent U (Gandhi and Prasad, 1993). Other mineralized zones found in white felsic volcanic units contain disseminated magnetite and/or streaky aggregates of biotite, hornblende, and magnetite, and rarely magnetite streaks as much as 10 cm long. Uranium is preferentially concentrated in these mafic aggregates.

Uranium occurs mainly as euhedral crystals of uraninite, but pitchblende is also present as grains and overgrowths on uraninite (Paterson, 1975b). Miller (1982a, b) noted an association of epidote, apatite, and fluorite, and some scapolite in the host rocks. He obtained an age of 1864 ± 14 Ma for the uraninites in relatively more mafic rocks from the UGI/DV prospect.

Monometallic and polymetallic magnetite-rich deposits

A metallogenically distinctive feature of the Great Bear magmatic zone is the presence of numerous magnetite-rich veins and breccia-fillings, which contain various proportions of other minerals (Fig. 8). Field relations observed at many of these occurrences indicate that they: 1) were formed during the episodic Great Bear magmatic activity; 2) are closely associated in time and space with early quartz monzonitic intrusions; and 3) formed prior to the emplacement of the abundant granites, which marked the closing stages of the magmatic activity. Based on their mineralogy and morphology, these deposits can be subdivided two subgroups.

Subgroup 1 veins and fracture-fillings, which contain variable amounts of magnetite, apatite, and actinolite, with traces of pyrite and chalcopyrite, but little or no uranium or other metals, are regarded here as essentially monometallic (Fe only) occurrences. These are comparable morphologically and mineralogically with the much larger tabular magnetite deposits of the Kiruna district in northern Sweden (Geijer, 1931; Parák, 1975; Badham and Morton, 1976; Hildebrand, 1986; Gandhi and Bell, 1990, 1993). The Kiruna deposits are associated with ca. 1885 Ma old continental felsic volcanic rocks, and have aggregate resources of greater than 3 billion tonnes of iron ore (Frietsch et al., 1979; Skiöld, 1987; Cliff et al., 1990). Magnetite deposits of similar mineralogy, but pipe-like in form, occur in a ca. 1500 Ma old continental felsic volcano-plutonic setting in the St. Francois Mountains of Missouri, U.S.A. (Bickford and Mose, 1975; Bickford et al., 1986; Kisvarsanyi and Kisvarsanyi, 1989; Marikos et al., 1989).

Subgroup 2 breccia-fillings, which contain abundant magnetite, hematite (specularite), and epidote, as well as different amounts of minerals containing uranium, copper, gold, cobalt, and nickel, are referred to as polymetallic deposits. Two important deposits of this type in the southern Great Bear magmatic zone are the Sue-Dianne and Mar deposits (Fig. 2, 8). They are similar in many respects to the giant Olympic Dam deposit in South Australia, which contains 2 billion tonnes of ore averaging 1.6% Cu, 0.05% U, 0.06 g/t Au, and notable amounts of rare-earth elements (Roberts and Hudson, 1983; Reeve et al., 1990; Oreskes and Einaudi, 1990; Gandhi and Bell, 1990, 1993). The Olympic Dam deposit is hosted by a hematite-magnetite-rich multistage breccia zone related to a continental (ca. 1600 Ma old) felsic volcano-plutonic complex within the Gawler Ranges (Fanning et al., 1988; Mortimer et al., 1988; Johnson and Cross, 1991).

It is important to note that copper sulphides and/or pitchblende also occur in some of the magnetite-apatite-actinolite veins at the Fab and Tan showings (Fig. 2, 8), and in other veins found along the east arm of Great Slave Lake, some of which also contain nickel-cobalt arsenides (Gandhi, 1988; Badham, 1978a; Badham and Muda, 1980; Gandhi and Prasad, 1982). Most of these polymetallic veins have marginal breccia zones in places, and they locally form stockworks. It is thus apparent that mineralogically, as well as morphologically, these deposits/occurrences represent a gradation between the monometallic veins (subgroup 1) and polymetallic breccias (subgroup 2).

Magnetite-apatite-actinolite veins (Kiruna-type)

A number of veins of magnetite, containing variable amounts of apatite and actinolite, occur in the southern Great Bear magmatic zone. Most of them are small; they range in length from a few metres to a few tens of metres and are as much as a metre in width. A few larger ones occur at the Fab showings, and clusters of small veins are found here and at the Nod showings. They are generally hosted by felsic volcanic units and dacite; however, quartz monzonite is exposed in the vicinity of the Fab North showings. In the Hump Lake region, small veins are observed in and adjacent to quartz monzonitic intrusions.

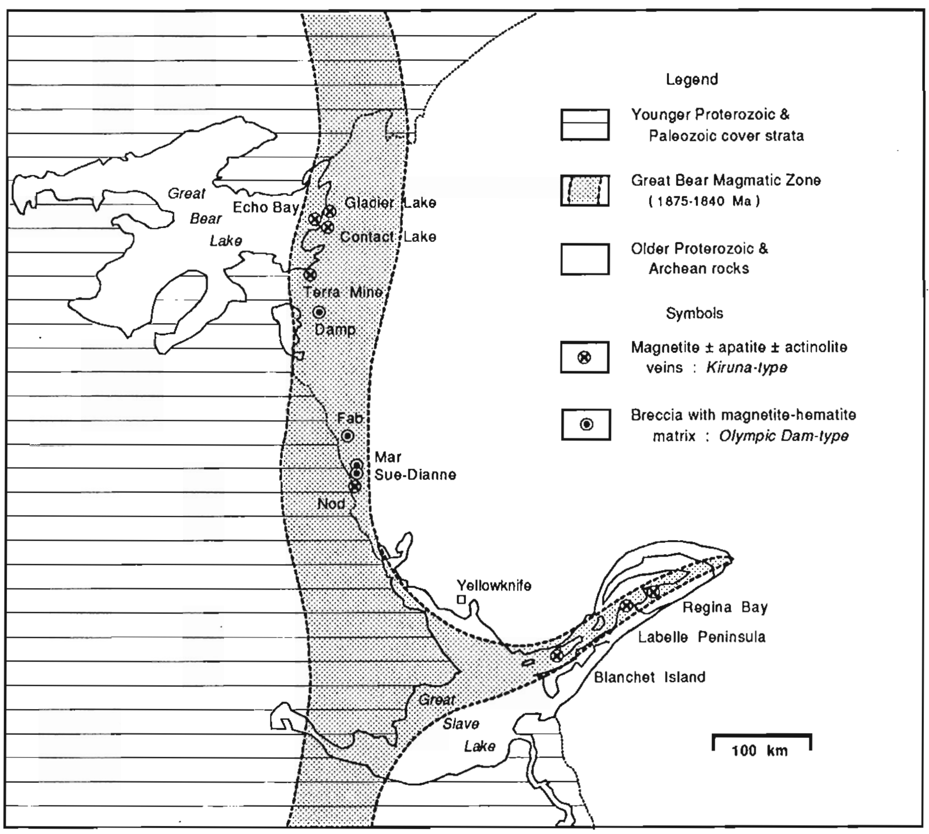

Figure 8. *Areal extent of the Great Bear magmatic zone and selected occurrences of magnetite veins and breccia-fillings. Outline of the magmatic zone in the area covered by younger strata and lakes is based on continuation of the high magnetic anomalies, which are distinctive of the zone in its exposed part, as noted from the regional airborne magnetic survey maps.*

Fab North showings

A north-trending vein, as much as 2 m wide and 100 m long, is located near the northeast shore of Fab Lake (A-6, Fig. 9) (Gandhi, 1988). It is characterized by coarse crystal aggregates of magnetite, apatite, and actinolite. Proportions of these three minerals vary greatly. Magnetite and actinolite dominate in alternate bands parallel to the vertical walls. Apatite is the least abundant phase, and is concentrated in a few magnetite-rich bands. A few hundred metres northwest of this vein (A-7, Fig. 9), a cluster of similar veins occur which typically have a gentle to moderately northward dip. Vein contacts are commonly sharp, but in a few places brecciation and slight hematitic alteration of wall rock have been observed. Pinching and swelling, as well as bifurcation and coalescence, are common features of the veins.

Nod prospect

A stockwork-like cluster of veins exposed on a hill at the Nod prospect (Fig. 10) is characterized by abundant coarse actinolite prisms as much as 5 cm long. The prisms contain inclusions of magnetite and apatite. Magnetite also forms aggregates that are interstitial to actinolite. Apatite is distributed irregularly and sparsely in the aggregates. Other veins in a nearby overburden-covered area to the northeast are magnetite-rich, contain chalcopyrite and pyrite, and have been explored by percussion drilling (Gandhi, 1992b).

Polymetallic magnetite-matrix breccias (Olympic Dam-type)

Two deposits near Mazenod Lake, namely the Sue-Dianne and Mar, are the best examples of the copper-uranium-gold-iron-bearing breccia deposits in the rhyodacite-rhyolite pile of the Great Bear magmatic zone (Fig. 11; Gandhi, 1989, 1992b). As previously mentioned, the discovery of the Sue-Dianne deposit resulted from the regional airborne gamma-ray spectrometer survey completed by the GSC in 1974 (Charbonneau, 1988). Further exploration of the southern Great Bear magmatic zone, led to the discovery of the Mar, Nod, and several other prospects in the area.

Sue-Dianne deposit

This deposit is an irregular, pipe-like breccia zone in a thick pile of rhyodacite ignimbrite (Gandhi, 1989). Exploratory drilling of 14 holes (Fig. 12) indicated the presence of 8 million tonnes averaging 0.8% Cu to a depth of 300 m. Magnetite forms fine- to medium-grained aggregates, and is associated with, and in part replaced by, hematite. Copper sulphides are distributed as veinlets, stringers, and disseminations within the breccia matrix, and to a lesser extent in the fragments. Chalcopyrite is the dominant sulphide, but bornite and chalcocite are widely distributed, and predominate over chalcopyrite in some drill sections. Some copper-rich drill intersections contain as much as 60 g/t Ag and 0.34 g/t Au. Pitchblende occurs in two modes: as finely disseminated grains in magnetite aggregates that commonly assay 75 to 150 ppm U, and as massive aggregates in veins cutting the magnetite-cemented breccia. The pitchblende veins contain variable amounts of copper sulphides, quartz, calcite, hematite, and traces of mineral phases containing bismuth, selenium, and tellurium, including kawazulite identified by Miller (1982a, b). Miller's (1982b) Pb isotopic dating of six samples, from two hand specimens, containing pitchblende defined an isochron age of 457 ± 26 Ma.

Mar deposit

The Mar deposit is 2.5 km northeast of the Sue-Dianne deposit, and is similar to it but smaller in size (i.e., nearly half in terms of surface area) (Fig. 3; Gandhi, 1992b). The deposit is a pipe-like breccia body that straddles the contact between a rhyolite sequence and a large diorite dyke (Fig. 13). The core of the breccia zone contains several irregular and dyke-like bodies of nearly massive magnetite with minor epidote. These bodies are as much as 8 m wide, and contain numerous angular and subrounded fragments of rhyodacite. Several large blocks of diorite are found in the east central part of the breccia zone. On the western side of the breccia zone, the diorite body is strongly brecciated and epidotized. Magnetite, forming coarse aggregates, is the dominant mineral in the deposit; associated minerals include hematite and epidote, and minor to trace amounts of pyrite, chalcopyrite, pitchblende/uraninite, quartz, chlorite, and amphibole. Chalcopyrite is sparsely and irregularly distributed in the magnetite aggregates. Pitchblende is common as fine grained disseminations, and a spectrometer survey of the deposit revealed 25 to 125 ppm equivalent U throughout many of the magnetite-rich portions of the breccia zone (Gandhi, 1992b). Similar distribution of these minerals is also observed in the core from a vertical drill hole 127 m long.

Fab uranium-copper showings

Magnetite-rich veins and associated small breccia-fillings, which comprise the Fab uranium-copper showings (A-1 to A-5, Fig. 9), are hosted by rhyodacite-rhyolite extrusive units, associated fragmental units and intrusive dacitic porphyry. They contain variable amounts of pitchblende, chalcopyrite, pyrite, fluorite, apatite, and actinolite (Gandhi, 1988). The veins are widely distributed in a north-trending zone 7 km long and 2 km wide. The showings are as much as 100 m long and 5 m wide. Four of the showings that contain copper and uranium have been trenched (A-1 to A-4, Fig. 9). In these showings, uranium and fluorite commonly occur as veinlets and fracture fillings, and only small amounts of apatite and actinolite are present.

Granite-related occurrences

Although granitic plutons are aerially extensive in the southern Great Bear magmatic zone, few mineral occurrences are related to them. The most important of these occurrences are the molybdenum-uranium-copper-bearing veins in the DeVries Lake area. Other occurrences are mostly small veins that contain copper±uranium and variable amounts of quartz and other gangue minerals. Small radioactive pegmatitic patches have been noted at several localities.

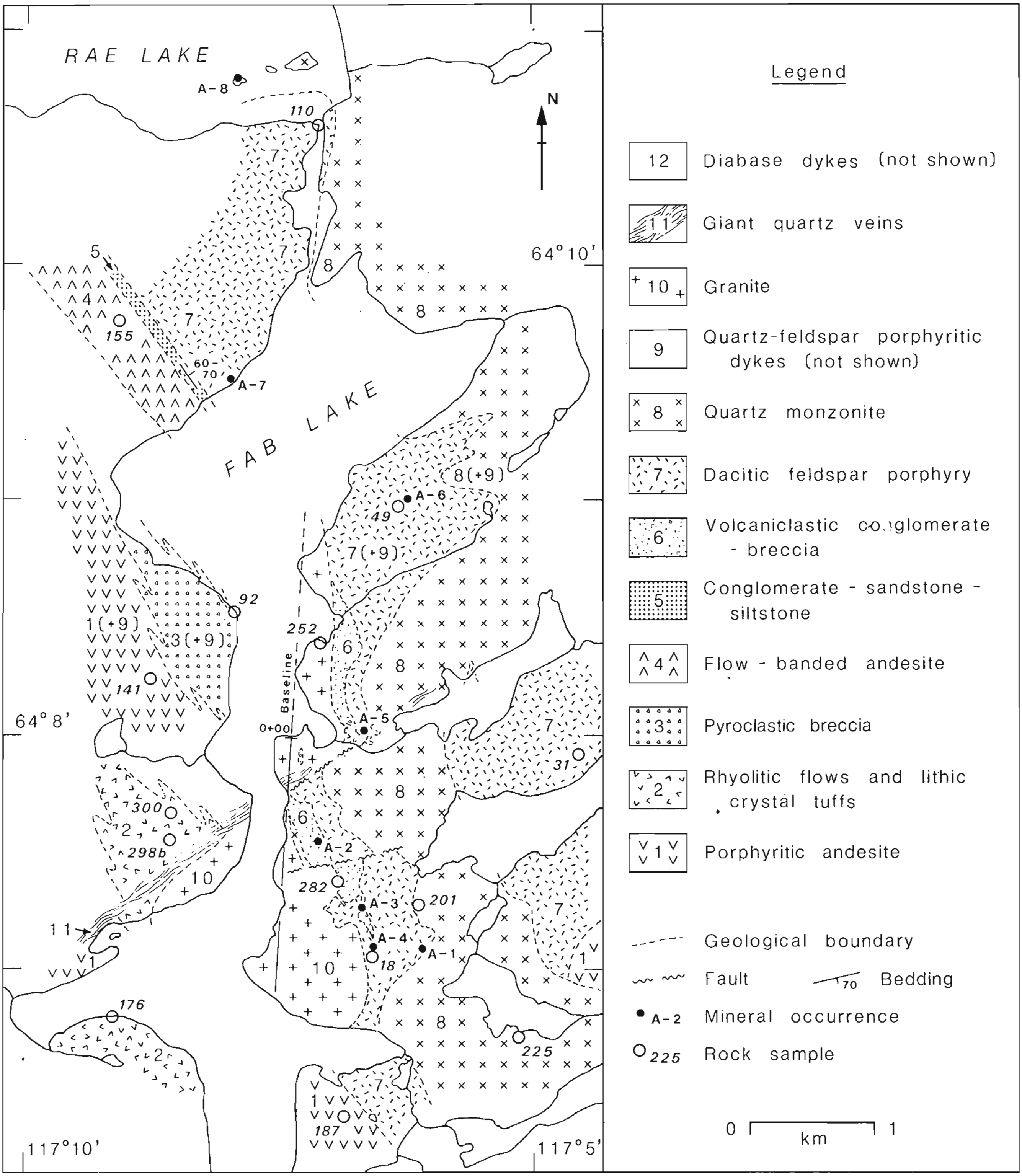

Figure 9. Geology and mineral occurrences of the Fab Lake area, southern Great Bear magmatic zone, Northwest Territories (after Gandhi, 1988).

Nori/Ra molybdenum-uranium±copper showings

Veins containing molybdenite, pitchblende, tourmaline, and traces of sulphides are widely distributed in an area 1.5 by 1 km within the Nori/RA claims on the north shore of DeVries Lake (Fig. 6). They occur in highly crenulated biotite-bearing metasiltstones that are close to migmatized zones. The veins pinch and swell, and range in width from a few centimetres to 0.5 m. The larger ones are as much as 30 m long. They have variable strike, and are generally steeply dipping. They are discordant to the bedding in the folded biotite-rich metasiltstone host.

Aggregates of coarse biotite are present along the margins of the veins. The presence of tourmaline, apatite, and cerium- and lanthanum-rich allanite was reported by Miller (1982a, b). Anomalously high contents of rare-earth elements in a pitchblende sample have been reported by Gandhi and Prasad (1993). Variable amounts of magnetite occur in the veins. Molybdenite and pitchblende are irregularly distributed in them, and are commonly concentrated within coarse biotite-rich material. The best assay values reported from a trench sample are 2.4% MoS_2 and 0.42% U over a width of 1 m (Thorpe, 1972). Some uraniferous veins contain little or no molybdenite and chalcopyrite, whereas some other veins are pyrite-rich and contain little or no biotite and magnetite, and have only traces of uranium. Miller (1982a) reported that uraninite occurs as zoned euhedral crystals in some veins and as spherical grains in others. Some of the euhedral uraninite crystals occur as inclusions in biotite, and some others have overgrowths of younger uraninite. Lead isotopic analyses of uraninite samples and pyrite indicate ages of 1853 ± 19 Ma and 1836 ± 32 Ma, respectively (Miller, 1982a, b).

Polymetallic arsenopyrite-dominated deposits

Arsenopyrite veins and disseminations with associated notable amounts of bismuth, cobalt, copper, and gold occur near Lou Lake along a 4 km strike zone in sandy and argillaceous

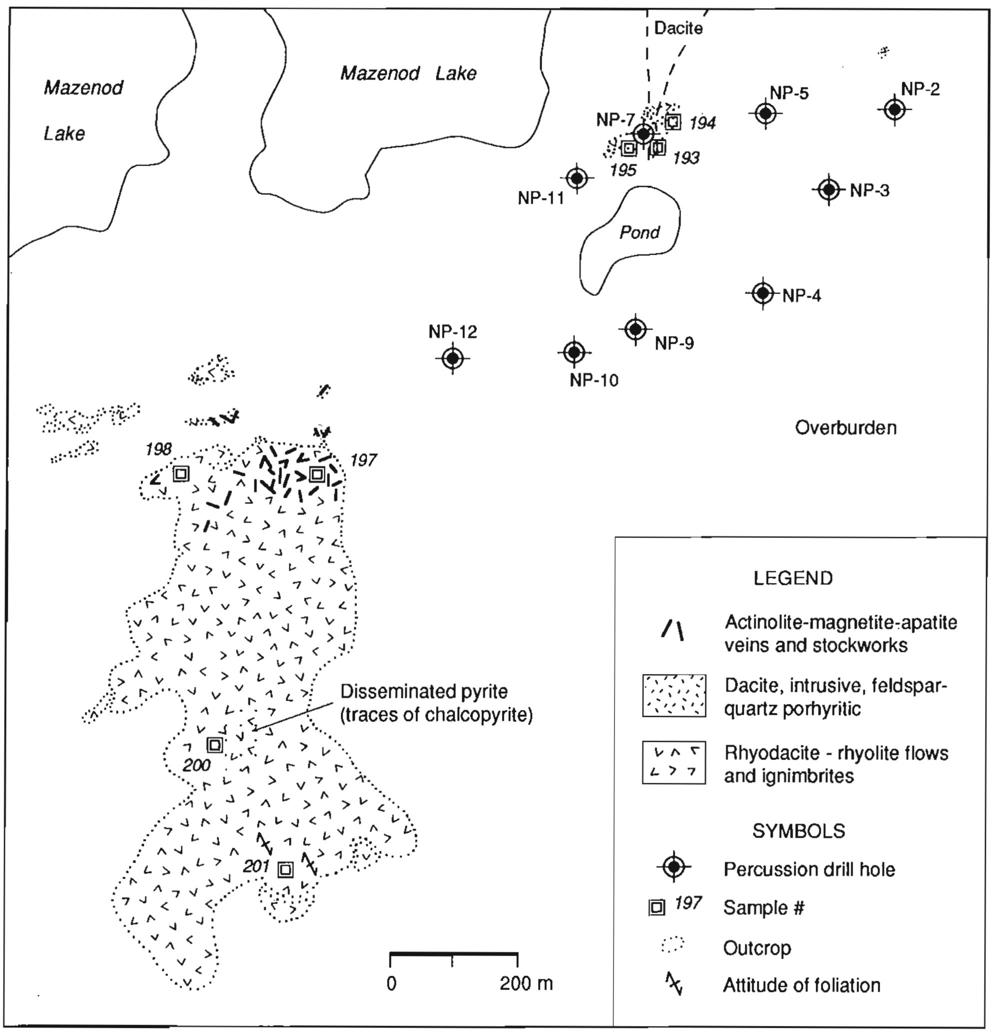

Figure 10. Geology and drill holes of the Nod prospect, Mazenod Lake (after Gandhi, 1992b).

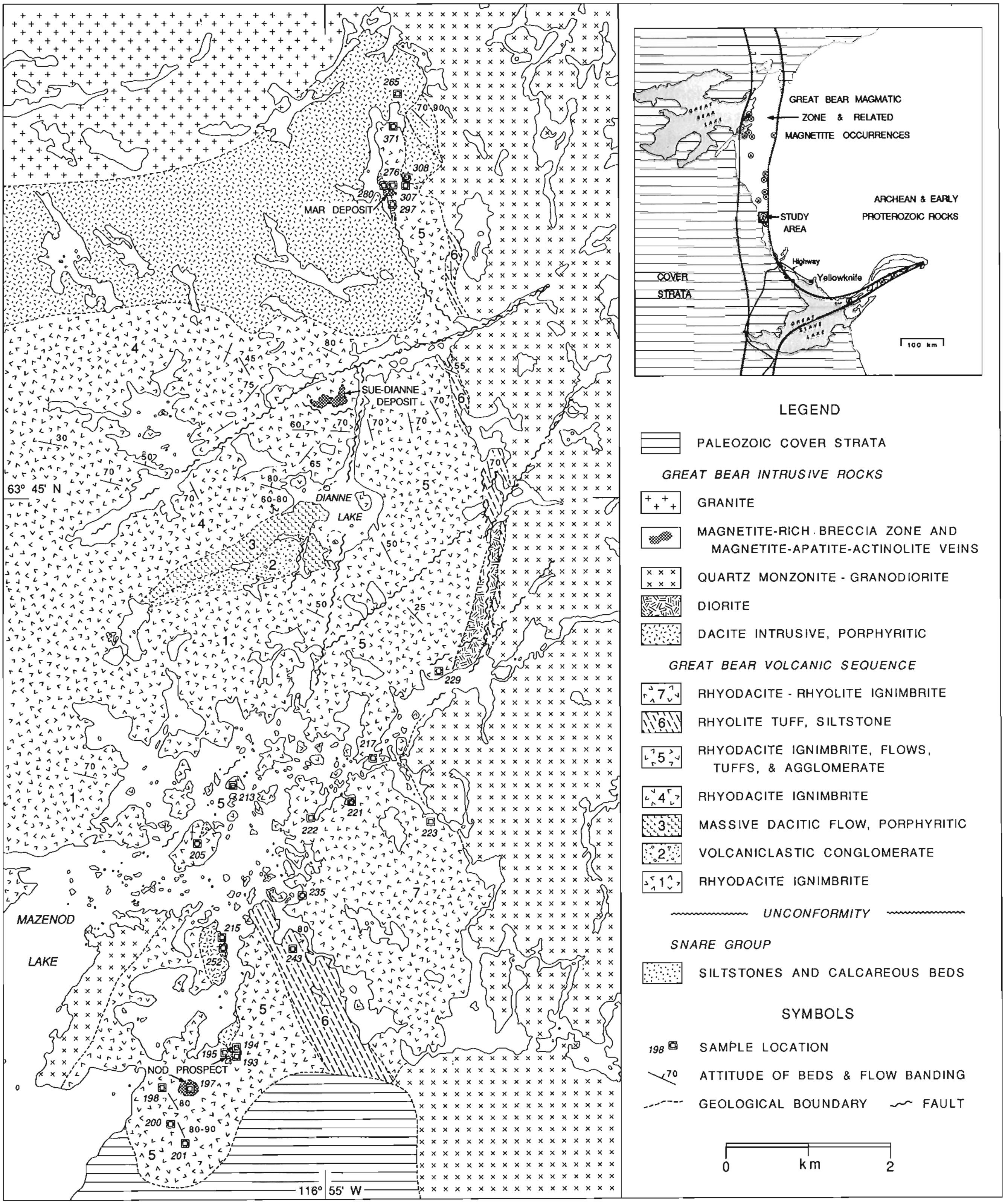

Figure 11. *Geology of the area around the Sue-Dianne and Mar deposits, southern Great Bear magmatic zone, Northwest Territories (after Gandhi, 1992b).*

metasedimentary rocks of the Aphebian Snare Group and in unconformably overlying felsic volcanic and volcaniclastic units of the southern Great Bear magmatic zone (Fig. 14). Similar occurrences are present in the metasedimentary rocks near Burke Lake.

Gar bismuth-cobalt-gold-copper deposit

The Gar deposit is the main mineralized zone located on the original Cab claims near Lou Lake. The main prospect has drill-indicated resources of 195 000 tonnes averaging 0.162% Bi and lesser values in cobalt, copper, and gold (Gandhi and Lentz, 1990). A 56 kg, high grade bulk sample from the main prospect contained 4.80 g/ton Au, 2.36% Co, 0.63% Bi, 40.8% As, 22.5% Fe, and 16.0% S. Microscopic and microprobe analyses of arsenopyrite, the dominant mineral in all these occurrences, indicate variable contents of cobalt (with as much as 14.7 wt.% Co) and the presence of minute inclusions of native gold, native bismuth, bismuthinite, and pyrrhotite. Arsenopyrite in some outcrops has partially weathered to green scorodite.

In addition to arsenopyrite, associated mineralogy of this deposit type includes pyrite and magnetite-hematite, with minor to trace amounts of chalcopyrite, bismuthinite, native bismuth, emplectite, pyrrhotite, cobaltite, loellingite, wittichenite, tennantite, molybdenite, scheelite, and wolframite.

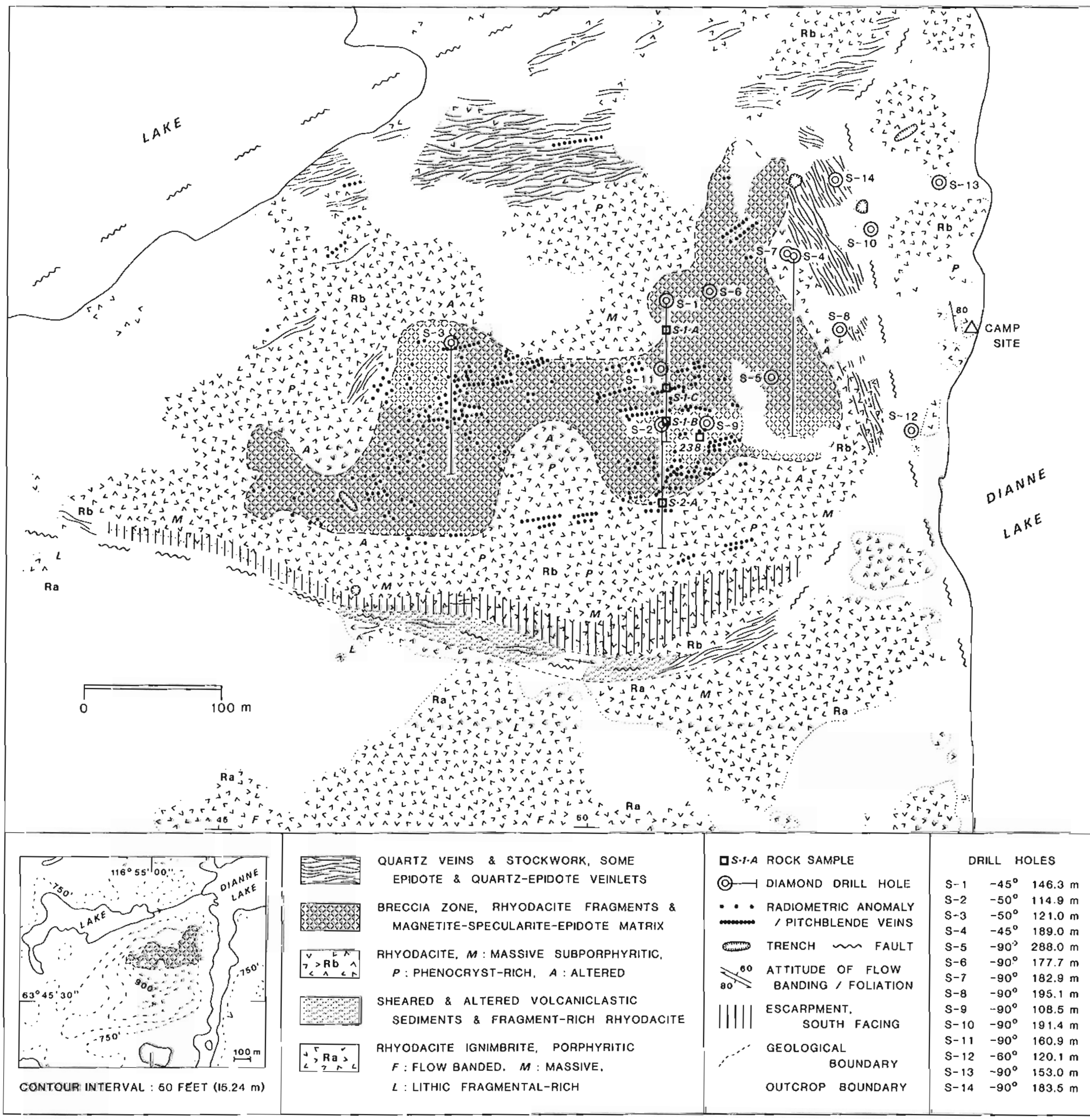

Figure 12. *Surface geology and diamond drill holes of the Sue-Dianne deposit, southern Great Bear magmatic zone, Northwest Territories (after Gandhi, 1989).*

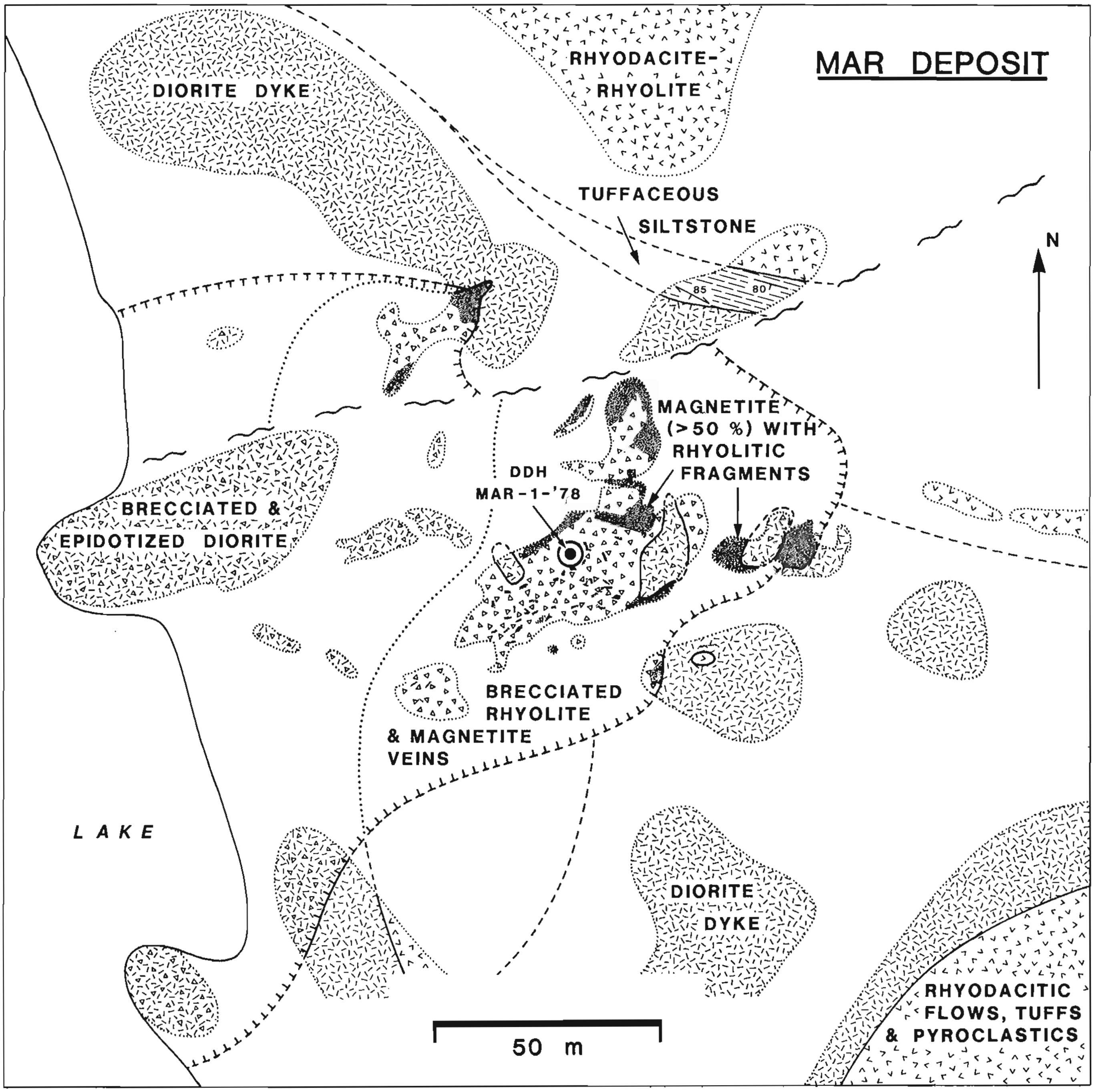

Figure 13. Surface geology of the Mar deposit, southern Great Bear magmatic zone, Northwest Territories (after Gandhi, 1992b).

Pyrite has been commonly replaced partly or wholly by magnetite, and the magnetite in some places has been replaced by hematite. Magnetite associated with arsenopyrite is generally coarser grained than the magnetite present in thin layers and lenses in the host chloritic argillaceous beds. Magnetite, commonly containing chlorite and/or quartz, is also found in veinlets within the host beds.

Vein-type uranium±copper deposits

Pitchblende veins and fracture-fillings are common throughout the Great Bear magmatic zone, and the southern part has dozens of occurrences. Most of these are too small to be of economic interest. They occur in brittle fractures that postdate the Great Bear magmatic activity. The host fractures are commonly subsidiary to the major faults. Some of the major and minor faults host giant quartz veins or quartz stockworks (Furnival, 1935, 1939). Some clusters or individual fracture-fillings occur at considerable distances from major faults, and they may not be directly related to these faults. In many cases the occurrences are close to granitic rocks, which are anomalously radioactive and have high U/Th values. Thus the overall picture is that of elevated uranium contents in the felsic volcanic and plutonic rocks of the Great Bear magmatic zone, and late stage hydrothermal and surficial concentration of uranium in tension fractures related to brittle faults. Although small amounts of copper sulphides and other minerals are associated with pitchblende, for the most part the mineralogy of these veins is simple compared with the complex mineralogy of the polymetallic (uranium-silver-copper-cobalt-nickel) veins found near Great Bear Lake (Robinson and Ohmoto, 1973; Gandhi, 1978a).

Rayrock deposit

The principal example of this type of mineralization is the Rayrock deposit, which is contained in a giant quartz vein zone (Fig. 2, 15). The deposit produced 150 t U from 63 500 tonnes of ore during the period 1957-1959 (Byrne, 1957; Lang et al., 1962, p. 193-196; McGlynn, 1971, p. 88-92). Initial discovery of uranium in the region was by officers of the GSC in 1934, who observed yellow secondary uranium minerals at a locality near Treasure Lake, 6 km northwest of the Rayrock mine (Lang, 1952, p. 61; McGlynn, 1971, p. 97). The discovery of pitchblende veins on, or very near, the Rayrock property was made in 1948. The deposit is located 300 m west of, and in a fault subsidiary to, the Marian River fault. The Marian River fault is a major northeast-trending, right-lateral fault which dips 70° to 85° to the southeast and has a right-lateral displacement of approximately 10 km (McGlynn, 1968, 1971). The host subsidiary fault is one of many that are parallel to or branch off in an easterly direction from the main fault. These faults are more numerous on the north side (footwall side) of the main fault where it changes direction slightly. Quartz veins or stockworks occur along many of the subsidiary faults, and along the main fault where they are as much as 60 m wide and extend along a strike length of 5 km in the vicinity of the mine.

The country rock is mainly gneissic granodiorite, which contains some xenoliths of metasedimentary rocks that are granitized in some places. The rocks along the main and subsidiary faults have been commonly crushed or mylonitized, and display variable degrees of alteration due to silicification, chloritization, epidotization, and hematization. Albitization of these rocks was noted by Miller (1982a, b). The alteration zone ranges in width from a few centimetres to 10 m. Movements along the faults occurred in at least three stages, each marked by the generation of quartz veins. Massive, milky white or greyish to greenish, first generation quartz veins are the most abundant. They have been fractured, and brecciated, and are cut by younger quartz veins. Many of these younger veins have a banded appearance, and some have comb quartz at their cores. Some of the vuggy zones have well developed coarse quartz crystals more than 5 cm long.

Metallic minerals are sparse and most of the quartz veins are barren. Some of the younger veins contain variable amounts of hematite, specular hematite, copper sulphides, pyrite, and pitchblende. These minerals occur in veins and as fracture-fillings hosted by the quartz vein stockwork as well as by the country rocks. Pitchblende is mostly fine grained, rather than massive, and has been finely crushed. According to Byrne (1957) this suggests slight fault movement during deposition. Miller (1982a, b) found that pitchblende is paragenetically an early metallic mineral and fills the interstices between some quartz crystals, and is followed by bornite, chalcocite, covellite, and hematite intergrowths. Trace amounts of niccolite were also detected. Miller (1982a, b) reported on the Pb isotopic analyses of 14 pitchblende samples from the Rayrock deposit. Thirteen of these defined an isochron age of 517 ± 80 Ma. Miller (1982a, b) related this age to the early Paleozoic marine transgression in the area, which either formed the deposit or profoundly altered it.

The main No. 6 zone of the Rayrock deposit, is within a stockwork zone that strikes 035° and dips 65° to the east (Fig. 15A, B). The zone is 3 to 15 m wide and 100 m long, and provided most of the mined ore. The bulk of the 1950s mining was between the 38 m and 152 m levels (Fig. 15C). Mining was done from an adit and an internal shaft, using a modified cut-and-fill method that extended to the 200 m level. Much of it was selective because of the irregular nature of the orebodies. A longitudinal section of the mine (Fig. 15D) illustrates the 'rolls' in the stockwork caused by minor changes in dip. The crest of these rolls are the sites of intense fracturing, and hence of ore shoots (McGlynn, 1971). The No. 1 ore zone is located approximately 25 m southeast of the No. 6 zone at the adit level, and is in a fault that strikes southwest and dips to the northwest at about 70° (Fig. 15A, D). Pitchblende occurs here in fractures in brecciated, hematite-stained granodiorite. The best ore intersections occur where the fracturing is most intense. Only one ore shoot was mined in this zone.

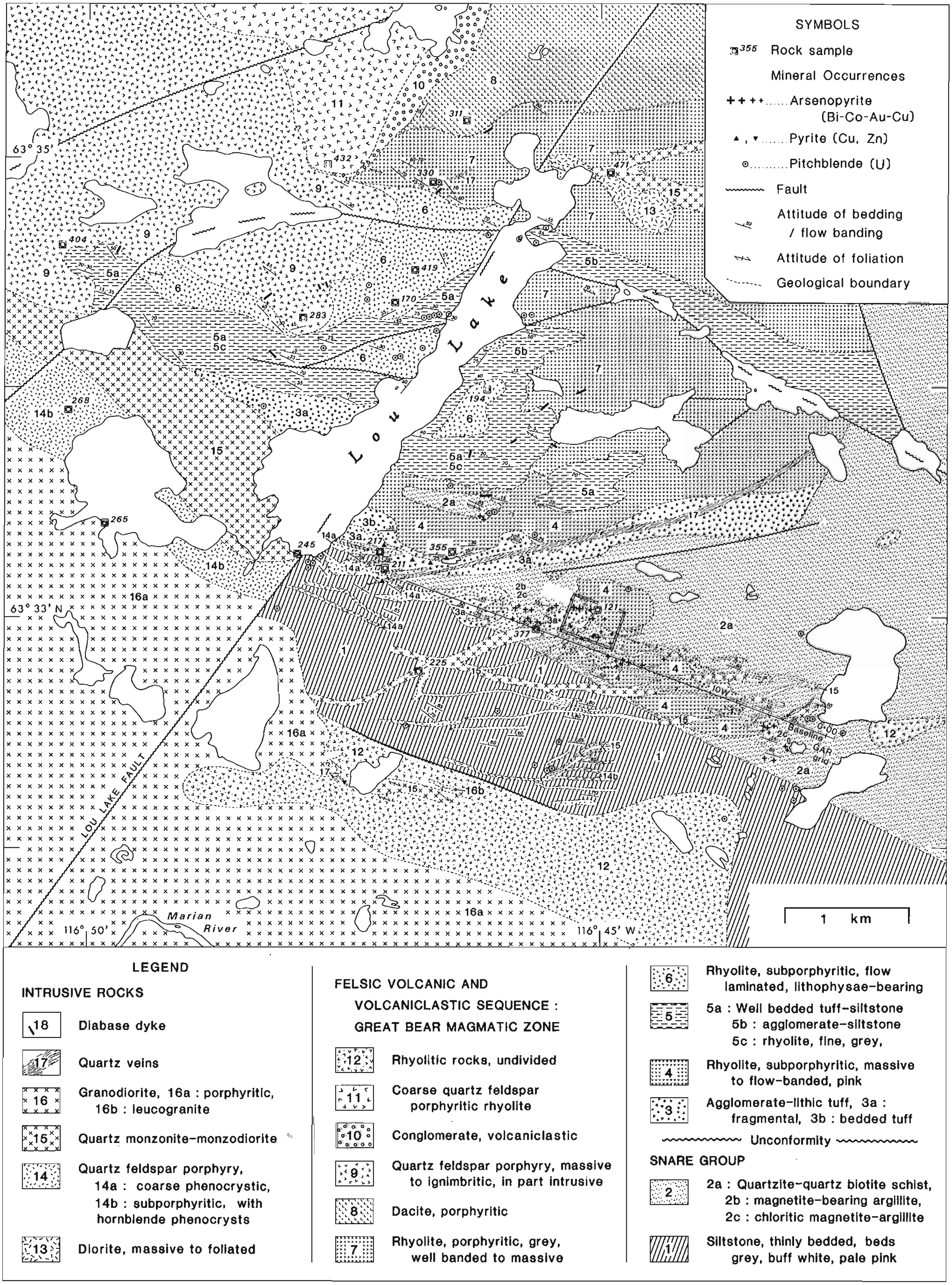

Figure 14. Geology and mineral occurrences of the Lou Lake area, southern Great Bear magmatic zone, Northwest Territories (after Gandhi and Lentz, 1990)

GENETIC ASPECTS

The genetic aspects of the mineral occurrences in the southern Great Bear magmatic zone can be conveniently discussed in terms of the processes that occurred prior to, during, and after Great Bear magmatic activity; however, the relative timing and possible connections between these processes remains obscure.

Mineralization that predates Great Bear magmatic activity: synsedimentary/diagenetic deposition of sulphides and oxides

The iron-sulphide bearing argillaceous beds formed under euxenic conditions where iron was chemically precipitated. From a metallogenic standpoint, this represents a favourable environment for synsedimentary/diagenetic concentration of many metals, in particular base metals and precious metals, cobalt, and nickel. Such environments existed during the deposition of many Proterozoic platform-shelf sequences, including the one whose remnants are seen in the southern Great Bear magmatic zone. The large shale-hosted or 'SEDEX' base metal deposits, such as the well known Sullivan deposit in British Columbia and the Broken Hill and Mount Isa deposits of Australia, are in comparable early Proterozoic sequences. The local conditions that favoured deposition of large concentrations of metals and barite in these deposits include the presence of deep-seated faults that controlled the sedimentation as well as the ingress of metals in solution from depth (Morganti, 1988). The previously described Norris showing suggests that such favourable conditions prevailed during the deposition of the Snare Group. This interpretation is supported by the overall stratabound distribution of the sulphides, and also unpublished Pb isotopic data for two galena samples, which indicate an age of ca. 2000 Ma (M. Osatenko, Cominco Limited, pers. comm., 1990). The presence of epigenetic galena-sphalerite pyrite veins at this deposit may be attributed to the later remobilization and deposition of the components of the veins during deformation. To the north-northwest of the Norris showing, in the Grant Lake area, Easton (1981) drew attention to the potential for sediment-hosted sulphide deposits in the strata correlative with the Snare Group (Lord, 1942; McGlynn, 1964).

Sediments originally enriched in certain metals may serve as the source of mineral deposits/occurrences during subsequent metallogenic events. It has been suggested in a previous section that the pyrite±magnetite-bearing argillaceous beds in the Lou Lake area may have been enriched in metals such as copper, bismuth, cobalt, and gold. These metals could have been scavenged by hydrothermal solutions related to the Great Bear magmatic activity, and later deposited in the polymetallic arsenopyrite occurrences. In fact, for the polymetallic uranium-silver-copper-cobalt-nickel deposits of the Great Bear Lake area, Morton and Changkakoti (1987) have suggested that the ultimate source of elements (i.e., U, Ag, Cu, Co, Ni, As, Bi, S) may be traced back to the organic-rich sediments of early Proterozoic age, which were later flushed hydrothermally during metamorphism, and perhaps underwent anatexis, generating some S-type granitoid melts with associated magmatic-hydrothermal systems. They emphasized the world-wide proliferation of biomass during early Proterozoic time, as being capable of capturing a wide spectrum of metals and metalloids in organometallic associations, similar to processes involving younger black shale, coal, and oil-bearing strata. The metasedimentary rocks in the southern Great Bear magmatic zone have not yet been well studied or explored for their mineral potential, but their significance in terms of regional metallogeny is apparent from the above considerations.

The early Proterozoic platform-shelf sequences throughout the world are characterized by the presence of beds rich in chemically precipitated iron oxide. The metasiltstones of the southern Great Bear magmatic zone contain magnetite-rich beds and lenses which are interpreted here as metamorphosed equivalents of hematitic sediments. They differ from typical Proterozoic iron-formations, which are the great source of iron ore in the world, in that the associated strata are quartzofeldspathic siltstones rather than the cherty beds more commonly associated with iron-formations. The environment and process of iron deposition were, however, similar, and some beds containing iron-rich silicates are found in the metasiltstone-dominated sequence. The bedded character of these iron oxide-rich and silicate-rich sediments is apparent on a major and minor scale from observed fold structures. Boudin-like massive magnetite lenses occur at some places in the metasiltstones. These could be due to either local high concentration of iron during deposition or later segregation during deformation and metamorphism.

A geochronological study of pitchblende/uraninite from the Nori/RA, Ham, and Jones occurrences and from a similar occurrence in the northern Great Bear magmatic zone (Jackpot showing) was carried out by Miller (1982a, b). He obtained U/Pb ages for uraninites from these occurrences in the range of 1880 to 1840 Ma. Miller (1982a, b) advocated a placer origin for the magnetite and associated uraninite within these occurrences. According to Miller (1982a, b), these paleoplacers, contained in arkosic sediments, were originally deposited in a desert environment or along marine beaches. This led him to postulate that the source of the detrital magnetite and uraninite was the region of the Hepburn intrusive suite, and that the minerals occur in a mollase-type sedimentary sequence related to the uplift of the ca. 1890 Ma old intrusive suite. Gandhi (1992a) pointed out, however, the scarcity or absence of typical detrital minerals such as zircon, the lack of lithologies and structures expected in high energy environments of placer-hosting sequences, and the presence of argillaceous beds in the siltstones, reflect a low-energy sedimentary environment. These features are more consistent with the chemical deposition of iron during sedimentation and a later introduction of uranium, rather than with a detrital origin. Derivation of the detrital minerals from the Hepburn intrusive suite would mean that these sediments are much younger than the Snare Group, and thus would have undergone deformation and metamorphism after the Calderian orogeny, but prior to the postorogenic 1875-1840 Ma Great Bear magmatic activity (Hildebrand et al., 1987). Since such an event is not documented, it is likely that the uraninite ages reflect either an isotopic re-equilibration of the uranium occurrences during the Great Bear magmatic activity, or more probably, the addition of uranium to the magnetite deposit during this magmatic activity.

Observations on other stratiform magnetite occurrences support younger episodes of mineralization. At Hump Lake and Lou Lake, the magnetite-rich metasediments are not uraniferous, but spotty radioactivity is noted in them where they are in contact with, or very close to, granitic intrusions or dykes. At the Nori/RA showings, magnetite-rich metasiltstones host veins containing tourmaline, molybdenite, chalcopyrite, pyrite, and pitchblende which are evidently later additions from a granitic source. In some localities, relatively competent magnetite lenses in biotite-bearing metasiltstones were fractured during deformation, and were the preferred sites for emplacement of pegmatitic veins and pods. The magnetite lenses thus seem to provide, structurally as well as

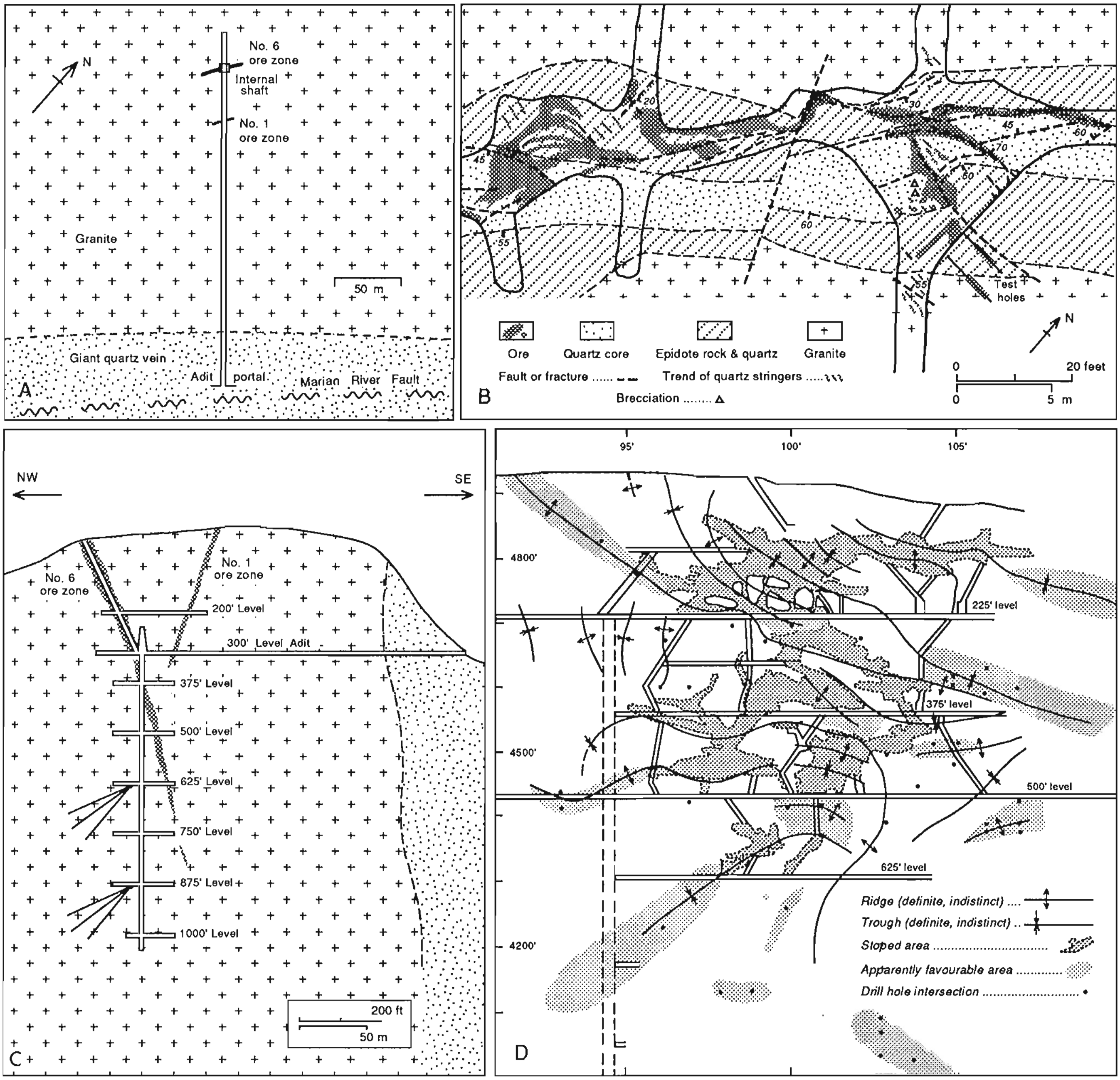

Figure 15. Plan and sections of the Rayrock uranium mine, southern Great Bear magmatic zone (after Lang et al., 1962; McGlynn, 1971; and unpublished mine records). A) Geological plan map showing the location of the No. 1 and No. 6 ore zones and trace of adit; B) plan of part of adit level showing main ore bodies in generalized manner; C) schematic longitudingal cross-section and level plan along the plane of the adit shown in A; D) longitudinal section showing folds in footwall of the quartz core.

chemically, favourable sites for younger hydrothermal mineralization. Oxidation of magnetite to hematite creates favourable conditions for reduction and precipitation of uranium from either magmatogenic or meteoric circulating solutions. This suggests that some of the uranium associated with the magnetite-rich metasediments could be either older or younger than the Great Bear magmatic activity.

The above considerations also suggest the possibility that the chalcopyrite associated with magnetite-rich beds in meta-siltstones at the Kol and Jones showings is epigenetic. The textures and structures observed at these occurrences, however, favour the synsedimentary deposition of the sulphides. This requires availability of sulphur and fluctuation in redox conditions during deposition, which is not uncommon. Sulphide-bearing veins found in the vicinity of these showings, are not abundant and can be explained either by mobilization and redeposition of the sulphides from the stratiform accumulations, or by a younger episode of vein formation in the region.

The presence of older stratabound iron deposits in the many districts where magnetite-apatite-actinolite deposits occur in volcano-plutonic settings was noted by Park (1972). It is clear that the Great Bear magmatic zone is not exceptional in this regard. The possibility that older deposits could be remobilized during magmatism on a large enough scale to ultimately form younger deposits was also suggested by Park (1972). Local remobilization on a small scale has been noted in the occurrences at Hump Lake and elsewhere in the Great Bear magmatic zone (Gandhi, 1992a; Miller, 1982a). Whether it occurred on a much larger scale to yield the veins and breccia-fillings hosted by the volcanic rocks and related plutons of the magmatic zone remains speculative.

Mineralization related to the Great Bear magmatic activity

Field relations, deposit characteristics, and geochronological data point to a genetic relationship between the Great Bear magmatic activity and four different styles of mineralization seen in the southern Great Bear magmatic zone.

Volcanogenic uranium concentrations

The uranium concentrations at the UGI and FXO prospects at DeVries Lake are mainly in the felsic volcanic assemblage, and occur along zones that are broadly conformable with the stratigraphy. This close association suggests a genetic link of the mineralization with the host felsic volcanic rocks. The occurrence of much of the uranium as disseminated grains of uraninite is a feature typical of volcanogenic deposits. Other metals are scarce or absent in these deposits. The concentration of uranium in parts of the host rocks that are relatively rich in primary magnetite and/or mafic silicates reflects the presence of favourable redox conditions for its precipitation. Because the latter association is observable at depths of as much as 55 m in drill holes (Male, 1978), it is not considered a supergene phenomenon. Supporting evidence is provided by an isotopic age of 1864 ± 14 Ma for the uraninites from the UGI prospect (Miller, 1982a, b). Although the host rocks have not yet been dated, they are similar to felsic volcanic rocks elsewhere in the southern Great Bear magmatic zone dated at 1870-1860 Ma (Gandhi and Mortensen, 1992). They are, however, in a highly strained zone near the Wopmay fault zone, and show some shearing, unlike the volcanic rocks elsewhere in southern Great Bear magmatic zone. Whether this implies an age older than that of Great Bear magmatic activity remains uncertain, and U-Pb zircon geochronology is needed to resolve the problem. The high grade uraninite/pitchblende veins and fracture-fillings that occur at these prospects are interpreted here as the result of migration of the disseminated uranium into openings formed during deformation, and local reconcentration at the margin of mafic intrusions and pegmatitic veins. Weak and spotty radioactivity found in arkosic quartzite at the Tyke showing, located a few kilometres south of the UGI/DV prospect, may be due to a more distant secondary concentration of uranium.

The Great Bear magmatic zone is characterized by an abundance of felsic volcanic rocks of the type seen at DeVries Lake. Hence the potential for the discovery of larger volcanogenic uranium deposits, such as the Michelin deposit, contained in rhyolites of the 1850-1805 Ma old Aillik Group in the central Labrador Mineral belt (Gandhi, 1978b), is regarded as very good. Furthermore, the iron-uranium enrichment in these rocks represents a stage in the metallogenic evolution of the magmatic zone which eventually led to the formation of the magnetite-rich breccias and veins that occur elsewhere in the region.

Magnetite-rich veins and breccia-fillings (Kiruna/Olympic Dam-type)

One of the most outstanding metallogenic features of the Great Bear magmatic zone is the presence of magnetite-apatite-actinolite veins and magnetite-rich breccia-fillings that contain copper, gold, and uranium, referred to as Kiruna-type and Olympic Dam-type occurrences, respectively. Based on this study, the geological settings and genetic aspects of these deposits are illustrated conceptually in Figure 16.

As previously noted, the monometallic magnetite-apatite-actinolite veins, found at the Fab and Nod showings and other occurrences in the southern Great Bear magmatic zone are similar to the ones near Great Bear Lake in the north and in the east arm of Great Slave Lake (Fig. 7)(Badham and Morton, 1976; Badham, 1978a; Gandhi and Prasad, 1982; Hildebrand, 1984, 1986; Reardon, 1989, 1990, 1993). Most of these occurrences are closely associated with quartz monzonitic intrusions, which were emplaced as thick sheet-like bodies, laccoliths, and irregular plutons. The magnetite-apatite-actinolite veins, and related breccias of similar mineralogy, occur in the roof zones and margins of the intrusions. Although they have been regarded as genetically linked to these intrusions by most workers, there is a debate regarding the precise processes involved in their formation.

The processes invoked in more recent work include: liquid immiscibility (Badham and Morton, 1976), hydrothermal circulation (Hildebrand, 1986), and volatile-rich magmatic fractionation (Gandhi, 1992b; Gandhi and Bell, 1990, 1993). An immiscible iron-phosphorus liquid seems untenable for two reasons: i) many of the veins contain abundant actinolite and hence indicate significant silica contents in the melts from which they crystallized, and ii) many veins are banded or zoned, and have actinolite and magnetite at their margins and relatively abundant apatite at their cores. These features indicate crystallization from fluids at submagmatic temperatures rather than from an iron-phosphate melt, which would require temperatures in the order of 1000°C. Furthermore, it is difficult to deduce how such iron-phosphorus immiscible liquids, if they accumulated at depth, could be injected to bring about the observed distribution of the veins.

In the Great Bear Lake area, the roof and marginal zones of the quartz monzonite intrusions, and the adjacent andesitic volcanic rocks, are characterized by intense sodium metasomatism (albitization). The metasomatism is pervasive and widespread, i.e., regional in character, in contrast to the small veins that occur locally, in and near the metasomatized zones. The veins themselves have little visible associated alteration of the wall rock, but replacement textures are seen in sedimentary beds of the volcanic sequence near Terra mine. According to Hildebrand (1984, 1986) and Reardon (1989, 1990), the sodium metasomatism, vein mineralization, and some of the younger quartz-pyrite veins in the region, are part of the same mineralizing episode, and form a zoned sequence from the intrusion outwards. The oxygen isotopic data obtained by Reardon (1990, 1993) indicate that the hydrothermal solutions were essentially of magmatic origin, and that meteoric waters played only a minor role in mineralization. Alteration patterns are somewhat different in the southern part of the magmatic zone and in the Great Slave Lake region to the east. The magnetite-apatite-actinolite veins are mostly in the marginal zones of the intrusions, and little wall rock alteration is recognizable along these veins. Badham (1978a) and Gandhi and Prasad (1982) have studied many of the occurrences in the east arm of Great Slave Lake, and have not reported any significant alteration, except a slight reddish coloration at the margins of some veins. Alkali metasomatism in the host quartz monzonites, although not studied in detail, is apparent from the variable sodium and potassium contents in the marginal parts of the intrusions. It can not, however, be directly related to the magnetite-apatite-actinolite veins. Variation in alkali contents is also seen in the volcanic rocks in the southern part of the Great Bear magmatic zone. Field investigations by the author suggest that alkali exchange is a common phenomenon throughout the volcanic and plutonic rocks of the magmatic zone. In the case of the quartz monzonite intrusions, in situ alkali exchange probably occurred at a late stage of crystallization differentiation, and the magnetite-apatite-actinolite veins formed later from deeper seated magmatic fractions after the intrusions cooled sufficiently to develop tensional fractures. Some of the quartz monzonite intrusions display strong differentiation. Others appear uniform, but this may be because only their outer zones are exposed. Differentiation of a magma of quartz monzonitic composition at depth, or the accumulation of a volatile-rich fraction in the magma source region is believed to generate fractions enriched in Fe, P, and volatiles (Fig. 16). Late stage tensional fractures, formed during cooling of these epizonal intrusions, are both the preferred channels for transport of the fluids and sites for eventual deposition of the vein minerals. The pegmatoid character of the veins, which contain coarse crystals growing from the wall rock inwards, attest to open space deposition, and would account for the lack of wall rock alteration.

Some of the magnetite-apatite-actinolite veins in the east arm of Great Slave Lake and at the Fab prospect contain pyrite, copper sulphides, and uranium. Cobalt-nickel arsenides occur in a few veins in the Great Slave Lake area. The arsenides commonly form lenticular vein-like aggregates, and also form separate veins, which suggests a possible separate episode of arsenide mineralization. Hematite is common as an alteration product of magnetite. In general, these polymetallic veins have some mineralogical similarities with the breccia zones which are regarded as of Olympic Dam-type. As previously noted, they are thought to represent a transitional type between the monometallic veins and polymetallic breccia zones.

The polymetallic breccia zones occur in rhyodacite-rhyolite ignimbrite piles. Angular fragments of the volcanic rocks commonly range in size from half a metre to a few millimetres, and some larger and smaller ones also occur. Except for late stage epidotization in some places, the fragments generally do not show signs of significant alteration. Chemical analysis of a rhyolitic fragment within a magnetite matrix in the Mar deposit did not reveal significant differences from the rhyolitic samples from the surrounding area, except for some enrichment in potassium over sodium (Gandhi, 1992b). Variation in alkali contents, however, are common in the volcanic pile, and it is difficult to judge how much of the variation is due to mineralization. In the case of the Damp deposit in the north, however, there is significant sodium metasomatism of the rhyolitic ignimbrite host unit.

The breccia-filling is mainly medium grained magnetite, and lesser hematite/specularite. Magnetite ranges in abundance from a few per cent to more than 75% locally. More than one generation of magnetite is apparent in some places. Partial alteration of magnetite to hematite, and in some cases to specularite, is seen in polished sections. Although the possibility of primary deposition of hematite or specularite cannot be dismissed, particularly in view of the presence of some sizable aggregates of specularite, it seems unlikely. Pyrite and copper sulphides are sparsely distributed, as disseminated grains, small aggregates, and veinlets. The textures suggest that they were deposited synchronous with, or later than, magnetite. Pitchblende/uraninite occurs as very finely disseminated grains interstitial to magnetite, which indicates primary deposition with magnetite and the sulphides, in contrast to the younger pitchblende veins that cut the breccia zones.

Epidote is the major hydrous phase in the breccia zones. Some chlorite is also seen at a few places, but its abundance is small in comparison with that of epidote. Epidotization postdates brecciation and crystallization of magnetite. It is locally intense and partially or completely replaces the minerals in breccia fragments and wall rock. At the Mar deposit, a diorite body that has intruded the volcanic rocks is fractured and strongly epidotized adjacent to the breccia zone. Veinlets of epidote and quartz-epidote also occur, but are few and sparsely distributed except at the Sue-Dianne deposit, which is unique in that it is surrounded by numerous quartz-epidote and barren quartz veins. Gandhi (1989) interpreted the abundance of quartz veins at the Sue-Dianne deposit to be related to the giant quartz veins and stockworks that characterize the northeast-trending right lateral faults common throughout the Great Bear magmatic zone. This interpretation is based on the close proximity of the Sue-Dianne deposit to one of these faults.

Field investigations suggest that the polymetallic breccia deposits, like most of the magnetite-apatite-actinolite veins, do not have significantly large and intense alteration zones associated with them. The absence of alteration indicated that these deposits were formed by essentially magmatic fluids, with rapid deposition in tensional fractures and in open spaces created by escaping volatiles in the breccia zones. This contrasts with the scenario of large meteoric water circulation systems, which would have been capable of producing an extensive wall rock alteration, marked by abundant hydrous, low temperature minerals. These features are clearly lacking in the breccia zones.

It should be noted that contact relationships between the magnetite-rich occurrences and the large granitic plutons of the Great Bear magmatic zone have not yet been established. A magnetite-apatite-actinolite occurrence near the Terra mine in the Great Bear Lake area is cut by a quartz feldspar porphyry dyke believed to be related to the volcanic rocks of the Sloan Group. The granites in the area, however, are younger than the Sloan Group. This suggests that the metallogenic episode throughout the magmatic zone is probably close to the time of emplacement of the quartz monzonite intrusions (ca. 1865 Ma).

Several authors have drawn attention to general similarities between the Olympic Dam deposit in South Australia and deposits in the Kiruna and Bergslagen districts in Sweden, the St. Francois Mountains in Missouri, U.S.A., and the Great Bear magmatic zone (Hauck, 1990; Hauck and Kendall, 1984; Hagni and Brandom, 1988; Hitzman et al., 1990, 1992; Marikos et al., 1989; Kisvarsanyi and Kisvarsanyi, 1989; Gandhi and Bell, 1990, 1993; Oreskes and Einaudi, 1990). All these deposits are characterized by an abundance of iron, either as magnetite and/or hematite. They show great variations in the proportions of the associated minerals and in morphology, but they all occur in continental volcanic sequences which are dominated by dacitic to rhyolitic extrusive rocks and related epizonal plutons. It has also been noted that large magnetite deposits comparable to those listed above, occur in Phanerozoic magmatic zones, e.g., in Chile (Bookstrom, 1977; Frutos and Oyarzun, 1975; Henriquez and Martin, 1978; Oyarzun and Frutos, 1984), northern Mexico (Lyons, 1988) and the middle-lower Yangtze valley, China (Research Group on Porphyrite Iron Ore of the Middle Lower Yangtze Valley, 1977), and in the Bafq region in central Iran (Förster and Knittel, 1979; Förster and Jafarzadeh, 1983; Förster, 1990). These magmatic zones are also noteworthy for their porphyry copper deposits, and more broadly for a "trinity" of deposits - porphyry (sensu stricto), skarn, and exhalative (copper and iron).

In many deposits mentioned above, intrusive and extrusive features are well documented and, as pointed out by Park (1961, 1972) and several other workers, these features provide compelling evidence for iron-rich volatile-charged magmatic fractions, related to dacitic or more felsic magma. Most deposits contain a paragenetically early, euhedral magnetite phase, and also a later magnetite phase or phases. Some of the magnetite has been altered to hematite (or specularite) due to postdepositional changes. Replacement features implying hydrothermal transport and deposition, particularly those involving hematite, are also reported in many of the deposits. Opinions differ, however, as to the extent of replacement of host rocks by hematite and of primary deposition of hematite. Apatite is commonly associated with iron oxides, and hence the role of phosphorus in lowering the crystallization temperature of magnetite and thus facilitating generation of an iron-rich magmatic fraction and its transport, has been strongly emphasized by many workers. Volatiles would further enhance enrichment of iron in a residual fraction. Violent escape of volatiles would create space and conditions favourable for forceful or passive ingress of an iron-rich fluid, and for deposition of iron oxide. This process is manifested on a small scale as veins and breccia fillings in the roof zones and along the margins of epizonal quartz monzonite plutons in the Great Bear magmatic zone (Fig. 16). Strong in situ differentiation of subvolcanic plutons may be adequate to explain the formation of small closely associated occurrences. However, larger deposits and the giant Kiruna and Olympic Dam deposits were most likely developed by differentiation of larger magma chambers at depth, which were the source of the volcanic rocks, subvolcanic plutons, and iron-rich fractions. Emplacement of the iron-rich fractions at higher levels took place by their ascent, in one or more pulses, either with associated silicate fractions or separately, in tectonically prepared zones or in outlets created by explosive discharge of contained volatiles.

Among the volatiles, F, Cl, and H_2O are considered most important. Paucity of hydrous alteration minerals suggest low water/rock ratios, and the limited role of meteoric water. Furthermore, sulphides and carbonates are generally scarce or present in only small amounts, reflecting the paucity of S, CO, and CO_2 in the mineralizing fluids. The system thus differs from the porphyry copper system, which involves development of a carapace in the roof zone of the pluton and second boiling, prior to mineralization (Burnham and Ohmoto, 1980). The porphyry copper systems have relatively greater water/rock ratio, lower abundances of iron, lower oxygen fugacity and higher sulphur pressure. Alkaline gold porphyry systems on the other hand, contain pods and veins of magnetite and apatite (±actinolite/amphibole), and may represent an intermediate situation between the porphyry copper and Olympic Dam-type systems.

As expected for such a diverse group of deposits, the ultimate source of iron and mechanisms of its concentration in mineralizing fluids are topics of considerable speculation and debate. The sources invoked are the calc-alkaline mafic and/or intermediate and felsic magmas (Geijer, 1931; Frietsch, 1978; Oyarzun and Frutos, 1984), alkaline and peralkaline magmas (Förster and Jafarzadeh, 1983; Förster, 1990), and pre-existing sedimentary iron deposits (Park, 1972). In the case of a magmatic source of iron, concentrating mechanisms invoked include liquid immiscibility (Badham and Morton, 1976), crystallization differentiation (Geijer, 1931; Magnusson, 1970; Frietsch, 1978), volatile transfer (Lyons, 1988), volcanic exhalative activity (Parák, 1975), and hydrothermal activity (Bookstrom, 1977; Hildebrand, 1986; Oreskes and Einaudi, 1990). In the case of a sedimentary source of iron, high grade metamorphism and assimilation of iron-rich rocks by magma has been suggested by Park (1972) as a plausible concentrating mechanism. Based on the work of the author, the most likely scenario is differentiation at depth in dacitic to rhyolitic magma chambers that generated iron-rich magmatic fractions charged with volatiles (Fig. 16). Escape of the volatiles created openings in which magnetite and associated minerals were deposited.

These types of magnetite deposits form in extensional environments, in late orogenic and anorogenic settings; the critical factor would therefore seem to be the generation of large quantities of dacite-rhyodacite magmas, either by

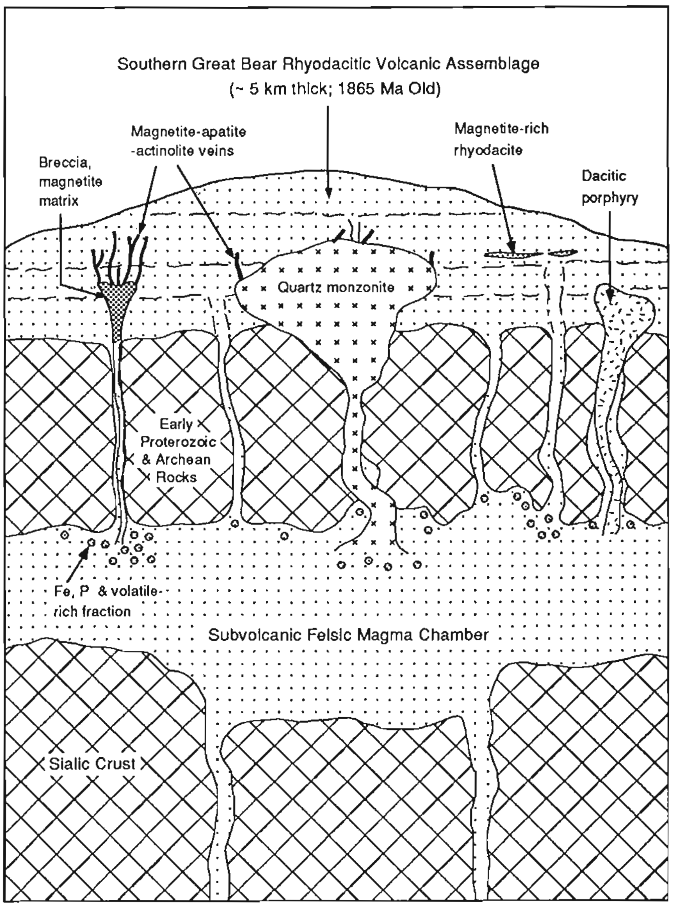

Figure 16. Diagram illustrating a genetic model for the magnetite-rich veins and breccia-fillings related to the Great Bear magmatic activity.

subduction or by crustal underplating. Gandhi and Bell (1990, 1993) favoured the latter interpretation, and suggested that the most favourable conditions for the formation of these magmas developed with gradual decline in secular radiogenic heat which led to major cratonization ca. 1900 Ma ago (West, 1980).

Granite-related hydrothermal molybdenum-uranium-copper vein-type mineralization

The molybdenum-uranium-copper association seen in veins of the Nori/RA occurrences is typical of granite-related mineralization in many parts of the world. The veins contain variable amounts of molybdenite, uraninite/pitchblende, copper sulphides, and pyrite. The presence of fluorite, tourmaline, apatite, and allanite in them further supports granitic affiliation. The development of coarse biotite in association with the veins is clearly a result of hydrothermal alteration of the host siltstones, which contain variable amounts of finer grained biotite. Magnetite is also present in the host rocks and forms coarse aggregates in the occurrences. This indicates local reconstitution during mineralization. Miller's (1982a, b) Pb isotopic analyses of uraninites from the Nori/RA veins resulted in an upper discordia intercept at 1853 ± 19 Ma and a lower intercept at 70 ± 84 Ma. The time of formation of the uraninites is close to that of the volcano-plutonic activity in the southern Great Bear magmatic zone, as indicated by U-Pb zircon ages in the range 1870 to 1860 Ma (Gandhi and Mortensen, 1992). It is thus possible that the molybdenum-uranium-copper mineralization is related to an unexposed granitic pluton of this age at depth, and that the veins represent an upper level of a large hydrothermal system where the mineralization is widely dispersed.

Hydrothermal mobilization and deposition of bismuth-cobalt-copper-gold-arsenic

Arsenopyrite mineralization associated with this deposit-type is regarded as a product of distal magmatic hydrothermal activity involving meteoric waters. The mineralizing solutions may have scavenged some of the elements during their passage through the argillaceous strata in the Lou Lake area. The deposition of arsenopyrite and associated minerals is localized at the unconformity between chemically reactive metasedimentary units and the overlying volcanic sequence (Gandhi and Lentz, 1990); it occurred at the unconformity in response to the significant lithological and structural changes encountered by the mineralizing solutions. The abundance of magnetite in the arsenopyrite occurrences reflect, on one hand, the ready availability of iron from some of the metasedimentary strata, and, on the other hand, a possible link to magnetite mineralization as seen in the veins and breccia-fillings, which are genetically related to the felsic magmas as discussed above. From a regional metallogenic standpoint, these magnetite-rich veins and breccia-fillings, and the arsenopyrite-rich polymetallic occurrences represent two manifestations of the same metallogenic episode of the Great Bear magmatic activity (Gandhi, 1990).

Mineralization that postdates Great Bear magmatic activity: formation of brittle fracture-controlled giant quartz veins and uranium-copper veins

Pitchblende veins and fracture fillings are found in many of the rock units of the southern Great Bear magmatic zones. The most conspicuous of these are in the giant quartz veins found along the trace of northeast-trending right lateral faults, which have been attributed to collision of the craton on which the Great Bear magmatic zone was developed with a continental block to the west (Hoffman, 1980; Hildebrand et al., 1987). A few giant quartz veins and stockworks also occur along the faults subsidiary to, and in a set complimentary to, the northeast-trending faults, as well as along the Wopmay fault zone. The collision of continental blocks is believed to have occurred soon after the cessation of the Great Bear magmatic activity. Thus the host structures of the veins are rather old, and appear to have been activated several times. Such a long history would favour 'healing' of the tensional openings along the faults by the episodic deposition of quartz derived from circulating ground waters. It is plausible that uranium and other associated metals, which commonly occur in the youngest generation of quartz veins, were extracted from the country rock by these waters, and carried in solution with silica.

The precise timings of events that formed the veins are not known; however, Miller (1982a, b) has suggested that much of the silica in the giant quartz veins is considerably older than the pitchblende age of 511 ± 86 Ma that he obtained from the Rayrock deposit. It is likely that the pitchblende date does not reflect the oldest age of vein formation but rather indicates the minimum time when the circulation of ground waters was active, and was instrumental in redepositing uranium or resetting the isotopic equilibrium in these open systems. Miller's (1982a, b) study of a number of other pitchblende veins in the Great Bear magmatic zone revealed isotopic ages in the range of 395 and 660 Ma. In the interpretation of these geochronological data, Miller (1982a, b) considered the possible roles played by weathering during prolonged exposure of the magmatic zone, the extent of the mid-Proterozoic and Paleozoic cover, and effects of intrusion of late Proterozoic diabase sheets and dykes. All these factors may have played a part in the deposition of uranium or the later modification of isotopic equilibrium in veins that were probably formed much earlier than the isotopic data indicate.

The possible sources of uranium include felsic volcanic rocks and granitic intrusions of the Great Bear magmatic zone. Copper associated with uranium may have also been derived from these source rocks or from metasedimentary rocks, or even from mafic sheets and dykes. Traces of nickel are found in the veins at the Rayrock mine and of bismuth in the veins at the Sue-Dianne deposit (Miller, 1982a). Cobalt had been reported in some of the other veins in the region. Thus, although there are some indications of polymetallic character, abundances of other metals in the veins in the southern Great Bear magmatic zone do not approach the metal contents present in uranium-silver-copper-cobalt-nickel veins at Great Bear Lake, and in uranium-gold-platinum-palladium veins at the Rah prospect, 50 km northeast of Great Bear Lake, which postdate the Great Bear magmatic activity (Gandhi and Paktunc, 1989).

CONCLUSIONS

The metallogenic evolution of the southern Great Bear magmatic zone began with the synsedimentary/diagenetic concentrations of base metals and iron sulphides and of iron oxides in the early Proterozoic metasedimentary rocks of the basement. These occurrences in turn presented favourable sites for superimposed granite-related molybdenum-uranium-copper mineralization associated with the Great Bear magmatic activity that occurred ca. 1870 to 1840 Ma. Three other types of mineralization genetically linked to the magmatic activity are the felsic volcanic-associated uranium, magnetite-rich veins and breccia zones, and hydrothermal bismuth-cobalt-copper-gold-arsenic veins and disseminations.

The magnetite-rich veins are comparable in terms of their geological setting and deposit characteristics, with the huge magnetite deposits of the Kiruna district in Sweden, and the breccia deposits are likewise comparable with the giant Olympic Dam copper-uranium-gold-silver-rare-earth element deposit in South Australia. In the Great Bear magmatic zone, they are closely related in time and space to quartz monzonite intrusions emplaced ca. 1865 Ma ago. They are interpreted here to have been formed by volatile-rich fractions carrying iron and other components, in tensional openings and breccia openings created by escaping volatiles. The breccia deposits are particularly interesting as they indicate a potential for much larger polymetallic deposits of the Olympic Dam-type in the magmatic zone.

The polymetallic hydrothermal veins and disseminations likely contain, at least in part, the metals scavenged from the metasedimentary rocks by circulating mixed magmatic and meteoric waters. The favourable deposition site was the unconformity between the metasedimentary rocks and the overlying felsic volcanic sequence. The rocks of the Great Bear magmatic zone were affected by a set of major northeast-trending right lateral faults and their subsidiary fractures, which are the hosts of giant quartz veins and of veinlets and fracture-fillings of pitchblende and copper sulphides. A small deposit of this type, namely the Rayrock deposit, produced uranium in the 1950s.

GUIDES TO EXPLORATION

Among the possible exploration targets in the southern Great Bear magmatic zone, the most attractive from an economic standpoint are the Olympic Dam-type deposits, followed by stratabound base metal deposits, polymetallic hydrothermal veins and disseminations, and volcanogenic and Rayrock-type uranium deposits. It should be emphasized that this assessment is based on limited exploration and geoscience databases, and that with further exploration, additional deposit types of economic interest may become apparent. Some of the exploration techniques discussed below are applicable to more than one type of deposit.

In the search for Olympic Dam-type deposits, geologically favourable factors are the proximity to the centres of continental felsic volcanic activity and the presence of magnetite-hematite-rich occurrences. Coincident magnetic and gravity anomalies provide very useful guides (Gandhi and Halliday, 1993), and are indispensable in exploration of those parts of the magmatic zone that are covered by younger strata and overburden. The discovery of the Olympic Dam deposit, which is under 300 m of younger strata, was based on the testing of coincident gravity and magnetic anomalies. As it is a 2 billion tonne deposit, it has a most pronounced magnetic and gravity expression. Relatively smaller deposits, which could still be of economic interest, would have proportionately smaller gravity and magnetic expressions. The usefulness of airborne radiometric surveys in exposed parts of the Great Bear magmatic zone has been demonstrated by the discovery of the Sue-Dianne deposit and numerous other prospects (Charbonneau, 1988). They are, however, of limited use in large areas covered by Paleozoic strata, overburden, and lakes. Major lineaments were used as guides during exploration of the Olympic Dam deposit in South Australia (Reeve et al., 1990). In this regard, the intersection of the Wopmay fault zone and the northeast-trending fault zone of the east arm of Great Slave Lake is of interest as these zones represent fundamental crustal breaks that controlled the development of the Wopmay Orogen and Great Bear magmatic activity.

Other deposit types in the southern Great Bear magmatic zone present targets smaller than the Olympic Dam-type deposits, although stratabound deposits in the metasedimentary rocks could potentially be large. Detailed stratigraphic and structural studies of these rocks, combined with prospecting, are essential for definition of target zones for stratabound deposits. Careful delineation of the unconformity between these rocks and the overlying volcanic rocks is essential in the search for polymetallic hydrothermal vein-type and disseminated deposits. Additional favourable indicators include multi-element geochemical anomalies that are useful in delineating polymetallic deposits which are characterized by specific metal associations. A plutonic source for the known granite-related copper, molybdenum, and uranium occurrences still remains to be identified. Continued exploration for this phase of granite in the vicinity of these occurrences and elsewhere may result in the further discovery of economically interesting concentrations of these metals. Lithogeochemical and geophysical techniques like the spectrometer and induced polarization, respectively, are useful tools in exploration for deposits of this type.

Exploration for uranium deposits in the southern Great Bear magmatic zone has been intensive in the past and a number of occurrences, including the Rayrock deposit, have been found by prospecting and airborne radiometric surveys of selected areas. This does not, however, preclude the possibility of finding other larger volcanogenic and fault-controlled uranium deposits and uranium-silver-copper-cobalt-nickel veins, because faults and fractures are common throughout the area and many have not been adequately tested. Multi-element analyses of veins in major faults and subsidiary fractures may reveal the presence of valuable metals including gold and platinum group metals.

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REFERENCES

Allan, R.J. and Cameron, E.M.
1973: Lake sediment geochemical survey, Bear-Slave operation, District of Mackenzie; Geological Survey of Canada, Preliminary Maps 1-1972 to 9-1972.

Badham, J.P.N.
1973: Calc-alkaline volcanism and plutonism from the Great Bear batholith, N.W.T.; Canadian Journal of Earth Sciences, v. 10, p. 1319-1328.
1978a: Magnetite-apatite-amphibole-uranium and silver-arsenide mineralizations in lower Proterozoic igneous rocks, East Arm, Great Slave Lake, Canada; Economic Geology, v. 73, no. 8, p. 1474-1491.
1978b: Has there been an oceanic margin to western North America since Archean times?; Geology, v. 6, p. 621-625.

Badham, J.P.N. and Morton, R.D.
1976: Magnetite-apatite intrusions and calc-alkali magmatism, Camsell River, N.W.T.; Canadian Journal of Earth Sciences, v. 13, p. 348-354.

Badham, J.P.N. and Muda, M.M.
1980: Mineralogy and paragenesis of hydrothermal mineralizations in the east arm of Great Slave Lake; Economic Geology, v. 75, no. 8, p. 1220-1225.

Baragar, W.R.A.
1977: Volcanism of the stable crust; in Volcanic Regimes in Canada, (ed.) W.R.A. Baragar, L.C. Coleman, and J.M. Hall; Geological Association of Canada, Special Paper 16, p. 377-406.

Bickford, M.E. and Mose, D.G.
1975: Geochronology of Precambrian rocks in the St. Francois Mountains, southeast Missouri; Geological Society of America, Special Paper 165, 48 p.

Bickford, M.E., Van Schmus, W.R., and Zietz, I.
1986: Proterozoic history of the midcontinent region of North America; Geology, v. 14, p. 492-496.

Bookstrom, A.A.
1977: The magnetite deposits of El Romeral, Chile; Economic Geology, v. 72, no. 6, p. 1101-1130.
Bowring, S.A.
1984: U-Pb zircon geochronology of early Proterozoic Wopmay orogen, N.W.T., Canada: An example of rapid crustal evolution; Ph.D. thesis, University of Kansas, Kansas, U.S.A., 138 p.
Bowring, S.A., Van Schmus, W.R., and Hoffman, P.F.
1984: U-Pb zircon ages from Athapuscow Aulacogen, east arm of Great Slave Lake, N.W.T., Canada; Canadian Journal of Earth Sciences, v. 21, p. 1315-1324.
Burnham, W.C. and Ohmoto, H.
1980: Late stage processes of felsic magmatism; Mining Geology Special Issue, no. 8, Society of Mining Geologists of Japan, Tokyo, p. 1-11.
Byrne, N.W.
1957: The Rayrock story; Western Miner, v. 30, no. 4. p. 71-77.
Charbonneau, B.W.
1988: Gamma spectrometric and magnetic anomalies associated with Cu-U mineralization, Faber Lake volcanic belt, District of Mackenzie, N.W.T.; in Current Research, Part C; Geological Survey of Canada, Paper 88-1C, p. 255-258.
Cliff, R.A., Rickard, D., and Blake, K.
1990: Isotopic systematics of the Kiruna magnetite ores, Sweden, Part I - Age of the ore; Economic Geology, v. 85, no. 8, p. 1770-1776.
Creaser, R.A. and White, J.R.
1991: Yardea Dacite - Large volume, high-temperature felsic volcanism from the Middle Proterozoic of South Australia; Geology, v.19, p. 48-51.
Dobek, G.
1985: Norris Lake area, District of Mackenzie; Report to Gerald Ryznar, Department of Indian and Northern Affairs, Document 081841.
Douglas, R.J.W., Norris, A.W., and Norris, D.K.
1974: Geology, Horn River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1372A, scale 1:500 000.
Easton, R.M.
1981: Geology of Grant Lake and Four Corners map area, Wopmay orogen, District of Mackenzie; in Current Research, Part B; Geological Survey of Canada, Paper 81-1B, p. 83-94.
Fahrig, W.F. and West, T.D.
1986: Diabase dyke swarms of the Canadian Shield; Geological Survey of Canada, Map 1627A, approximate scale 1:4 873 900.
Fanning, C.M., Flint, R.B., Parker, A.J., Blissett, A.H., and Ludwig, K.R.
1988: Refined Proterozoic evolution of the Gawler Range craton, South Australia, through U-Pb geochronology; Precambrian Research, v. 40/41, p. 363-386.
Förster, H.
1990: Scapolite-analcite-bearing magnetite ore from Seh Chahoon, central Iran; in Program with Abstracts, 8th IAGOD Symposium, International Association on the Genesis of Ore Deposits, August 1990, Ottawa, Ontario, p. A196.
Förster, H. and Jafarzadeh, A.
1983: The Chador Malu iron ore deposit (Bafq district, central Iran) magnetite filled pipes; in Geodynamic Project (Geotraverse) in Iran, Final Report, (ed.) V. Madechat; Geological Survey of Iran, Report No. 51, p. 501-510.
Förster, H. and Knittel, U.
1979: Petrographic observations on a magnetite deposit at Mishdovan, central Iran; Economic Geology, v. 74, no. 6, p. 1485-1510.
Fraser, J.A.
1967: Geological map, Hardisty Lake (West Half); District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 224A, scale 1 inch to 4 miles.
Frietsch, R.
1978: On the magmatic origin of iron ores of the Kiruna type; Economic Geology, v. 73, no. 4, p. 478-485.
Frietsch, R., Papunen, H., and Vokes, F.M.
1979: The ore deposits in Finland, Norway and Sweden - a review; Economic Geology, v. 74, p. 975-1001.
Frith, R., Frith, R.A., and Doig, R.
1977: The geochronology of the granitic rocks along the Bear-Slave Structural Province boundary, northwest Canadian Shield; Canadian Journal of Earth Science, v. 14, p. 1356-1373.
Frith, R.A.
1993: Precambrian geology of the Indin Lake map area, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Memoir 424, 63 p.
Frutos, J. and Oyarzun, J.
1975: Tectonic and geochemical evidence concerning the genesis of El Laco magnetite lava flow deposits, Chile; Economic Geology, v. 70, no. 5, p. 988-990.
Furnival, G.M.
1935: Large quartz veins of the Great Bear Lake, Canada; Economic Geology, v. 30, p. 843-859.
1939: Geology of the area north of Contact Lake, N.W.T.; American Journal of Science, v. 237, p. 478-489.
Gaäl, G. and Gorbatschev, R.
1987: An outline of the Precambrian evolution of the Baltic Shield; Precambrian Research, v. 35, p. 15-32.
Gandhi, S.S.
1978a: Geological observations and exploration guides to uranium in the Bear and Slave structural provinces and the Nonacho basin; in Current Research, Part B; Geological Survey of Canada, Paper 78-1B, p. 141-149.
1978b: Geological setting and genetic aspects of the uranium occurrences in the Kaipokok Bay-Big River area, Labrador; Economic Geology, v. 73, p. 1492-1522.
1988: Volcano-plutonic setting of U-Cu bearing magnetite veins of FAB claims, southern Great Bear magmatic zone, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 88-1C, p. 177-187.
1989: Rhyodacite ignimbrites and breccias of the Sue-Dianne and Mar Cu-Fe-U deposits, southern Great Bear magmatic zone, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 89-1C, p. 263-273.
1990: Paragenesis of magnetite-dominated and arsenopyrite-dominated polymetallic deposits in the southern Great Bear magmatic zone, Northwest Territories, Canada; in Program with Abstracts, 8th IAGOD Symposium, International Association on the Genesis of the Ore Deposits, August 12-18, 1990, Ottawa, Ontario, p. A197.
1992a: Magnetite deposits in metasiltstones of the Snare Group at Hump Lake, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 92-1C, p. 225-235.
1992b: Magnetite-rich breccia of the Mar deposit and veins of the Nod prospect, southern Great Bear magmatic zone, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 92-1C, p. 237-249.
1992c: Polymetallic deposits of the southern Great Bear magmatic zone; in Project Summaries: Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991; Geological Survey of Canada, Open File 2484, p. 135-139.
Gandhi, S.S. and Bell, R.T.
1990: Metallogenic concepts to aid exploration for the giant Olympic Dam-type deposits and their derivatives; in Program with Abstracts, 8th IAGOD Symposium, International Association on the Genesis of Ore Deposits, August 12-18, 1990, Ottawa, Ontario; p. A7.
1993: Metallogenic concepts to aid exploration for the giant Olympic Dam-type deposits and their derivatives; Proceedings of the Eighth Quadrennial IAGOD Symposium, held in Ottawa, Ontario, August 12-18, 1990; International Association on the Genesis of Ore Deposits, (ed.) Y.T. Maurice; E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, p. 787-802.
Gandhi, S.S. and Halliday, D.
1993: Gravity survey of the Sue-Dianne deposit, Northwest Territories; in Current Research, Part E; Geological Survey of Canada, Paper 93-1E, p. 231-238.
Gandhi, S.S. and Lentz, D.R.
1990: Bi-Co-Cu-Au-As and U occurrences in the Snare Group metasediments and felsic volcanics of the southern Great Bear magmatic zone, Lou Lake, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 90-1C, p. 239-253.

Gandhi, S.S. and Mortensen, J.K.
1992: 1.87-1.86 Ga old felsic volcano-plutonic activity in southern Great Bear magmatic zone, N.W.T.; in Geological Association of Canada-Mineralogical Association of Canada Annual Meeting, Abstracts Volume 17, p. A37.

Gandhi, S.S. and Paktunc A.D.
1989: Au, Pt and Pd in pitchblende and copper sulphide veins at the Rah, Far and Jaciar prospects, norther Bear Province, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 89-1C, p. 243-253.

Gandhi, S.S. and Prasad, N.
1982: Comparative petrochemistry of two cogenetic monzonitic laccoliths and genesis of associated uraniferous actinolite-apatite-magnetite veins, east arm of Great Slave Lake, District of Mackenzie; in Uranium in Granites, (ed.) Y.T. Maurice; Geological Survey of Canada, Paper 81-23, p. 81-90.
1993: Regional metallogenic significance of Cu, Mo, and U occurrences at DeVries Lake, southern Great Bear magmatic zone, Northwest Territories; in Current Research, Part C; Geological Survey of Canada, Paper 93-1C, p. 29-39.

Gandhi, S.S., Prasad, N., and Morgan, J.
1992: Geological setting of sedimentary and magmatogenic copper-uranium-bearing magnetite deposits of southern Great Bear magmatic zone; in Exploration Overview 1992, Northwest Territories, (ed.) J.A. Brophy; Department of Indian and Northern Affairs, Yellowknife; p. 24-25.

Garrett, R.G.
1975: Copper and zinc in Proterozoic acid volcanics as a guide to exploration in the Bear Province; in Geochemical Exploration 1974, (ed.) I.L. Elliot and W.K. Fletcher; Association of Exploration Geochemists, Special Publication No. 2, Proceedings of the 5th International Geochemical Exploration Symposium held in Vancouver, British Columbia, April 1974; Elsevier Publishing Company, Amsterdam, p. 371-388.

Geijer, P.
1931: The iron ores of Kiruna type; Sveriges Geologiska Undersökning, ser. C, no. 367, 39 p.

Giles, C.W.
1988: Petrogenesis of the Proterozoic Gawler Range volcanics, South Australia; Precambrian Research, v. 40/41, p. 407-427.

Hagni, R.D. and Brandom, R.T.
1988: Comparison of the Boss-Bixby, Missouri and Olympic Dam, South Australia ore deposits, and potential for these deposits in the midcontinent region; in Proceedings, North American Conference on Tectonic Control of Ore Deposits and the Vertical and Horizontal Extent of Ore Systems, (ed.) G. Kisvarsanyi and S.K. Grant; University of Rolla, Missouri, p. 333-335.

Harris, J.F. and Ryznar, G.
1984: Norris Lake area, District of Mackenzie; Department of Indian and Northern Affairs, Document 081700.

Hauck, S.A.
1990: Petrogenesis and tectonic setting of Middle Proterozoic iron oxide-rich ore deposits - an ore deposit model for Olympic Dam-type mineralization; in The Midcontinent of the United States - Permissive Terrane for an Olympic Dam-Type Deposit?, (ed.) W.P. Pratt and P.K. Sims; United States Geological Survey, Bulletin 1932, p. 4-39.

Hauck, S.A. and Kendall, E.W.
1984: Comparison of middle Proterozoic iron oxide rich ore deposits, midcontinent U.S.A., South Australia, Sweden, and the People's Republic of China; in 30th Annual Meeting, Institute on Lake Superior Geology, Wausau, Wisconsin, U.S.A., Program with abstracts, p. 17-18.

Henriquez, F. and Martin, R.F.
1978: Crystal-growth textures in magnetite flows and feeder dykes, El Laco, Chile; Canadian Mineralogist, v. 16, pt. 4, p. 581-589.

Hildebrand, R.S.
1981: Early Proterozoic LaBine Group of Wopmay orogen: remnant of a continental volcanic arc developed during oblique convergence; in Proterozoic Basins of Canada, (ed.) F.H.A. Campbell; Geological Survey of Canada, Paper 81-10, p. 133-156.

Hildebrand, R.S. (cont.)
1984: Geology of the Rainy Lake White Eagle Falls area, District of Mackenzie: Early Proterozoic cauldrons, stratovolcanoes and subvolcanic plutons; Geological Survey of Canada, Paper 83-20, 42 p.
1986: Kiruna-type deposits: their origin and relationship to intermediate subvolcanic plutons in the Great Bear magmatic zone, northwest Canada; Economic Geology, v. 81, no. 3, p. 640-659.

Hildebrand, R.S., Bowring, S.A., and Housh, T.
1990: The medial zone of Wopmay orogen, District of Mackenzie; in Current Research, Part C; Geological Survey of Canada, Paper 90-1C, p. 167-176.

Hildebrand, R.S., Hoffman, P.F., and Bowring, S.A.
1987: Tectono-magmatic evolution of the 1.9-Ga Great Bear magmatic zone, Wopmay orogen, northwestern Canada; Journal of Volcanology and Geothermal Research, v. 32, p. 99-118.

Hildebrand, R.S., Paul, D., Peitikäinen, P., Hoffman, P.F., Bowring, S.A., and Housh, T.
1991: New geological developments in the internal zone of Wopmay orogen, District of Mackenzie; in Current Research, Part C; Geological Survey of Canada, Paper 91-1C, p. 157-164.

Hitzman, M.W., Oreskes, N., and Einaudi, M.T.
1990: Geologic characteristics and tectonic setting of Proterozoic Olympic Dam (Kiruna)-type deposits; in Program with Abstracts, 8th IAGOD Symposium, International Association on the Genesis of Ore Deposits, Ottawa, Canada, 1990, p. A164.
1992: Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits; Precambrian Research, v. 58, p. 241-287.

Hoffman, P.F.
1980: Wopmay Orogen: a Wilson cycle of Early Proterozoic age in the northwest of the Canadian Shield; in Continental Crust and its Mineral Deposits, (ed.) D.W. Strangway; Geological Association of Canada, Special Paper 20, p. 523-549.
1984: Geology, Northern Internides of Wopmay Orogen, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1576A, scale 1:250 000.
1988: Geology and tectonics: east arm of Great Slave Lake, Northwest Territories; Geological Survey of Canada, Map 1628A, sheet 1 - scale 1:250 000, sheet 2 - scale 1:500 000.

Hoffman, P.F. and McGlynn, J.C.
1977: Great Bear batholith: a volcano-plutonic depression; in Volcanic Regimes in Canada, (ed.) W.R.A. Baragar, L.C. Coleman, and J.M. Hall; Geological Association of Canada, Special Paper 16, p. 169-192.

Hoffman, P.F., Bell, I.R., Hildebrand, R.S., and Thorstad, L.
1977: Geology of Athapuscow Aulacogen, east arm of Great Slave Lake, District of Mackenzie; in Report of Activities, Part A; Geological Survey of Canada, Paper 77-1A, p. 117-129.

Irvine, T.N. and Baragar, W.R.A.
1971: A guide to the chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Johnson, J.P. and Cross, K.C.
1991: Geochronological and Sm-Nd isotopic constraints on the genesis of the Olympic Dam Cu-U-Au-Ag deposit, South Australia; in Proceedings of the 25th Anniversary Meeting of the Society for Geology Applied to Mineral deposits: Source, Transport, and Deposition of Ore Minerals, (ed.) M. Pagel and J.L. Leroy; A.A. Balkema, Rotterdam, p. 395-400.

Kidd, D.F.
1936: Rae to Great Bear Lake, Mackenzie District, N.W.T.; Geological Survey of Canada, Memoir 187, 44 p.

Kisvarsanyi, G. and Kisvarsanyi, E.B.
1989: Precambrian geology and ore deposits of the southeast Missouri iron metallogenic province; in Olympic Dam-type deposits and geology of middle Proterozoic rocks in the St. Francois Mountains terrane, Missouri, (ed.) V.M. Brown, E.B. Kisvarsanyi, and R.D. Hagni; Society of Economic Geologists Guidebook Series, v. 4, p. 1-54.

Lang, A.H.
1952: Canadian deposits of uranium and thorium (Interim account); Geological Survey of Canada, Economic Geology Report 16, 173 p.

Lang, A.H., Griffith, J.W., and Steacy, H.R.
1962: Canadian deposits of uranium and thorium; Geological Survey of Canada, Economic Geology Report 16, 324 p.
Legagneur, G.P.
1969: DV Claims, DeVries Lake, Assessment Report, Giant Yellowknife Mines Limited; Department of Indian and Northern Affairs Document 061467, 5 p.
Lord, C.S.
1942: Snare River and Ingray Lake map-areas, Northwest Territories; Geological Survey of Canada, Memoir 235, 35 p.
1951: Mineral industry of the District of Mackenzie, Northwest Territories; Geological Survey of Canada, Memoir 261, 138 p.
Lyons, J.I.
1988: Volcanogenic iron oxide deposits, Cerro de Mercado and vicinity, Durango, Mexico; Economic Geology, v. 83, no. 8, p. 1886-1906.
Magnusson, N.H.
1970: The origin of the iron ores in central Sweden and the history of their alterations; Sveriges Geologiska Undersökning, ser. C, no. 643, pt. 1, 127 p., pt. 2, 364 p.
Male, M.J.
1978: Assessment Report, UGI Group, DeVries Lake Diamond Drilling Project, Uranerz Exploration and Mining Limited; Department of Indian and Northern Affairs Document 061945, 7 p.
Marikos, M.A., Nuelle, L.M., and Seeger, C.M.
1989: Geology of the Pea Ridge mine; in Olympic Dam-type deposits and geology of middle Proterozoic rocks in the St. Francois Mountains Terrane, Missouri, (ed.) V.M. Brown, E.B. Kisvarsanyi, and R.D. Hagni; Society of Economic Geologists Guidebook Series, v. 4, p. 41-54.
McConnell, G.W.
1970: Norris Lake area, District of Mackenzie; Report to Granex Mines Limited; Department of Indian and Northern Affairs, Document 062057.
McGlynn, J.C.
1964: Grant Lake area; Geological Survey of Canada, Paper 64-1, 14 p.
1968: Tumi Lake, District of Mackenzie; Geological Survey of Canada, Map 1230A, scale 1:63 360.
1971: Metallic mineral industry, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Paper 70-17, 194 p.
1977: Geology of Bear-Slave Structural Provinces, District of Mackenzie; Geological Survey of Canada, Open File 445, scale 1:1 000 000.
1979: Geology of the Precambrian rocks of the Rivière Grandin and part of the Marian River map areas, District of Mackenzie; in Current Research, Part A; Geological Survey of Canada, Paper 79-1A, p. 127-131.
McGlynn, J.C., Richardson, K.A., Holman, P.B., and Elliot, B.
1974: Gamma-ray spectrometer maps and profiles, Marian River, Wecho River, Carp Lakes, McKay Lake, District of Mackenzie, Northwest Territories, (NTS 85N, O, P, 75M); Geological Survey of Canada, Open File 188, 15 maps, scale 1:250 000.
Miller, R.G.
1982a: The metallogeny of uranium in the Great Bear Batholith complex, Northwest Territories; Ph.D. thesis, University of Alberta, Edmonton, Alberta, 271 p.
1982b: The geochronology of uranium deposits in the Great Bear batholith, Northwest Territories; Canadian Journal of Earth Sciences, v. 19, no. 7, p. 1428-1448.
Morganti, J.
1988: Sedimentary-type stratiform ore deposits: some models and a new classification; in Ore Deposit Models, (ed.) R.G. Roberts and P.A. Sheahan; Geoscience Canada, Reprint Series 3, p. 67-78.
Mortimer, G.E., Cooper, J.A., Paterson, H.L., Cross, K., Hudson, G.R.T., and Uppill, R.K.
1988: Zircon U-Pb dating in the vicinity of the Olympic Dam Cu-U-Au deposit, Roxby Downs, South Australia; Economic Geology, v. 83, no. 4, p. 694-709.
Morton, R.D. and Changkakoti, A.
1987: The possible roles of Precambrian biota in the origin of magmatogene and hydrothermal silver-bearing vein deposits; Canadian Journal of Earth Sciences, v. 24, no. 2, p. 291-295.
Oreskes, N. and Einaudi M.T.
1990: Origin of rare earth element-enriched hematite breccias at the Olympic Dam Cu-U-Au-Ag deposit, Roxby Downs, South Australia; Economic Geology, v. 85, no. 1, p. 1-28.
Oyarzun, J. and Frutos, J.
1984: Tectonic and petrological frame of the Cretaceous iron deposits of north Chile; Mining Geology, v. 34, no. 1, p. 21-31.
Parák, T.
1975: The origin of Kiruna iron ores; Sveriges Geologiska Undersökning, ser. C, no. 709, 209 p.
Park, C.F.
1961: A magnetite "flow" in northern Chile; Economic Geology, v. 56, no. 2, p. 431-441.
1972: The iron ore deposits of the Pacific basin; Economic Geology, v. 67, no. 2, p. 339-349.
Paterson, J.
1974: Assessment Report, FXO Claim Group, Uranerz Exploration and Mining Limited; Department of Indian and Northern Affairs Document 080194, 4 p.
1975a: DeVries Lake Project 71-25, Yearly Report 1975, Uranerz Exploration and Mining Limited; Department of Indian and Northern Affairs Document 061467, 17 p.
1975b: Assessment Report, UGI Claim Group, Uranerz Exploration and Mining Limited; Department of Indian and Northern Affairs Document 080484, 12 p.
Pugh, D.C.
1993: Subsurface geology of pre-Mesozoic strata, Great Bear River map area, District of Mackenzie; Geological Survey of Canada, Memoir 430, 137 p.
Reardon, N.C.
1989: The Mystery Island intrusive suite and associated alteration haloes, Great Bear Lake, District of Mackenzie, N.W.T.; in Current Research, Part C; Geological Survey of Canada, Paper 89-1C, p. 37-42. 1990:
1990: Altered and mineralized rocks at Echo Bay, N.W.T., and their relationship to the Mystery Island intrusive suite; in Current Research, Part C; Geological Survey of Canada, Paper 90-1C, p. 143-150.
1993: Magmatic-hydrothermal systems and associated magnetite-apatite-actinolite deposits, Echo Bay, Northwest Territories; M.Sc. thesis, University of Ottawa, Ottawa, Ontario, 154 p.
Reeve, J.S., Cross, K.C., Smith, R.N., and Oreskes, N.
1990: Olympic Dam copper-uranium-gold-silver deposit; in Geology of the mineral deposits of Australia and Papua New Guinea, (ed.) F.E. Hughes; The Australasian Institute of Mining and Metallurgy, Melbourne, Victoria, Australia, p. 1009-1035.
Reichenbach, I.G.
1991: The Bell Island Bay Group, remnant of an early Proterozoic ensialic marginal basin in Wopmay orogen, District of Mackenzie; Geological Survey of Canada, Paper 88-28, 43 p.
Research Group on Porphyrite Iron Ore of the Middle-Lower Yangtze Valley
1977: Porphyrite iron ore - a genetic model of a group of iron ore deposits in andesitic volcanic area; Acta Geologica Sinica, v. 51, no. 1, p. 1-19.
Richardson, K.A., Holman, P.B., Elliot, B., Charbonneau, B.W., and McGlynn, J.C.
1973: Gamma-ray spectrometer maps and profiles, District of Mackenzie, Northwest Territories, (NTS 86A, B, C, F, G, H); Geological Survey of Canada, Open File 140, 8 maps, scale 1:250 000.
Roberts, D.E. and Hudson, G.R.T.
1983: The Olympic Dam copper uranium-gold deposit, Roxby Downs, South Australia, Economic Geology; v. 78, no. 5, p. 799-822. (see also discussions by I.P. Youles and reply in Economic Geology, v. 79, p. 1941-1945).
Robinson, B.W. and Ohmoto, H.
1973: Mineralogy, fluid inclusions and stable isotopes of the Echo Bay U-Ni-Ag-Cu deposits, Northwest Territories, Canada; Economic Geology, v. 68, p. 635-656.

Ross, G.M. and Kerans, C.
1989: Geology, Hornby Bay and Dismal Lakes groups, Coppermine Homocline, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1663A, scale 1:250 000.

Shegelski, R.J. and Thorpe, R.I.
1972: Study of selected mineral deposits in the Bear and Slave provinces; in Report of Activities, Part A; Geological Survey of Canada, Paper 72-1A, p. 93-96.

Skiöld, T.
1987: Implications of new U-Pb zircon chronology to early Proterozoic crustal accretion in northern Sweden; Precambrian Research, v. 38, p. 147-164.

St-Onge, M.R., King, J.E., and Lalonde, A.E.
1984: Deformation of the Coronation Supergroup and its basement in the Hepburn metamorphic-plutonic zone of Wopmay orogen: Redrock Lake and eastern portion of Calder River map area, District of Mackenzie; in Current Research, Part A; Geological Survey of Canada, Paper 84-1A, p. 171-180.

Thorpe, R.I.
1972: Mineral exploration and mining activities, mainland Northwest Territories, 1966 to 1968; Geological Survey of Canada, Paper 70-70, 204 p.

Van Schmus, W.R. and Bowring, S.A.
1984: Chronology of igneous events in the Wopmay Orogeny, Northwest Territories, Canada; in Geological Society of America, Abstracts with Programs, v. 54, p. 169-193.

West, G.F.
1980: Formation of continental crust; in The Continental Crust and its Mineral Deposits, (ed.) D.W. Strangway; Geological Association of Canada, Special Paper 20, p. 117-148.

Wyborn, L.A.I.
1988: Petrology, geochemistry and origin of a major Australian 1880-1840 Ma felsic volcano plutonic suite: a model for intracontinental magma generation; Precambrian Research, v. 40/41, p. 37-60.