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MINERAL EXPLORATION OPPORTUNITIES IN LABRADOR —A PERSPECTIVE FOR THE 1990'S

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ABSTRACT

Despite its vast extent and geological diversity, Labrador has not been explored to the extent of equivalent areas of the Canadian Shield to the west. However, a substantial improvement in the geoscientific database for Labrador has been wrought by almost 20 years of work, mainly funded by four successive Canada–Newfoundland Mineral Development Agreements. The results of these geoscience programs, including regional mapping, metallogeny, Quaternary geology, geochemistry and geophysics have substantially changed our understanding of the broad framework and many of the details of Labrador geology. New geological provinces have been recognized and the boundaries of the previously recognized provinces refined, previously unknown orogenies have been discovered, and the accretionary history of the eastern part of the North American Shield has been documented.

To the end of 1990, approximately 56 percent of Labrador has been mapped at 1:100,000 scale. This mapping has, in some areas, identified geological environments where a significant economic potential can be postulated but where no deposits are known. Elsewhere, there remain large areas where geological mapping may identify significant new mineral potential. Reconnaissance lake-sediment sampling is complete for Labrador and the suite of elements mapped is being expanded.

The improved geological understanding has produced a new generation of genetic models for known mineral deposits and enhanced metallogenic interpretations. Exploration targets for mineral-resource development have been identified including: 1) Cu–Ni(PGE) and Cu–Zn polymetallic massive sulphides and structurally hosted mesothermal gold in Archean greenstone belts; 2) lode gold in a variety of settings including eastern Superior Province high-grade terranes, major fault zones in the Labrador Trough, Central Mineral Belt, and Grenville Province; 3) clastic sediment-hosted exhalative massive sulphides in Lower Proterozoic basins in the Nain, Churchill, Makkovik and Grenville provinces; 4) Proterozoic volcanogenic massive sulphides in the Churchill Province; 5) PGE deposits associated with a wide variety of intrusive environments; 6) granophile elements associated with orogenic and anorogenic intrusions; and 7) industrial minerals of many types in a wide variety of geological settings.

INTRODUCTION

Labrador is a vast territory lying on the eastern edge of the Canadian Shield (Figure 1). It covers more than 250,000 km², and extends from the Straits of Belle Isle westward to the Labrador City area (more than 700 km) and northward to Cape Chidley (more than 800 km). Labrador's size reflects its geological complexity; it encompasses parts of five Canadian Shield structural provinces, within which is found a wide variety of geological environments and more than 3 billion years of geological history. Relatively little mineral exploration has been conducted in Labrador, at least in comparison to the rest of the Canadian Shield, and large tracts remain virtually unexplored. Most of Labrador remains an exploration frontier in every sense of the word.

There is a common perception that Labrador is remote and inaccessible. Although this impression was perhaps true during the heyday of iron-ore exploration and development in the 1950's and 1960's, it is far less true in the 1990's. The main centres of Goose Bay, Labrador City–Wabush, and Churchill Falls are all linked by daily scheduled air service to insular Newfoundland, Quebec and Nova Scotia. Labrador is also connected to the Quebec highway system by a road leading from Baie Comeau to Labrador City (Figure 2). During 1991, the final link will be completed between this road system and the summer-only gravel road that connects Churchill Falls with Goose Bay, thereby completing the road connection between all of the major population centres in Labrador and the Canadian highway system to the south. With the prospect of further hydro development along the Churchill

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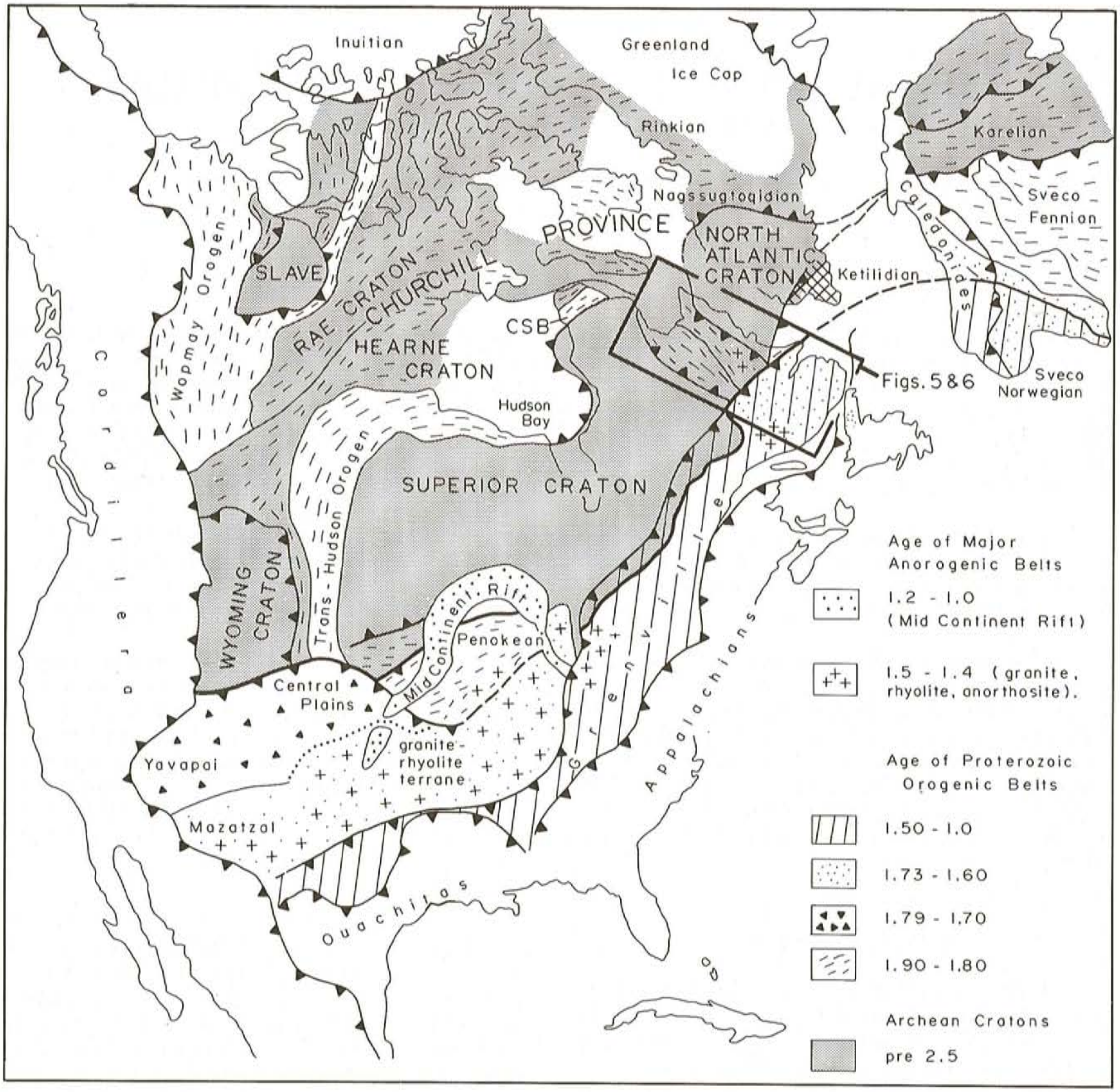


Figure 1. *Structural provinces of the North America–Greenland–Baltic shields, after Hoffman (1988). Location of Labrador and adjacent areas is shown by box.*

River, the road system will probably be further upgraded in the near future. Western Labrador continues to be served by the Quebec North Shore and Labrador (QNS&L) railway, which offers transport to and from Sept Isles, Quebec. The coastal communities of Labrador, although they remain isolated from the road network, are served by daily scheduled Twin Otter airline service to Goose Bay year-round and by regular coastal-boat (freight and passenger) service from June to November.

Much of interior Labrador is still remote and the only practical means of access is by aircraft. Fixed-wing charter service is available from Goose Bay, Labrador City and Schefferville (Quebec). Helicopters can be chartered in Goose Bay.

As the Newfoundland and Labrador Geological Survey Branch and the Geological Survey of Canada embark upon a new Agreement on Mineral Development at the start of our third decade of concentrated geoscience activities in Labrador in support of mineral development, it is perhaps appropriate to review the significant gains in our understanding of the regional geology and metallogeny of Labrador that this work to date, has brought about. The past 20 years have seen

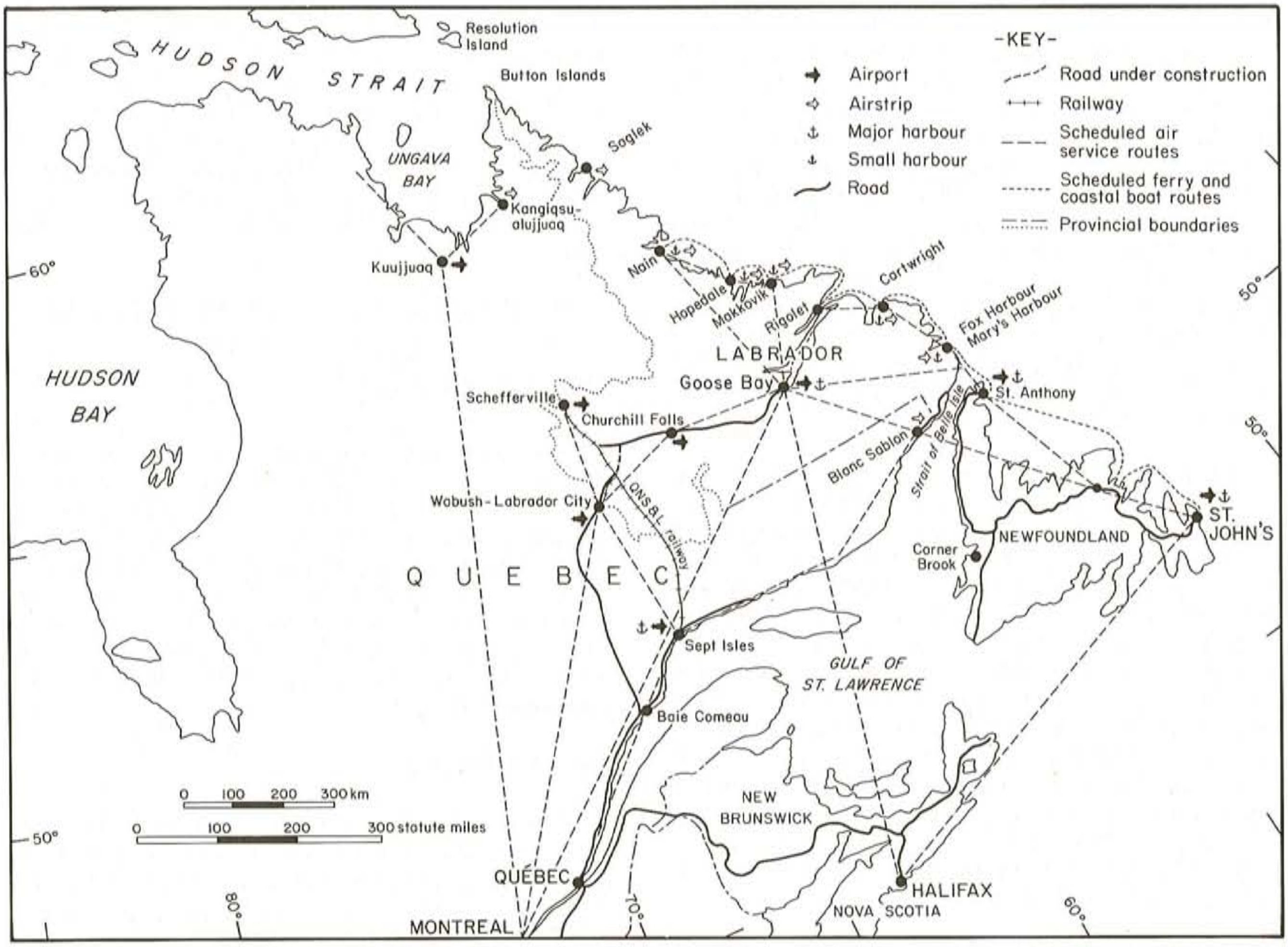


Figure 2. *Transport infrastructure of Labrador in the context of eastern Canada.*

significant advances in our understanding of the geology of Labrador, and this has in turn led to substantial changes in our perceptions of the mineral potential of this area. The objectives of this paper are threefold: 1) to point out some of the significant new developments in Labrador geology that might be of particular interest to the mineral-exploration industry; 2) to familiarize the readers with the scope and quality of the geoscientific database that is available for Labrador today; and 3) to suggest some exploration targets in Labrador, the potential of which has not been fully (or in some cases even partially) exploited. This article might be thought of as a road-map for exploration targets in Labrador. Space constraints do not permit all the details to be presented. However, the extensive reference list will lead the interested reader to further details in most areas and any of the authors would welcome personal inquiries on aspects of Labrador geology and mineral potential.

HISTORICAL REVIEW

In March, 1972, the first geological map of Labrador (Greene, 1972) was introduced at the annual meeting of the Prospector's and Developer's Association, compiled mainly from reconnaissance Geological Survey of Canada (GSC) mapping and from detailed exploration-company maps. Although the basic outlines of Labrador geology, including the approximate boundaries and general geology of the Superior, Churchill, Nain, and Grenville structural provinces, were reasonably well established at this time, detailed mapping was sparse and there was relatively little in-depth understanding of the internal geology of the various provinces. Mineral-exploration companies, operating under long-term concession agreements, had provided much of the geological information (a lot of which re-appeared in various Geological Survey of Canada compilations) and almost all of the information on Labrador's mineral resources. At that time, these included the major Fe deposits of the Labrador Trough, showings of Cu and Ni associated with mafic sills in the eastern part of the Trough, and Cu, U, Be and Mo deposits in Proterozoic supracrustal rocks of the Central Mineral Belt (CMB). With the notable exceptions of the western Labrador iron ranges, the Seal Lake Cu province and the U mineralization in the eastern Central Mineral Belt, there were few detailed mineral-deposits studies upon which to base regional metallogenic models, and little basis for suggesting mineral potential in areas where there were no known showings.

The Newfoundland Department of Mines and Energy (NDME) recognized in the early 1970's, that a much improved geoscientific database was essential for promotion of mineral-resource potential in Labrador, particularly in view of the anticipated replacement of the concession system with competitive claim-staking. Geological mapping and detailed study of the mineral deposits, begun in 1973 under the Canada–Newfoundland Mineral Exploration and Evaluation Agreement, was chiefly focussed on areas of demonstrated high-mineral potential in the Central Mineral Belt (Smyth *et al.*, 1974; Marten, 1975; Ryan, 1984) and two years later, programs were initiated in the Labrador Trough (Wardle, 1977). Work was carried out principally by the NDME, but included a significant contribution by geologists of the GSC and by research groups from geology departments of various Canadian universities.

By the early 1980's, mapping of the CMB and the Labrador Trough near the known mineral deposits was complete and genetic models based on detailed studies had been proposed for most deposit types. Mapping projects were expanding outward from these areas, and new projects were underway in the Nain and Churchill provinces in central and northern Labrador and along the northern margin of the Grenville Province. Regional geochemical studies were started in the eastern Grenville Province, Labrador Trough, CMB and parts of the Nain and Churchill provinces under the Canada–Newfoundland Uranium Reconnaissance Program and continued under the subsequent mineral-development agreements. Quaternary studies were initiated in the Melody Lake area in 1981, and industrial mineral-assessment programs began in western Labrador in 1984. Aeromagnetic mapping was begun in the late 1960's.

Now, at the beginning of the 1990's, government-sponsored geoscience programs, funded under four Canada–Newfoundland mineral-development programs, have revolutionized our understanding of the geological history of Labrador and of the exploration potential of the various geological provinces. Regional geological mapping at 1:100,000 scale has been completed over approximately 60 percent of Labrador (Figure 3). There is complete regional geochemical coverage in lake and stream sediments and regional contrasts in geochemical characteristics have been identified that correspond to contrasts in the underlying geology (Figure 4a, b) and re-analysis of archived samples for gold and related elements is underway, scheduled for completion in the early 1990's. Regional aeromagnetic surveys were completed in 1981. Systematic Quaternary mapping has been carried out in areas of high mineral industry interest (e.g., Central Mineral Belt, Strange Lake area, parts of the Labrador Trough) and mineral occurrences in the Central Mineral Belt, western Labrador and the north Labrador coast have been documented for inclusion in the provincial mineral-occurrence data system (MODS) and are or will soon be available as a database for microcomputer. Mineral-occurrence maps have been published or are in preparation for these areas (Figure 3).

The broad framework and many of the details of the geology of the region have now been established, new geological provinces have been recognized and the boundaries of the formerly recognized provinces refined, previously unknown orogenies have been discovered, and significant insights into the accretionary history of the eastern part of the North American Shield have been documented. The present state of knowledge of the geology of Labrador provides a framework for metallogenic interpretation of known mineral deposits and invites speculation concerning the potential of areas where occurrences have not yet been found.

NEW CONCEPTS OF THE GEOLOGY OF LABRADOR

GENERAL GEOLOGY

The general geology of Labrador is shown in Figure 5. Labrador contains parts of five structural provinces (Figure 1) that record a crustal history ranging from about 3.8 to 0.6 Ga. The oldest rocks are preserved in the Archean cratons of the Nain and Superior provinces. These are bounded by the Lower Proterozoic mobile belts of the Churchill and Makkovik provinces. The Grenville Province, which truncates the Churchill and Makkovik provinces in the south, contains vestiges of an Early Proterozoic mobile belt referred to as the Labrador Orogen.

NAIN PROVINCE

The Nain Province is divided broadly into a northern segment, the Saglek block, and a southern segment, the Hopedale block (Figure 6). The Saglek block (cf. Bridgwater *et al.*, 1978) consists predominantly of amphibolite- to granulite-facies granitoid gneiss (3.8 to 2.9 Ga) interspersed with narrow (tens of metres to 2 kilometres) supracrustal belts composed of pelitic–psammitic gneiss and mafic rocks representing mafic metavolcanic rocks and high-level intrusions.

The Hopedale block (cf. Korstgaard and Ermanovics, 1985) consists mainly of a rather similar, although slightly younger (2.9 to 2.3 Ga), granitoid–gneiss dominated terrane with an extensive ~2.8 Ga granitoid intrusive terrane at its southern end (Kanairiktok Intrusive Suite). It also contains two 'greenstone' belts, the relatively low-grade (greenschist) Florence Lake belt and the somewhat higher grade (up to amphibolite) Hunt River belt.

Ages within the Nain Province young to the south, suggesting that the craton has grown by progressive accretion in that direction.

SUPERIOR PROVINCE

The comparatively small part of the western Superior Province present in Labrador is composed of the granulite facies Ashuanipi Complex. As described by Percival (1987), this consists of an older sequence of migmatitic metasedimentary gneisses and lesser metavolcanic mafic rocks, intercalated with broad sheets of migmatitic tonalite

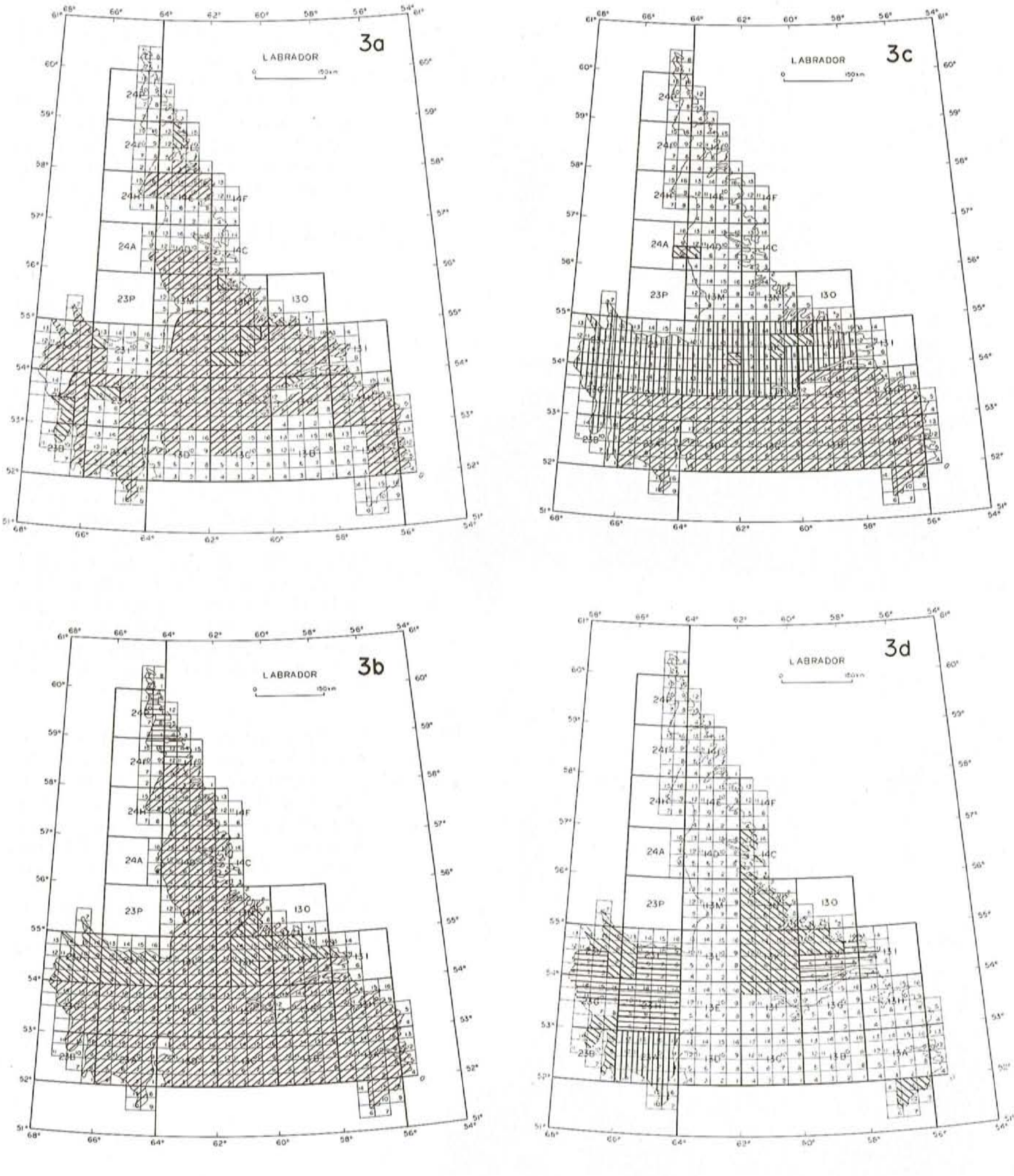
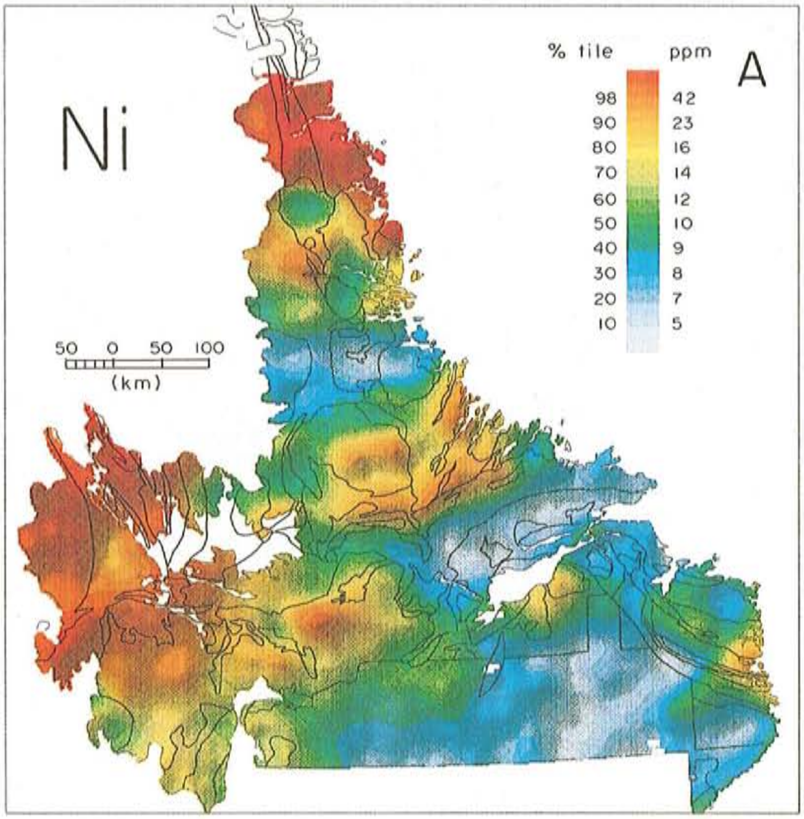


Figure 3. *Maps illustrating the geoscience data coverage for Labrador. a–regional geological mapping. 1:100,000; 1:50,000; b–regional geochemical surveys; lake sediment and water (GSC); analysis of archived lake-sediment samples for Au and related elements; stream sediment and water; c–Quaternary mapping; 1:50,000; 1:250,000; 1:500,000; d–Mineral Occurrence Data System; completed, map published; data compilation completed, maps to be published; data compilation in progress.*



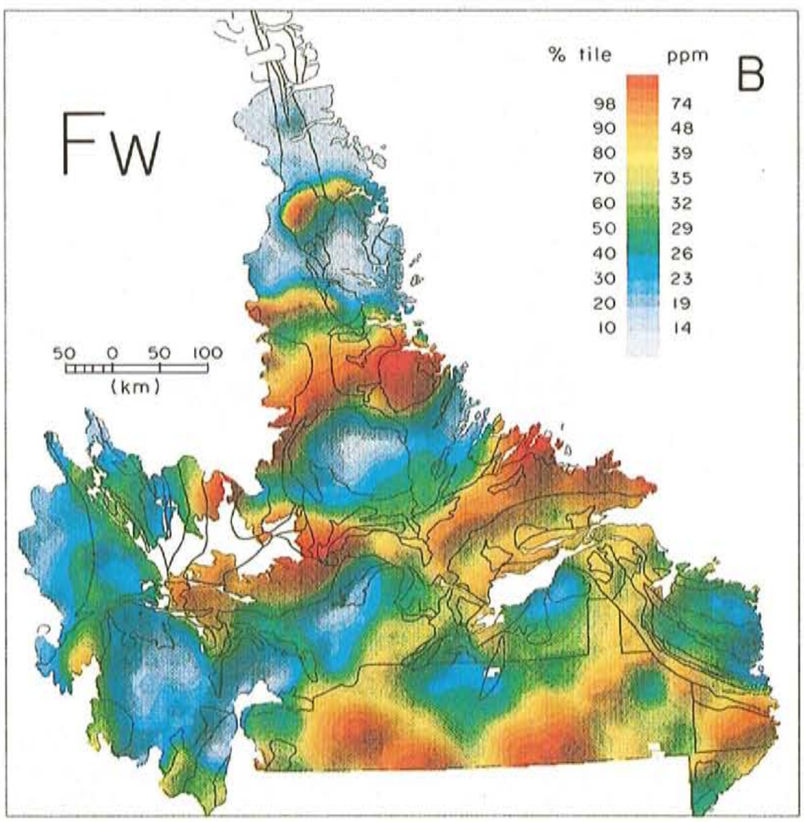


Figure 4. *Representative regional geochemical maps for Labrador. A—Ni in lake sediments; B—fluorine in lake waters. Geological boundaries as in Figure 5.*

gneiss. These are intruded by foliated to massive tonalite and diatexite and by late intrusions of granite and nepheline syenite. U–Pb age determinations indicate crust formation between approximately 2.78 and 2.64 Ga and suggest that the Ashuanipi Complex is a high-grade equivalent of the Quetico Subprovince of the western Superior Province (Mortenson and Percival, 1987).

CHURCHILL PROVINCE

The Churchill Province is now recognized to have a well-defined tripartite subdivision (Wardle *et al.*, *in press*,b) (Figure 6). The western part of the province consists of a west-verging fold and thrust belt formed by low-grade sedimentary and volcanic rocks of the Labrador Trough. This has been more recently referred to as the 'New Quebec Orogen' (Hoffman, 1988). The central Churchill Province is rather poorly known but appears to consist predominantly of reworked Archean rocks of the Rae Province (Hoffman, 1988), structurally juxtaposed with the Labrador Trough along mylonitic shear zones. The Rae Province rocks are intruded by the axial De Pas batholith. Recognizable Archean rocks include anorthosites and related gabbroic rocks, and a 'greenstone'-type belt near the eastern end of the Smallwood Reservoir area.

The eastern part of the Rae Province is structurally juxtaposed against reworked rocks of the Nain Province in the Torngat Orogen. The site of the suture is the Abloviak shear zone, a major sinistral shear located within a linear belt of mylonitized paragneiss (Tasiuyak gneiss). To the east of the Abloviak shear zone, the reworked Archean gneisses of the Nain Province and Lower Proterozoic Ramah Group cover rocks, define an east-verging fold-and-thrust belt. Lower Proterozoic orogenesis in the Churchill Province was largely transpressional involving oblique convergence of the Superior and Nain cratons on the Rae Province (see van Kranendonk, 1990; Wardle *et al.*, *in press*,a and references therein).

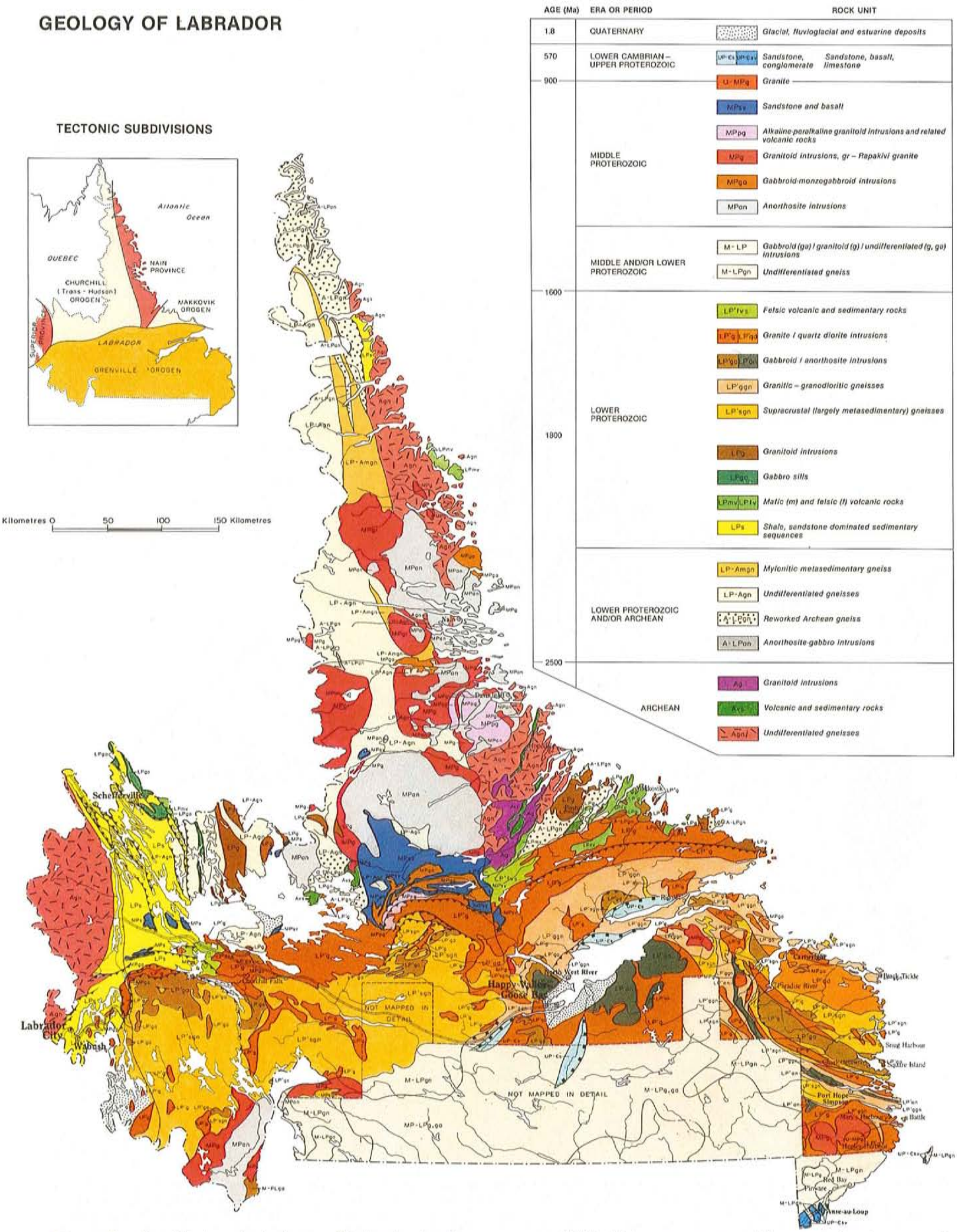


Figure 5. *Simplified geological map of Labrador (geology current to 1987). Units are represented in terms of rock type and age, rather than stratigraphic nomenclature. Names of major rock units referred to in the text are depicted in Figure 6.*

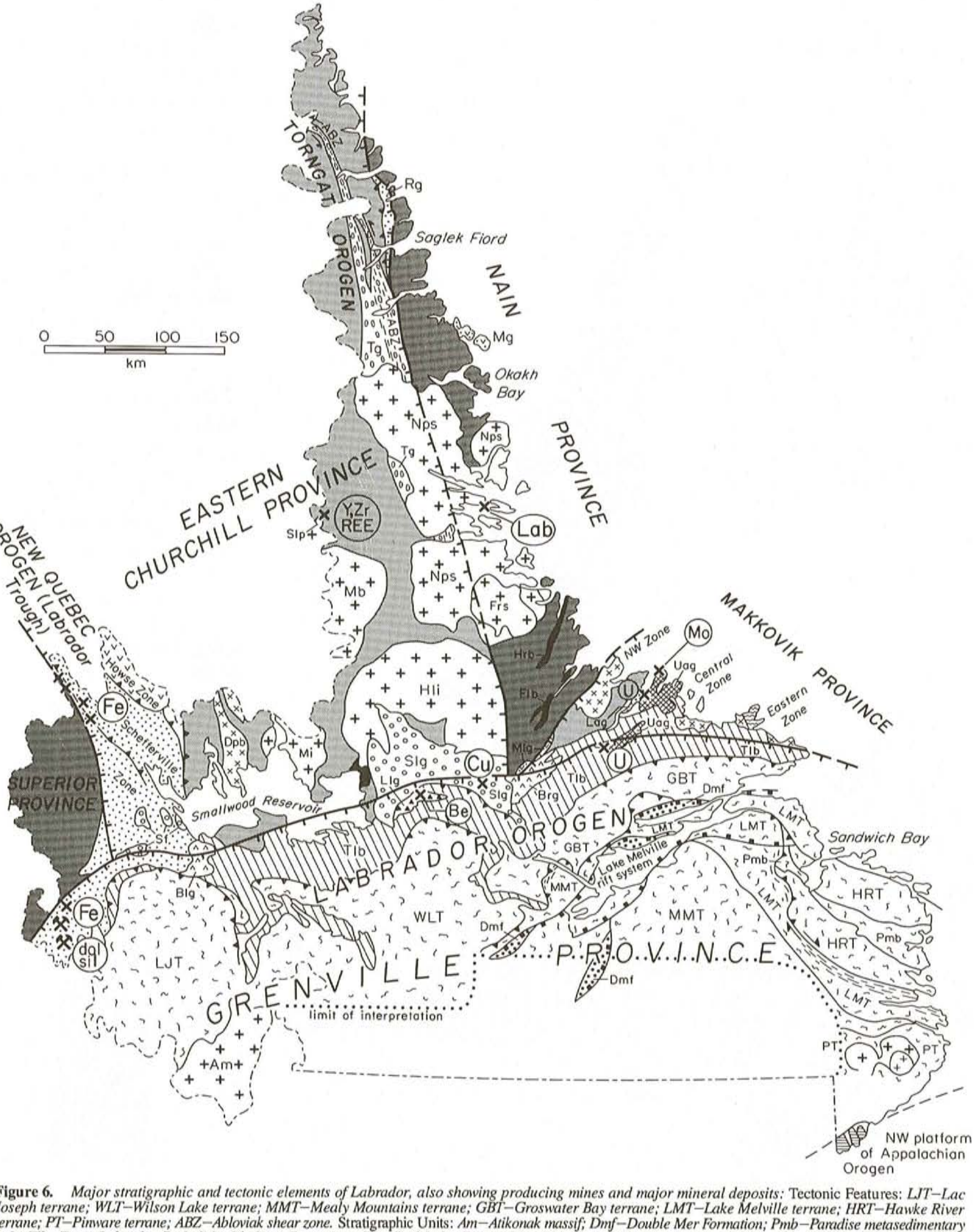


Figure 6. *Major stratigraphic and tectonic elements of Labrador, also showing producing mines and major mineral deposits:* Tectonic Features: *LJT–Lac Joseph terrane; WLT–Wilson Lake terrane; MMT–Mealy Mountains terrane; GBT–Groswater Bay terrane; LMT–Lake Melville terrane; HRT–Hawke River terrane; PT–Pinware terrane; ABZ–Abloviak shear zone.* Stratigraphic Units: *Am–Atikonak massif; Dmf–Double Mer Formation; Pmb–Paradise metasedimentary belt; Tlb–Trans-Labrador Batholith; Sf–Sims Formation; Slg–Seal Lake Group; Blg–Blueberry Lake Group; Llg–Letitia Lake Group; Brg–Bruce River Group; Mlg–Moran Lake Group; Lag–Lower Aillik Group; Uag–Upper Aillik Group; Flb–Florence Lake belt; Hrb–Hunt River belt; Nps–Nain Plutonic Suite; Hli–Harp Lake Intrusion; Mi–Michikamau Intrusion; Mb–Mistasin batholith; Slp–Strange Lake pluton; Mg–Mugford Group; Rg–Ramah Group; Tg–Tasiuyak gneiss; Frs–Flowers River suite.*

Legend for Figure 6

Paleozoic

Cambro-Ordovician rocks of NW platform to Appalachian Orogen

Upper Proterozoic (1.0 – 0.57 Ga)

Late Precambrian – Early Paleozoic rocks of Lake Melville rift system

Undifferentiated rocks of Grenville Province

Post-Grenville granites (ca. 0.97 – 0.95 Ga)

Middle Proterozoic (1.6 – 1.0 Ga)

Middle Proterozoic plutonic / sedimentary / volcanic rocks

Lower Proterozoic (2.1 – 1.6 Ga)

Late Lower Proterozoic (ca. 1.65 Ga) volcanic rocks

Late Lower Proterozoic plutonic rocks (ca. 1.65 Ga – only the Trans-Labrador batholith is shown)

Undifferentiated gneissic and plutonic rocks of Labradorian (1.7 – 1.6 Ga) age, overprinted by Grenvillian deformation

Early Lower Proterozoic (2.1 – 1.8 Ga) sedimentary / mafic volcanic / felsic volcanic rocks

Plutonic rocks

Tasiuyak paragneiss

Juvenile(?) gneiss of Makkovik Province

Gneissic rocks (largely reworked Archean) of Eastern Churchill and Makkovik provinces

Archean (>2.5 Ga)

Undifferentiated gneiss of Nain and Superior provinces

Archean metavolcanic belts

Symbols

Structural province boundaries

Thrust faults

Ductile shear zones

Normal fault

Mineral deposits

× *Major mineral deposit*

⚒ *Producing mine*

Fe – Iron
Cu – Copper
Y – Yttrium
Zr – Zirconium
Be – Beryllium
REE – Rare earth elements
U – Uranium
M – Molybdenum
Lab – Labradorite
Dol – Dolomite
SiO_2 – Silica

MAKKOVIK PROVINCE

This triangular crustal segment is the western continuation of the more extensive Ketilidian Mobile Belt of southern Greenland (Sutton *et al.*, 1972) and can be divided into three discrete zones (Gower and Ryan, 1986; Figure 6).

The northern zone consists mainly of reworked Archean granitoid gneisses equivalent to those in the southern Nain province, infolded with Proterozoic supracrustal rocks that are probably equivalent to the Moran Lake and Lower Aillik groups.

A narrow central zone includes the relatively well-preserved supracrustal rocks of the pre-1.86 Ga Moran Lake and Lower Aillik groups, comprising clastic sedimentary rocks overlain by thick submarine basalt sequences. Both groups are disposed in northwest-verging fold-and-thrust belts; the Lower Aillik Group is structurally overlain by the more extensive 1.86 to 1.81 Ga Upper Aillik Group, which is dominantly composed of felsic volcanic and pyroclastic rocks.

The eastern zone of the Makkovik Province is a complex, polyphase, syn- to posttectonic granitoid batholith, including suites of ca. 1.8, 1.72 and 1.65 Ga (Kerr, 1989; Kerr and Krogh, 1990) and containing small supracrustal and gneissic remnants. Although compositionally varied, the two older suites are dominated by potassic, high-silica granites; similar rocks intrude the Upper Aillik Group and gneisses of the central and northern zones respectively. This pre-1.65 Ga magmatism in the Makkovik Province has geochemical affinities to post-orogenic and anorogenic environments, whereas the 1.65 Ga magmatism is probably related to the Labradorian Orogeny.

Neodymium isotopic evidence indicates that the northern and central zones of the Makkovik Province are underlain by Archean basement, whereas the eastern zone shows no evidence of a significantly older basement complex (Kerr and Fryer, *in press*). It is likely that a substantial part of the gneisses and supracrustal rocks in the eastern part of the Makkovik Province comprises accreted juvenile crust.

GRENVILLE PROVINCE

The northern margin of the Grenville Province contains a belt of high-grade metamorphic and associated plutonic rocks (ca. 1.71 to 1.62 Ga) referred to as the Labrador Orogen (Figure 6) (Nunn *et al.*, 1985). The northern margin of this belt is marked by a curvilinear belt of granitoid rocks termed the Trans-Labrador batholith (TLB) and thought to be about 1.65 Ga old. At its eastern end, the 1.65 Ga TLB is only part of a composite granitic terrane that also includes ca. 1.80 and 1.72 Ga granitic suites (see above). The Labrador Orogen south of the TLB consists of tonalitic–granodioritic orthogneiss, pelitic paragneiss, numerous metagabbroic units (of which the anorthosite of the Mealy Mountains terrane is the largest and best preserved example) and voluminous granitoid plutonic rocks that range in age from 1.71 to 1.62 Ga.

The southward extent of the Labradorian rocks has yet to be fully established. Analogies with the western Grenville Province and the Baltic Shield suggest that Middle Proterozoic rocks should become more prevalent to the southeast (Gower and Owen, 1984; Gower and Ryan, 1986). Preliminary work on the southeast Labrador coast (Gower *et al.*, 1988; Tucker and Gower, 1990) has revealed the existence of middle Proterozoic granites in the Pinware Terrane and tends to confirm this suggestion. Syn- to post-Grenvillian granites also become increasingly prevalent to the south and form a major addition to the crust of the southern Grenville Province.

The Grenvillian Orogeny (ca. 1.0 Ga) resulted in regional high-grade metamorphism and north-directed thrusting, apparently in response to continental collision from the south. The zone within 100 km of the Grenville Front was subject to massive thrusting, local crustal imbrication and widespread ductile shearing. Large areas of the interior Grenville Province, however, escaped significant Grenvillian reworking and retain their generally Labradorian character.

MIDDLE PROTEROZOIC PLUTONISM AND SEDIMENTATION

Large areas of northern and central Labrador were subject to extensional tectonism in the period 1.45 to 1.1 Ga. The most obvious manifestations of this event are massif-type anorthosite–granite complexes and related gabbroic intrusions formed between 1.45 and 1.2 Ga. The largest and best examples were intruded within the Grenville Province and along the Nain–Churchill Province boundary zone and overlapped with a more limited period of dyke intrusion, and localized peralkaline–alkaline magmatism in the period 1.3 to 1.1 Ga (Hill and Miller, *in press*). The latter part of this period was marked by intrusion of the Strange Lake and Flowers River peralkaline centres, an igneous event that is probably equivalent to late alkaline magmatism of the Gardar Province in Greenland.

Middle Proterozoic sedimentation is represented by the Sims Formation (arkose, quartzite) of western Labrador and the Seal Lake Group (terrestrial arkose, quartzite, shale, basalt flows and gabbro sills) of central Labrador (Figure 6). The two groups were deposited in shallow-marine to terrestrial conditions but are not necessarily temporal equivalents. Both units span the Grenville–Churchill Province boundary and have been affected by Grenvillian deformation.

LATE PROTEROZOIC PLUTONISM AND SEDIMENTATION

Arkoses and conglomerates of the Double Mer Formation (late Precambrian to early Paleozoic) are preserved in a series of half-grabens, which form part of the Lake Melville rift system in eastern Labrador (Gower *et al.*, 1986a). A smaller, subparallel rift system has also been discovered in the Sandwich Bay area. Subparallel mafic dykes of ca. 0.615 Ga age (Kamo *et al.*, 1989) provide the best indication of the time of rift development and indicate a temporal link with initial rifting in the St. Lawrence rift system (northwestern margin of the Appalachian Orogen) to the south. Thin lamprophyre dykes of ca. 0.57 Ga in the Makkovik Province may be similarly related.

PHANEROZOIC

Cambro-Ordovician siliciclastic rocks, basalt flows and limestone of the Labrador Group are exposed on the southeast coast of Labrador, where they form part of the western platform to the Appalachian Orogen.

Younger rocks are volumetrically insignificant in Labrador. Various mafic dykes ranging in age from Carboniferous to Cretaceous are known from the coastal region and some of the Jurassic–Cretaceous examples have a kimberlitic affinity (Foley, 1989). Cretaceous gravels and lateritic deposits occur within a small graben in the Proterozoic iron deposits of western Labrador, and record a period of intense tropical weathering that led to the economically important secondary enrichment of the Schefferville iron deposits, and to the formation of leached silica deposits in the Labrador City area.

CORRELATIONS THROUGHOUT THE NORTH AMERICAN AND BALTIC SHIELDS

Broad correlations of the geology of Labrador with other parts of the North American Shield and with Greenland and Scandinavia (Figure 1) have been known for some time (Wynne-Edwards and Hasan, 1970; Sutton *et al.*, 1972; Bridgwater *et al.*, 1973; Gower and Owen, 1984; Gower *et al.*, *in press*,x). These correlations are of considerable economic significance, as they allow an evaluation of the mineral potential of areas in Labrador by analogy with other areas, where the metallogenic relationships are better documented and understood. They also allow us to use the presence of specific deposit types in geological terranes such as Scandinavia, Greenland, and other parts of Canada to predict mineral-exploration potential in correlative terranes in Labrador.

The Nain Province is part of the fragmented North Atlantic Craton, the greater part of which is now exposed in Greenland and northwest Scotland.

The part of the eastern Churchill Province exposed in Labrador forms a southern arm of the trans-Arctic portion of the Churchill Province. Rocks in the western part of this belt, referred to as the Labrador Trough (or 'New Quebec Orogen'; Hoffman, 1988) are correlative with the Cape Smith foldbelt and other rocks along the eastern side of Hudson Bay that form part of the 'Circum Ungava Belt' (Dimroth *et al.*, 1970). The central part of the eastern Churchill Province has been correlated with the Archean Rae Province (Hoffman, 1988), which forms a major interior part of the trans-Arctic Churchill Province. The eastern part of the eastern Churchill Province (Torngat Orogen) is inferred to extend through the southern tip of Baffin Island (Hoffman, 1989) and into the Nagssugtoqidian mobile belt of western Greenland (Korstgaard *et al.*, 1987).

The Makkovik Province of Labrador has long been recognized as the western extension of the Ketilidian mobile belt of southern Greenland (Sutton *et al.*, 1972; Gower and Ryan, 1986) which, in turn, is probably correlative with the Svecofennian belt of the Baltic Shield.

The Grenville Province in Labrador includes the ca. 1.65 Ga Labrador Orogen, which has correlatives in the Sveconorwegian Province of southern Scandinavia (Gaal and Gorbatschev, 1987) and the Mazatzal Orogen of the southwestern United States (van Schmus and Bickford, 1981; Hoffman, 1989). The exposed Grenville Province extends from southwestern Ontario and upstate New York to Labrador, and can be traced eastward into the Sveconorwegian Province of Scandinavia. A largely buried extension of the Grenville Province extends southward from Ontario as far as Texas and Mexico (Hoffman, 1989).

MINERAL ENVIRONMENTS OF LABRADOR

The increased geological understanding outlined above has spawned a new generation of metallogenic ideas and interpretations in Labrador. Coupled with data from mineral deposit, regional geochemical and Quaternary studies, our understanding of the genesis of known mineral deposits in Labrador has been improved, and new targets for future resource development have been identified.

In this section, we outline opportunities for mineral-resource development in Labrador that have been highlighted or identified during the past 15 years of geoscience activities. To this end, we have chosen to focus on exploration ideas and models that are relatively new. For example, geological descriptions and metallogenic models for the Fe deposits of the Labrador Trough (Stubbins *et al.*, 1961; Gross, 1968; Zajac, 1974), Cu deposits of the Seal Lake area (Evans, 1952; Brummer and Mann, 1961; Gandhi and Brown, 1975; Ryan, 1984; Wilton, 1989a), and U deposits of the Central Mineral Belt (Beavan, 1958; Bailey, 1979; Gandhi, 1976; Gower *et al.*, 1982; Ryan, 1984; White and Martin, 1980; Wilton and Wardle, 1987) have been extensively documented in the literature and are accordingly not treated further. Producing mines and major mineral deposits of Labrador are shown on Figure 6.

This paper is not intended to present a lengthy discussion of the geological data and genetic arguments for the exploration targets and models we propose. Rather, it is meant to provide an up-to-date review of the potential of Labrador as a focus for exploration. To do this, we take a three-pronged approach to: i) provide a perspective on new metallogenic ideas that have been generated during 15 years of geoscientific research in Labrador; ii) set forth some ideas for grassroots exploration that may warrant follow-up; and, iii) cite appropriate literature references by which the reader can start to acquire the additional information needed to transform an idea into an exploration target.

BASE AND PRECIOUS METALS IN ARCHEAN GREENSTONE BELTS

Introduction

The mineral potential of large parts of the Canadian shield west of Labrador, and indeed of Archean cratons worldwide, is closely tied to the occurrence of Archean greenstone belts, particularly because of their endowment of volcanogenic polymetallic and mesothermal precious-metal deposits. In Labrador, rocks of the Nain and Churchill provinces contain both low-grade greenstone belts, and their high-grade equivalents, which may be prospective for these and other deposit types (Figure 7). High-grade supracrustal sequences in the northern Nain and Churchill provinces may be remnants of greenstone belts, with the attendant possibility that sulphide orebodies may have been preserved, albeit at high metamorphic grade.

Nain Province

The two best known Archean 'greenstone' belts in Labrador are the Florence Lake and Hunt River belts in the Hopedale Block, southern Nain Province (Figure 8). The generally greenschist-facies Florence Lake belt is a true greenstone belt. The Hunt River belt is locally metamorphosed to upper-amphibolite grade but is geologically similar to the Florence Lake belt; it is herein treated, for convenience, as a greenstone belt as well. Both trend approximately northeast, extend for several tens of kilometres along strike, and are intruded by the Kanairiktok Intrusive Suite, a typical Archean tonalite–trondhjemite–granodiorite association.

The Florence Lake belt consists mainly of mafic flows and pillow lavas, mafic subvolcanic intrusive rocks, and minor felsic metavolcanic and metasedimentary rocks, generally at greenschist to amphibolite facies (Ermanovics and Korstgaard, 1981; Ermanovics *et al.*, 1982; Brace and Wilton, 1990; Brace, 1991). The Hunt River belt is not as well known, but appears to contain a higher proportion of mafic intrusive rocks and is preserved in the amphibolite facies (Jesseau, 1976; Collerson *et al.*, 1976). Concordant lenses of ultramafic rocks are widespread in both belts and are interpreted as early intrusions related to the greenstone belt magmatism. The Hopedale Block generally has only a thin cover of till and geochemical exploration methods using soil or till should be effective exploration techniques over both of these 'greenstone' belts.

There are a number of pyritic–pyrrhotitic Cu–Ni prospects in the Florence Lake and Hunt River belts (Figure 8). The best known of these is the Baikie Prospect in the Florence Lake belt, comprising locally massive pentlandite, pyrrhotite, pyrite, minor chalcopyrite and magnetite associated with meta-ultramafic and actinolite schist enclaves in the Kanairiktok Intrusive Suite. The sulphides are enriched in PGE and normalized PGE profiles are similar to those for Archean, komatiite-related mineralization (Brace and Wilton, 1990). Several other small prospects within both the Florence

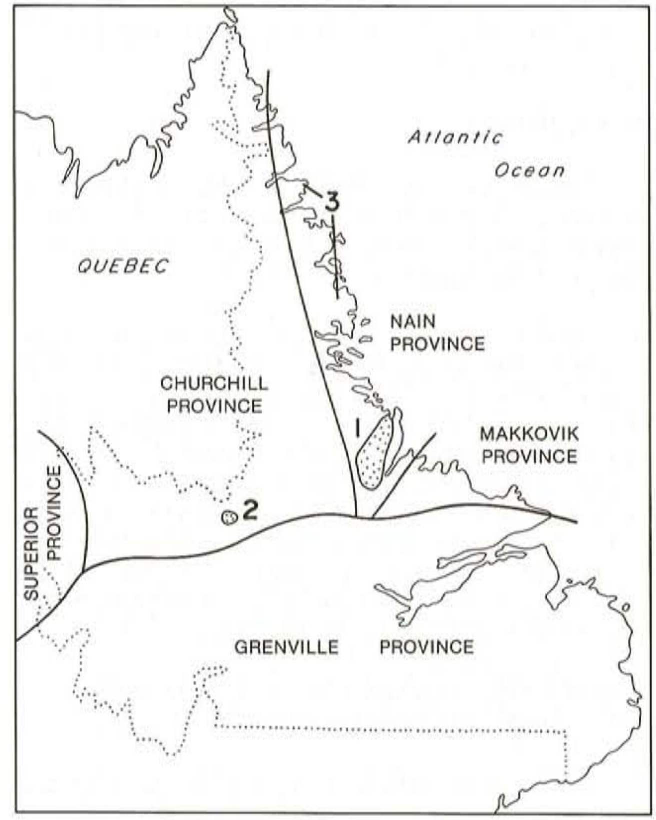


Figure 7. *Target areas for base and precious metals hosted by Archean supracrustal (greenstone) sequences. 1–Hopedale Block, southern Nain Province; 2–Petscapiskau Group, southern Churchill Province; 3–high-grade supracrustal rocks, Saglek Block, northern Nain Province.*

Lake and Hunt River belts contain Cu and Ni, while others are dominantly pyritic, and there is a regional Ni lake-sediment anomaly over the southern part of the Florence Lake Belt (Hornbrook and Friske, 1988a). Brace (1991) has suggested that taken as a whole, these prospects may suggest a potential for further komatiite-related Cu–Ni mineralization.

Although it seems likely that deposition models appropriate to the Baikie prospects can be widely applied within these belts, it is not clear whether all known sulphide occurrences are part of a Cu–Ni–ultramafic assemblage. Felsic volcanic rocks occur locally and, by analogy with classic greenstone belts, may indicate that environments favourable for volcanogenic massive sulphide (VMS) deposition are also present. Minor sulphide mineralization is known to be spatially associated with felsic volcanics in the Florence Lake belt (particularly in the Adlatok Bay–Ujoktok Bay area). In this context, Brace (1991) has described some small Cu–Zn sulphide occurrences associated with ankeritic sedimentary (exhalative) rocks.

Finally, deformation in these greenstone belts is locally accompanied by carbonitization and quartz veining, and environments favourable for mesothermal gold deposits might

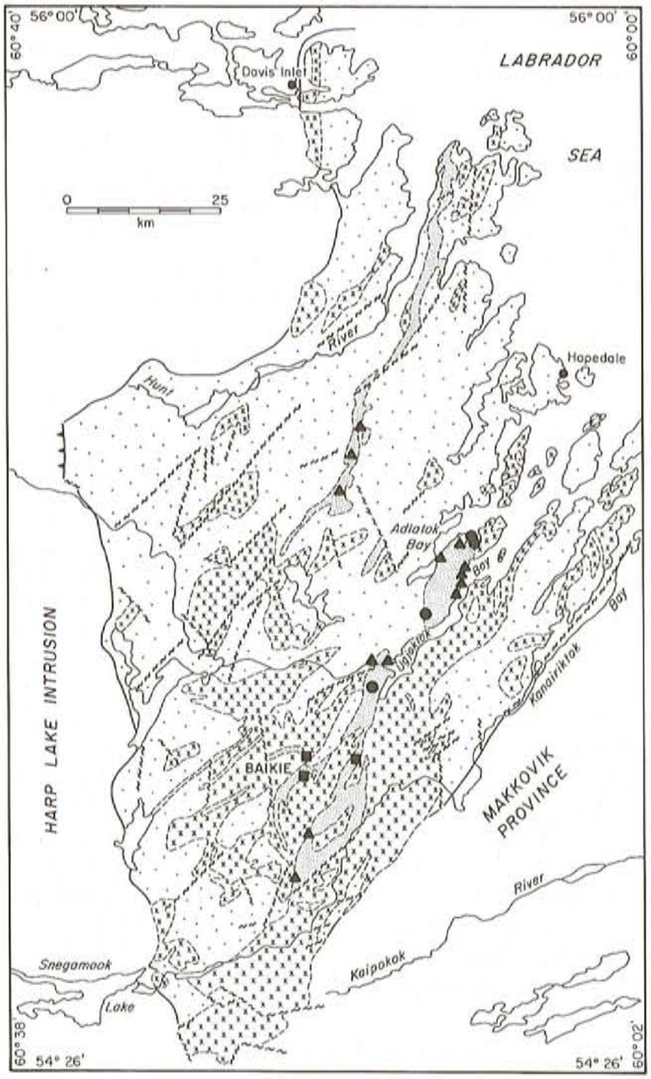


Figure 8. *General geology of the Hopedale Block. Light stipple–undifferentiated gneiss; heavy stipple–greenstone-belts, Hunt River belt in the north, Florence Lake belt in the south; x–intrusive rocks; symbols indicate known showings; squares–Cu-Ni; circles–Cu; triangles–Py.*

well exist. Regional lake-sediment surveys indicate locally elevated Au values over the Hunt River belt, Sb values over the Florence Lake belt, and As over both belts (Hornbrook and Friske, 1988a). However, investigations to date indicate that most deformation-related veins are relatively deficient in sulphides (Brace, 1991), and none has demonstrated precious-metal enrichments.

The Archean gneiss complex of northern Labrador includes numerous belts of amphibolite- to granulite-facies supracrustal rocks, among which are banded iron formation and banded metavolcanic rocks. Equivalent rocks in Greenland host widespread Cu and W showings, to the extent that the west coast of Greenland is cited as a tungsten province (Apell, 1988). The W was deposited in at least two mineralizing events, one of which is interpreted to be submarine exhalative in origin. In addition to anomalous Cu and W, some of the supracrustal rocks in Greenland are enriched in Sn and Zn. By analogy with northern Greenland, the northern part of the Nain Province might potentially contain similar mineralized environments. Lake sediments in this area contain generally high Ni and Cu and are locally high in Pb, As, Ag, Mo, U and Zn, especially over amphibolite-grade rocks south of Saglek Fiord (Hornbrook and Friske, 1988a).

Churchill Province

Recent U–Pb dating in western Labrador has suggested that volcanic and related rocks previously assigned to the Petscapiskau Group in the southern part of the Churchill Province (Emslie, 1970; Nunn and Noel, 1982; Figure 7) form part of an Archean greenstone belt (Nunn *et al.*, *in press*). The Archean rocks outcrop at the southeastern end of the Smallwood Reservoir and comprise a greenschist- to amphibolite-facies assemblage of dominantly mafic volcanic rocks, associated intrusive rocks and volcaniclastic sedimentary rocks. Rhyolite clasts in conglomerates indicate that there may have been coeval felsic volcanism. The area has received little exploration to date and there are no known showings. It may present a good grassroots target for volcanogenic massive sulphides and gold.

The northern part of the Churchill Province contains several belts of supracrustal gneisses. Rusty, sulphide-bearing zones are locally present, but none has been thoroughly examined, and the nature of the mineralization has not been documented. Reconnaissance sampling of several of these zones in 1987 did not produce any significant base- or precious-metal anomalies (A.B.R., unpublished data); however, more detailed work is warranted.

GOLD

Introduction

Although there are not many known gold occurrences in Labrador, there are several environments in which there appears to be a significant exploration potential (Figure 9). Minor gold occurrences are known from a variety of settings ranging from Archean high-grade terranes to Proterozoic supracrustals.

Eastern Superior High-Grade Terranes

The Ashuanipi Complex, western Labrador, comprises high-grade metamorphic rocks that constitute the eastern edge of the Superior Province. Interest in gold in this area was sparked by the report of a new gold discovery in adjacent Quebec (Lapointe, 1986) and by anomalous concentrations of gold pathfinder elements in regional lake-sediment data (Geological Survey of Canada, 1982a,b) in the mid-80's. During 1986, reconnaissance geological and regional geochemical studies carried out by the Newfoundland Department of Mines and Energy (Thomas and Butler, 1987;

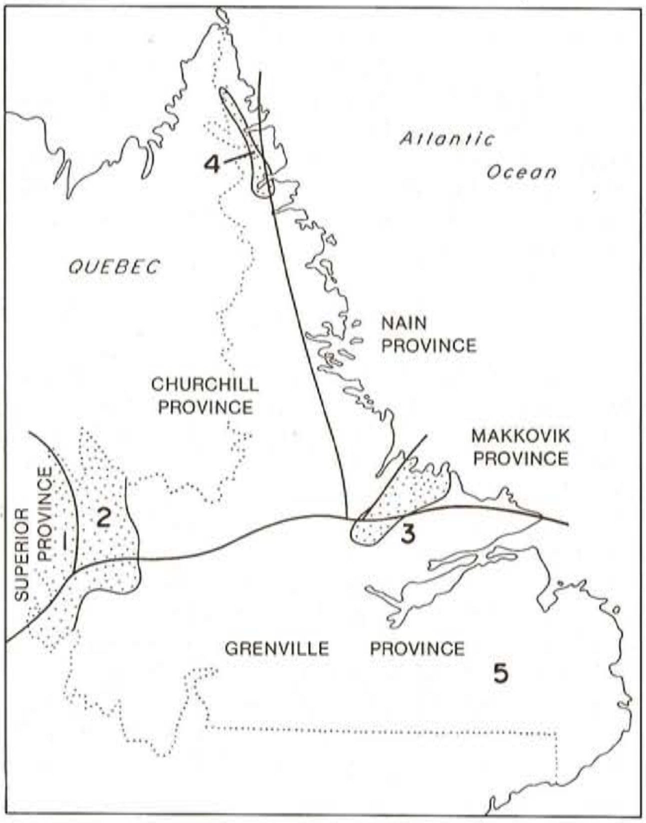


Figure 9. *Target areas for gold exploration. 1–High-grade terranes of the Ashuanipi Complex, eastern Superior Province; 2–Labrador Trough fault zones; 3–Central Mineral Belt (Moran unconformity, eastern Makkovik Province lodes, Bruce River Group); 4–north Labrador shear zones; 5–southern Grenville.*

Butler, 1987; McConnell and Newman, 1988) showed that anomalous concentrations of gold were also present in lake sediments and locally in bedrock, and this sparked considerable claim staking in the area.

More recently, the Geological Survey of Canada has re-analysed archived regional lake-sediment samples from the northern Ashuanipi Complex for gold and related elements (Hornbrook and Friske, 1989). These analyses have identified new areas of anomalous gold enrichment (Figure 10a) and indicate the coincidence of gold, arsenic, tungsten enrichments. Geochemical surveys using soil or till should provide an effective exploration approach in this area, because of the generally thin drift cover (McConnell and Newman, 1988).

Many of the gold deposits in Quebec, which have been drilled by Mazarin Inc., are spatially associated with magnetite iron formation in high-grade Archean supracrustal sequences. A possible deposit model might involve dilatancy in the iron formation during deformation resulting from competency contrast with the surrounding rocks, which would focus the metal-bearing fluids, with the iron acting as a chemical trap for gold. Gold showings in the equivalent rocks in Labrador are associated with pyritiferous zones and locally with mafic (amphibolitic) units. Whether these are sedimentary units or whether they contain iron formation has not been established.

Although Au mineralization is not widely known from high-grade terranes in Canada, significant deposits associated with meta-iron formations are currently being worked in similar Archean granulite-facies rocks in southern Zimbabwe (Böhmke and Varndell, 1986) and may provide an exploration model for gold in the Ashuanipi Complex.

Labrador Trough Thrust Faults

Recent results from the re-analysis of lake-sediment samples from western Labrador show elevated Au–As values over parts of the Labrador Trough (Hornbrook and Friske, 1989; Figure 10a); the highest concentrations are associated with the eastern margin of the Trough. Although the Au anomaly is too broad to allow definitive correlation with any single structure, the possible association with major thrust faults in this area is noteworthy. Mesothermal gold mineralization is commonly sited in second- and third-order structures related to major, trans-crustal faults (e.g., Eisenlohr *et al.*, 1989; Kerrich, 1989; Barley and Groves, 1990). An analogy for the Labrador Trough lake-sediment anomalies may be provided by east-central Newfoundland, where new gold discoveries are associated with Sb and As lake-sediment anomalies of regional extent. These anomalies apparently reflect large-scale movement of Au and related elements (Davenport and Nolan, 1989) and have locally resulted in ore-grade concentrations of Au and Sb (Tallman, 1990; Evans, *this volume*). Gold anomalies in the Labrador Trough may reveal a similar potential.

Kanairiktok Unconformity

Along the northern edge of the Central Mineral Belt, the basal Lower Proterozoic supracrustal rocks, clastic sedimentary and mafic volcanic rocks assigned to the Moran Lake Group, unconformably overlie foliated granite and tonalite assigned to the ca. 2.8 Ga Archean Kanairiktok Intrusive Suite. Carbonate–sericite alteration in the basement, immediately below the unconformity, is locally developed regionally along the strike extent of the Moran Lake Group (approximately 85 km), and is generally interpreted to reflect Lower Proterozoic weathering (Ryan, 1984).

There are a number of epigenetic galena and sphalerite bearing quartz–carbonate (± barite) veins both within the supracrustal shales and in the paleoweathered surface of the underlying basement, which appear to be spatially related to this unconformity (Figure 11). These include the Ellingwood, Green Pond and Kanairiktok #14 prospects (Ryan, 1984; Wilton *et al.*, 1987). At the Kanairiktok #14 prospect, the mineralization is in the basement, and is associated with quartz–sericite–pyrite wallrock alteration. Wilton *et al.* (1987) reported slightly elevated precious-metal values at several prospects along the unconformity.

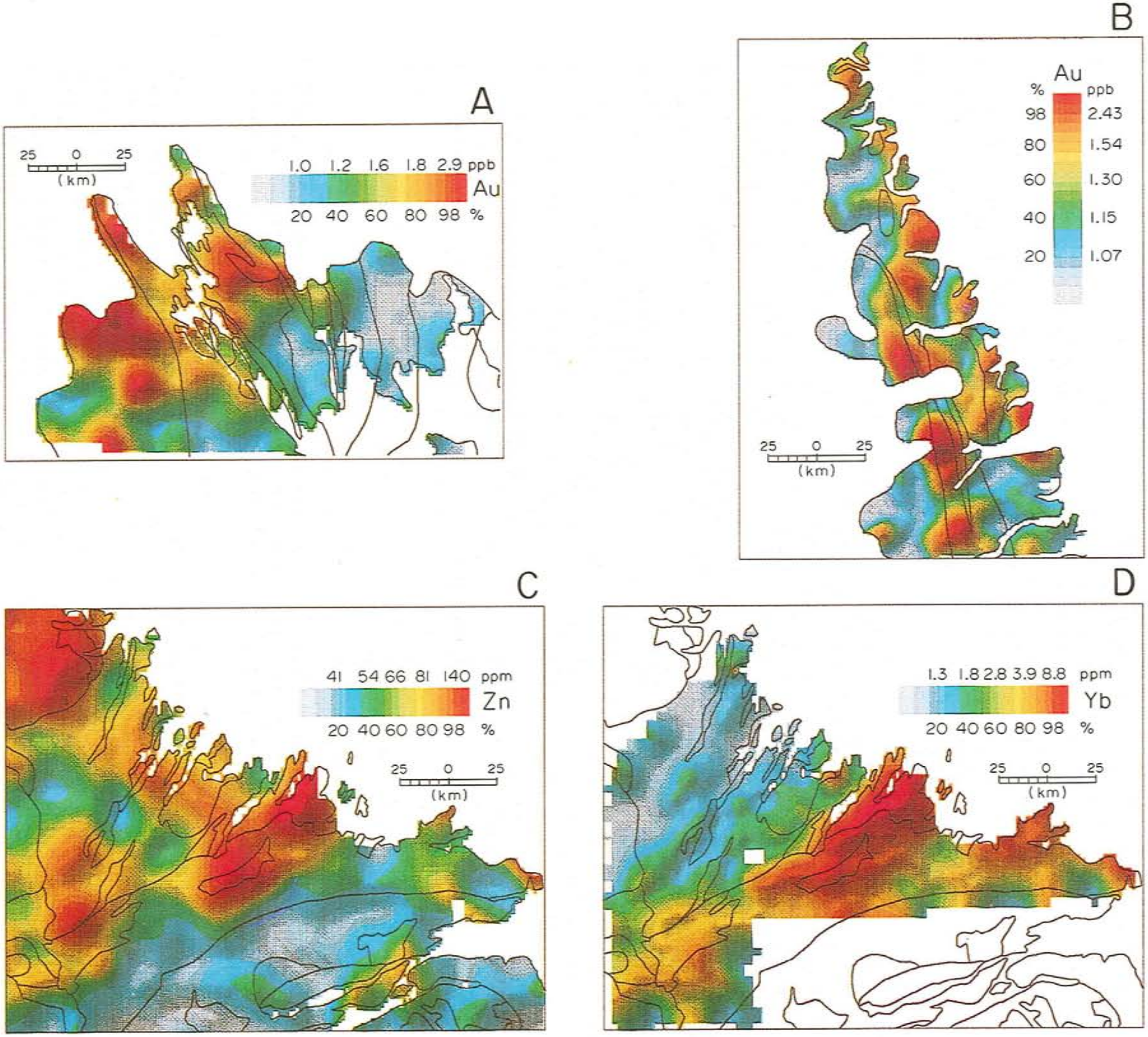


Figure 10. *Details of geochemical maps illustrating anomalies of economic interest. See text for discussion. 10a–Au in lake sediments, western Labrador; 10b–Au in stream sediments in northern Labrador; 10c–Zn in lake sediments in the Central Mineral Belt; 10d–Yb in lake sediments, eastern Central Mineral Belt.*

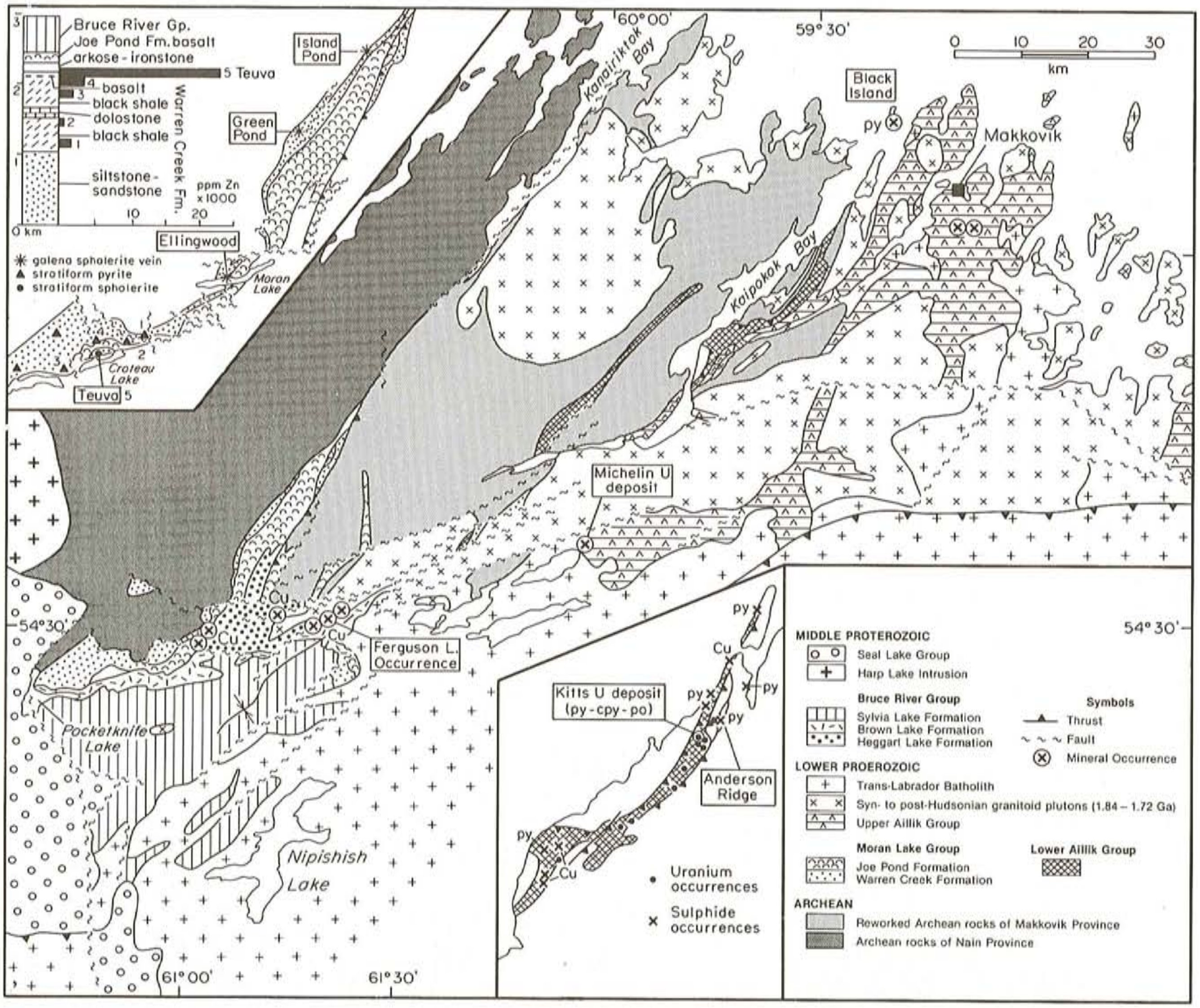


Figure 11. *Geology of the Makkovik Province (eastern Central Mineral Belt) showing the geological setting of the Moran Lake, Aillik and Bruce River groups. Inset at top left shows details of the Moran Lake Group and its mineral deposits (after Ryan, 1984; and North, 1988); inset at bottom illustrates the mineral occurrences of the Lower Aillik Group in the Kitts–Post Hill belt (after Gower* et al., *1982).*

The locally elevated gold values associated with the alteration and mineralization suggest that this environment has some potential for gold exploration. Detailed geochemical studies and prospecting might pinpoint targets where detailed exploration is warranted.

Eastern CMB Lode Veins

Gold values up to 8.8 ppm were reported from a quartz vein cutting the Upper Aillik Group near Pomiadluk Point by Wardle and Wilton (1985) (see Figure 21 for location). Anomalous gold values (1 to 2 ppm) were also found in nearby galena–sphalerite-bearing quartz–carbonate–fluorite veins at Big Bight and gabbro-hosted pyritiferous occurrences at Poodle Pond (Wardle and Wilton, 1985; Wilton *et al.*, 1987). The Big Bight occurrences are spatially and probably genetically associated with posttectonic granitoid stocks in the area. One of these, the Round Pond stock (ca. 1.65 Ga) has been studied in detail by MacDougall (1988) who described a porphyry-style mineralization around it. MacDougall and Wilton (1987b) reported the discovery of a 2.5-cm-wide carbonate vein system at Round Pond, which contained up to 7.4 percent Zn and minor Pb, Mo and Au (55 ppb). Adjacent altered country rocks host Au contents of up to 820 ppb and 3 ppm Ag.

Regional lake- and stream-sediment data (Hornbrook and Friske, 1988b) show generally anomalous As values in this area with local enrichments in Sb, Ag, Au, Cu and W.

Bruce River Group

The ca. 1.65 Ga Bruce River Group comprises a basal sequence of terrestrial conglomerates and arkoses (Heggart Lake Formation) that passes upward through sandstones (Brown Lake Formation) into a thick pile of felsic ash-flow tuffs and mafic volcanic flows (Sylvia Lake Formation) (Figure 11). The acid volcanic rocks have a predominantly rhyolite–dacite composition; the mafic rocks have shoshonitic affinities, and are likely to have formed in a mature continental arc environment. This group likely formed in a caldera setting (Ryan, 1984) and is interpreted, along with other 1.65 Ga volcanic groups along the northern side of the Trans-Labrador batholith (MacKenzie Lake group, Blueberry Lake group), to form the volcanic carapace to the batholith (Schärer *et al.*, 1988; Gower, 1990). The chemistry and caldera setting of these rocks are analogous to modern terrestrial volcanic arcs and suggests a similar potential for epithermal, vein-hosted precious-metal mineralization. Exploration to date has been directed at U- and Cu-bearing veins, mainly in the lower (clastic) part of the group with very little work directed toward precious-metal targets.

The only known syn-volcanic mineral occurrence in the Bruce River Group is the Ferguson Lake showing (Figure 11) (Wilton, 1988, *in press*), comprising sphalerite, galena, carbonate and fluorite in a pegmatitic(?) vein. Assay values (Wilton, *in press*) show anomalous concentrations of Au (up to 290 ppb), As (up to 400 ppm), and Sb (up to 340 ppm). The pegmatite may be a feeder to stratigraphically higher felsic volcanic rocks, suggesting a potential for Bonanza-type or epithermal types of precious-metal deposits.

Although the tectonic setting may not be strictly analogous, the style of volcanism is very similar to that of Nevada and New Mexico, where bimodal volcanic rocks similar to the Bruce River Group are host to epithermal gold and silver veins (Sillitoe, 1976; Elston *et al.*, 1976). In these areas, the most significant mineralization can be related to resurgent cauldrons. The gold and silver veins are spatially related to caldera structures, which acted as controls and traps for epithermal mineralization. Elsewhere in the southwestern United States, high-silica rhyolites host Mo, Sn, W and Be (Elston *et al.*, 1976). A reassessment of the Bruce River Group for such environments is in order.

North Labrador Shear Zones

Grassroots gold-exploration targets in northern Labrador are suggested by image analysis of Au and related elements in lake sediments from this area. In particular, there are a number of interesting Au anomalies along the Abloviak shear zone, a major sinistral shear that separates the Nain and Churchill provinces (Figures 6 and 10b). At present, there is no known source for these anomalies. It seems unlikely that they reflect individual gold deposits, as the sample spacing is too wide. However, considering the well-documented relationship between mesothermal gold deposits and major trans-crustal shear zones elsewhere in the Canadian shield and the world, it may be that they reflect hydrothermal systems (or parts of hydrothermal systems), which caused a regional gold enrichment in these areas. Detailed prospecting and geochemical work is needed to fully evaluate these targets.

Grenville

Although there are no known precious-metal occurrences in the Labrador Grenville, discoveries in probably correlative rocks in Scandinavia suggest that such deposits might be present. In the Sveconorwegian Province of Sweden, Au mineralization has been reported from quartz veins. In one example, in the Nyaster area north of Åmal, up to 7 ppm gold has been reported from a 0.5-m-wide quartz vein that intrudes mylonitized rocks probably derived from an orthogneiss protolith. The age of the mineralization is not known but is inferred to be Sveconorwegian, perhaps being genetically related to the Bohus granite nearby to the west.

Recent dating of granitoid plutons of Grenvillian age coupled with regional geological and geophysical interpretation (Gower *et al., in press*,b) suggests that plutonism of this age could be widespread in southern Labrador and adjacent Quebec. If there is a genetic link with such plutonism, there is ample scope for comparable mineralization.

SEDIMENTARY EXHALATIVE BASE METALS

Introduction

Labrador contains a number of Lower Proterozoic shale–sandstone basins preserved within the Churchill, Makkovik, Nain and Grenville provinces (Figure 12). The sedimentary sequences in these basins are generally interpreted to be basin infilling related to extensional tectonics and are locally accompanied by mafic magmatism. Although there are no documented stratiform mineral occurrences in the Labrador Lower Proterozoic clastic basins, analogy with other areas of the world (e.g., Aldridge Formation, B.C., MacArthur Group, N.T., Australia) suggests that several of them apparently contain the essential elements of sedimentary-exhalative (SEDEX) and Besshi-type deposit models.

Basal Clastic Sequences, Central Mineral Belt

The oldest supracrustal rocks in the Central Mineral Belt are Lower Proterozoic clastic sediments and associated mafic volcanic rocks assigned to the Moran Lake and Lower Aillik groups. Both contain stratiform pyritic showings hosted by graphitic argillites (Figure 11). In the Moran Lake Group, base metals are locally associated with these showings (inset, Figure 11). The presence of these showings, and comparison with similar geology in Scandinavia, suggest a potential for exhalative, shale-hosted base-metal sulphides.

The Moran Lake Group is divided into a lower Warren Creek Formation, comprising clastic sedimentary rocks, and an upper Joe Pond Formation comprising mafic volcanic rocks (Ryan, 1984). The Warren Creek Formation is divided

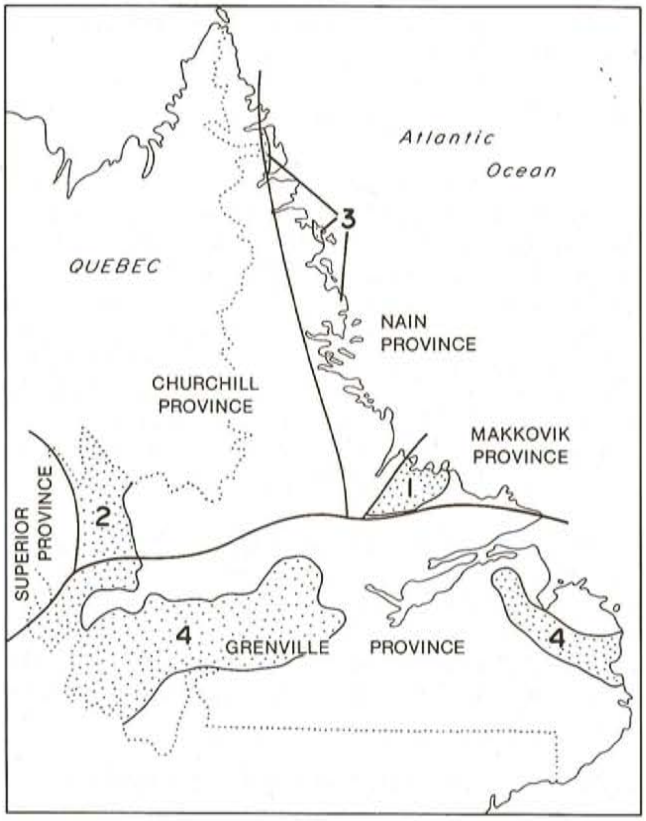


Figure 12. *Target areas for sediment-hosted massive sulphides. 1–basal clastic sequences of the Central Mineral Belt; 2–Labrador Trough; 3–Ramah–Mugford–Snyder groups, northern Labrador; 4–Grenville Province metasedimentary gneisses.*

into a lower member, comprising 180 to 1300 m of dominantly fine-grained feldspathic sandstone and siltstone and a conformable upper member of 550 to 3350 m of dominantly graphitic black shale along with lesser sandstone and siltstone. It is the upper member that hosts the stratiform sulphides (North, 1988; North and Wilton, 1988).

There are more than 16 occurrences of sulphide gossans containing stratiform disseminated to massive pyrite in the Warren Creek Formation shales. Stratiform mineralization in the Warren Creek Formation shales was first reported by Brinex geologists in the 1950's, who discovered and drilled a number of generally base-metal-poor showings. Ryan (1984) interpreted these showings to be distal accumulations related to exhalative processes. New sulphide occurrences were reported by North and Wilton, (1988) and North (1988) following regional metallogenic studies in the area. Perhaps more significantly, these authors reported anomalous base metals from some of these showings, including one zone (the Teuva or Heart Pond showing) that yielded grab samples up to 2.69 percent Zn (inset, Figure 11). North (1988) interpreted these deposits as sedimentary exhalative and presented a model for this mineralization that involved hydrothermal circulation driven by mafic magmas that later erupted to form the Joe Creek Formation basalts.

Although stratiform mineralization is not as widely documented in the Lower Aillik Group, there are a number of pyritic occurrences. The best known are the Anderson Ridge prospect in the Kitts–Post Hill belt and the Black Island occurrence in Kaipokok Bay, both comprising apparently bedded pyritic and pyrrhotitic sulphides hosted by graphitic argillite (inset, Figure 11). The presence of these and other small showings in the area indicates that mineralization processes similar to those in the Moran Lake Group may have been operating here, and suggests an exploration potential for deposits that might contain significant base-metal contents.

Regional lake-sediment geochemical data also indicate anomalous base metals associated with these sequences (Figure 10c). Strong anomalies in Zn, Ag, Ni, Hg, Cu, Sb, Cd and locally As are found over the southwestern part of the Moran Lake Group. Lake sediments over the Lower Aillik Group are strongly anomalous in Zn and enriched in Cu, Pb, Sb, Au, Cr and Ni.

Comparison with equivalent geological units in Scandinavia further emphasize the sulphide potential of the Makkovik Province. Although the Makkovik–Ketilidian Orogen forms a comparatively small part of Laurentia, broadly coeval rocks of the Svecofennian Orogen cover vast tracts of Baltica and include the well-known Skellefte and Bergslagen sulphide districts in Sweden. Massive stratabound polymetallic deposits in the Skellefte district are commonly localized in the contact zone between submarine felsic volcanic rocks and the overlying phyllites or metagreywackes (Pharaoh and Pearce, 1984) and have been interpreted as the product of magmatic processes in a volcanic arc. The Bergslagen district is characterized by Fe–Mn oxide and polymetallic sulphide mineralization. Current models envisage a continental rifting environment in which sedimentary exhalative deposits were associated with early felsic volcanism; as the rift grabens developed and volcanism became less explosive, epigenetic stratiform and massive sulphide mineral deposits were formed in the accumulating overlying sediments (e.g., Parr and Rickard, 1987; Vivallo and Rickard, 1990).

Labrador Trough

The largest lower Proterozoic sedimentary basin in the eastern Canadian Shield is represented by the Labrador Trough. In Labrador, this basin consists of a western component (Schefferville Zone) of predominantly shallow-water sedimentary rocks, and an eastern component (Howse Zone) dominated by deep-water turbidites, shales, basalt flows and massive volumes of gabbroic sills. The two zones are separated by the major Ferrum River thrust fault (Figure 13).

Stratigraphy in the Schefferville Zone consists of basal (rift-related) arkoses (Seward Subgroup) overlain by a shallowing-upward sequence of shale, dolomite and chert breccia of the Attikamagen Subgroup. This is disconformably overlain by the deepening-upward succession of quartzite, ironstone, shale, turbidite and arkose of the Ferriman

Subgroup. The turbidites–volcanic–sill association of the Howse Zone is probably correlative with the Attikamagen Subgroup, although this is by no means certain (Figure 14).

The rocks of the Attikamagen Subgroup (and their Howse Zone equivalents) are believed to have formed during the rift–drift breakup of the Superior craton and represent a well-preserved continental margin sequence (cf. Wardle and Bailey, 1981). The gabbro sill swarm of the Howse Zone is believed to be part of the continent–ocean transition and to represent attempted ocean crust formation in a sediment-dominated environment. Close analogies can be drawn with the Gulf of California (Einsele, 1986). The Howse Zone also contains numerous massive pyrite–pyrrhotite deposits located within graphitic black shale units sandwiched between gabbro sills. These are apparently of a syngenetic nature and contain minor amounts of copper and zinc mineralization (Baragar, 1967; Wardle, 1979a).

The shale formations of the Attikamagen Subgroup, notably the Le Fer and Dolly formations, in the Schefferville Zone are interpreted to have formed on extended continental crust and should have good potential for SEDEX mineralization, although little exploration activity has been targeted at these rocks.

The upper part of the Schefferville Zone, represented by the Ferriman Subgroup, is interpreted as a westward-prograding foredeep (Hoffman, 1987) developed in advance of a thrust stack encroaching from the east. The Menihek Formation shales and turbidites, which form the basinal part of the foredeep, are associated with lake-sediment zinc anomalies that have received extensive industry attention.

Ramah–Mugford–Snyder Groups

These groups occur as remnants of a lower Proterozoic cover sequence on the Nain Craton (Figure 15). Their development was likely broadly coeval with that of the Moran and Lower Aillik groups and possibly the Labrador Trough on the opposite side of the proto-Churchill Province. The basal clastic rocks of the Ramah–Mugford–Snyder sequences show an overall stratigraphic similarity and have been correlated by Smyth and Knight (1978).

The Ramah Group (Knight and Morgan, 1981; Morgan, 1975) is the most extensive unit. At its base it consists of a basal series of dolomitic sandstone, quartzite and dolomite (Rowsell Harbour and Reddick Bight formations) overlain by a series of shallow- to deep-water shales (Nullataktok Formation) including a widespread massive bedded pyrite–chert formation (Figure 16). The pyrite–chert association appears to have formed in a starved, euxinic basin and marks the end of shelf-type shallow-water sedimentation. The Nullataktok Formation is overlain by dolomite debris-flow breccias of the Warspite Formation, which passes up into voluminous turbidites of the Cameron Brook and Typhoon Peak formations. The Nullataktok–Typhoon Peak sequence has been interpreted by Hoffman (1987) as an eastward-prograding foredeep. The Ramah Group has been intruded

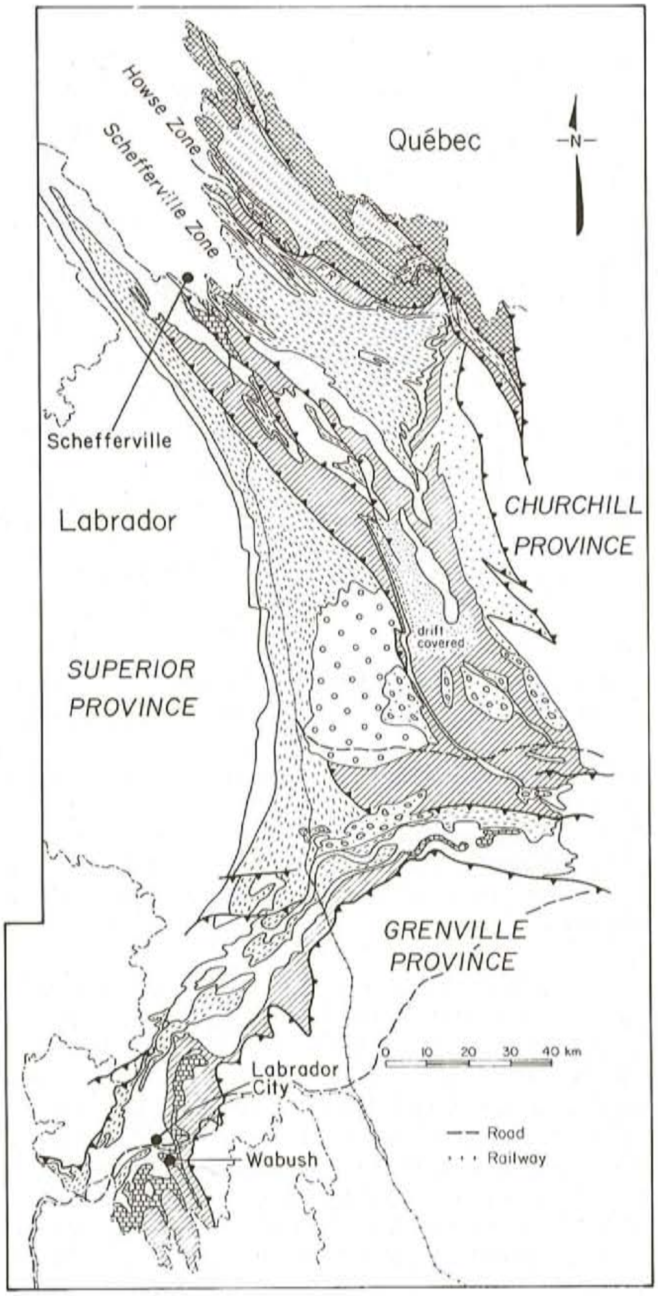


Figure 13. *Geological map of the Labrador Trough showing the shale–sandstone units thought to have potential for sediment-hosted massive sulphide deposits (See Figure 14 for legend.). Note that the Le Fer and Dolly formations of the Attikamagen Subgroup (see Figure 14) are combined on this map. They are generally separated by the Denault Formation dolomite, which in many areas is too thin to be shown at this scale. FRT = Ferrum River thrust.*

by gabbro sills, deformed, variably metamorphosed up to amphibolite facies and forms part of an east-verging fold-and-thrust belt developed along the eastern margin of the Churchill Province (the Torngat Orogen).

The basal Mugford Group consists of terrigenous clastics and shales containing dolomitic and pyritic beds correlated

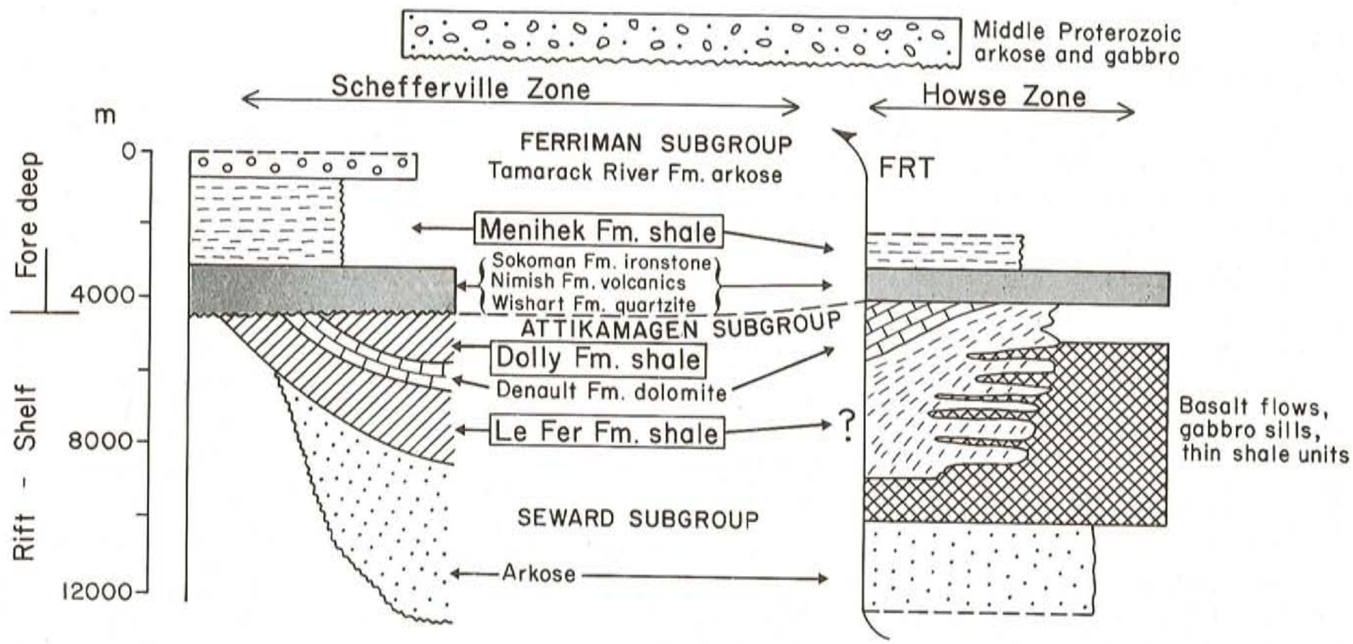


Figure 14. *Schematic stratigraphic sections of the Labrador Trough after Wardle* et al., in press,*b). Shale-dominated units considered to have SEDEX potential are shown boxed in bold type. Vertical scale is approximate. FRT = Ferrum River thrust.*

with those in the Reddick Bight and Nullataktok formations of the Ramah Group (Smyth and Knight, 1978; Figure 17). These are overlain by a thick pile of submarine, followed by subaerial, mafic volcanic flows, breccias and sills. The sequence is metamorphosed to greenschist facies and has been affected by open upright folds and normal faulting.

The Snyder and the overlying Falls Brook groups form an aerially restricted, wedge-shaped sequence underlying the northern edge of the Middle Proterozoic Kiglapait Intrusion. They have been contact metamorphosed at pyroxene–hornfels facies by the intrusion. Primary depositional features are well preserved in both Snyder and Falls Brook groups. A correlation with the basal Ramah and Mugford groups has been suggested by Smyth and Knight (1978) (Figure 17), although this correlation was later questioned by Berg (1983). Speer (1978) described a graphite–sulphide-bearing siltstone within the Snyder Group that contains abundant pyrrhotite, pyrite and sphalerite with chalcopyrite.

The pyrite bed of the Ramah Group is the most obvious target for sediment-hosted exhalative sulphides and is associated with several Pb–Zn stream-sediment anomalies (MacLeod, 1984, 1985). Early investigations of this unit did not return significant base- or precious-metal values although traces of chalcopyrite were noted locally (Douglas, 1953; Morgan, 1975) and several grassroots exploration programs have been directed at the pyrite bed without discovering significant base-metal mineralization. However, much of the Ramah Group remains to be explored. The similarity of the basal Mugford Group to the basal Ramah Group sequence suggests a similar potential. The presence of a thick volcanic pile in the Mugford Group may indicate higher heat-flow conditions and possibly enhanced hydrothermal activity. There are widespread polymetallic lake-sediment anomalies in Cu, Pb, Ni, Co, Mo, U, Zn, As, and Ag over the Mugford Group. Pb and As are locally enriched in lake sediments over the Ramah Group.

Grenville Metasedimentary Gneiss Terranes

Although there are no base-metal occurrences of documented sedimentary exhalative origin in the Grenville Province in Labrador, there are a number of sulphide-bearing mineral occurrences (cf. Gower and Erdmer, 1984). Geological and geochemical observations suggest an exploration potential for this deposit type.

A good example is provided by the Paradise metasedimentary gneiss belt in southeastern Labrador (Figures 6 and 12). Gower *et al.* (1987) described this belt as including gneisses of supracrustal origin dominated by pelitic and semipelitic rock types and with lesser associated amphibolite, calc-silicate rock and chert. Rocks have been metamorphosed in the amphibolite facies and are characteristically cordierite-bearing (Gower *et al.*, 1987). The amphibolites are dominantly banded, fine- to medium-grained rocks comprising mainly plagioclase and hornblende. Pillows are locally preserved, and elsewhere mafic dykes seem to be spatially associated with banded amphibolite. Recent geochemical analyses of unequivocal pillows from the Dead Islands suggest that they are mildly alkalic basalts (Gower and Swinden, *this volume*). Possible tectonic models include an oceanic island environment, an intra-oceanic rift (e.g., enriched major ocean or back-arc spreading centre) or rifting of a passive continental margin.

The overall depositional environment of the Paradise metasedimentary gneiss belt, therefore, appears to be

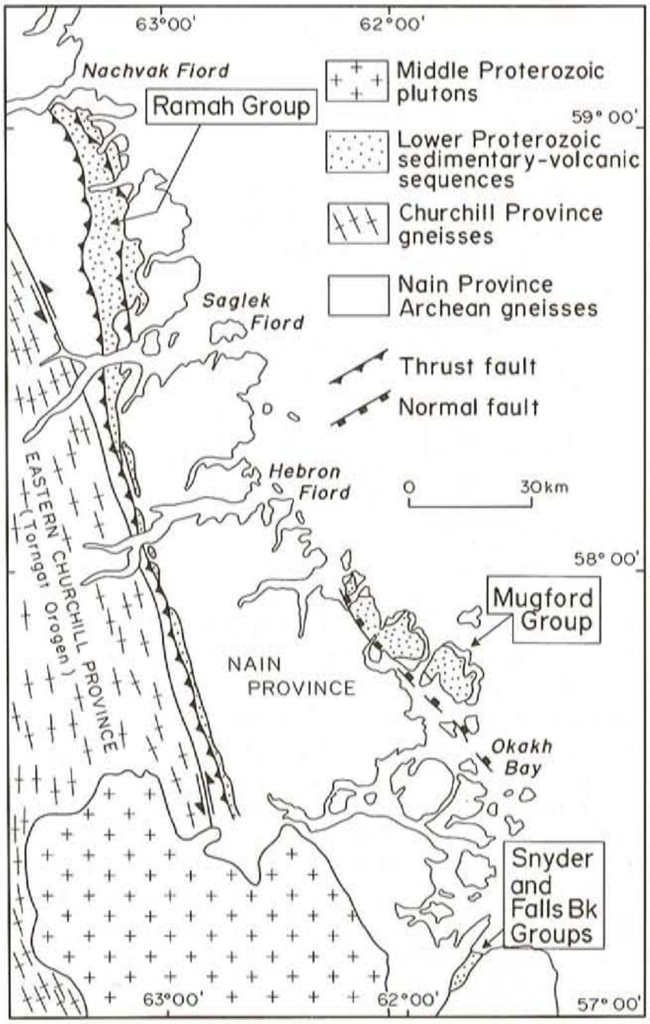


Figure 15. *Geological setting of the Ramah, Mugford and Snyder groups in northern Labrador. See Figure 4 for locations.*

extensive sedimentation accompanied by mafic volcanism in an oceanic rifting environment (Gower and Swinden, *this volume*). Such environments are known elsewhere to host both sedimentary exhalative and Besshi-type massive sulphide deposits (Mitchell and Bell, 1973; Slack and Shanks, 1989). Large massive sulphide deposits can typically survive very intense metamorphism and deformation intact (e.g., Broken Hill), and if such deposits were generated in the Grenville Province, there seems little reason to believe that they would not still be present. Regional lake-sediment data suggest the southeastern part of this belt as a primary target, having strongly anomalous Cu, Ni, Co and Hg with locally anomalous Pb and Mo.

Although the Paradise metasedimentary gneiss belt is the best-documented example, it should be noted that similar, less-studied rocks outcrop over vast areas of the northern Grenville Province in central and western Labrador (Figures 5 and 12). Consideration of regional lake-sediment data might provide rationale for focusing exploration in these regions in a grassroots exploration effort.

PROTEROZOIC VOLCANOGENIC MASSIVE SULPHIDES

Introduction

Proterozoic rocks in Labrador do not contain many well-documented mineral occurrences that are demonstrably of volcanogenic massive sulphide type. Although correlations with other areas suggest that an exploration potential might exist (e.g., the previously mentioned correlation between the Skellefte District, Sweden and the Makkovik Province), specific environments with exploration potential are not well documented. Present data suggest two environments that might bear exploration for this deposit type; the Letitia Lake Group in the Central Mineral Belt and the Blueberry Lake group in western Labrador (Figures 6 and 18).

Letitia Lake Group

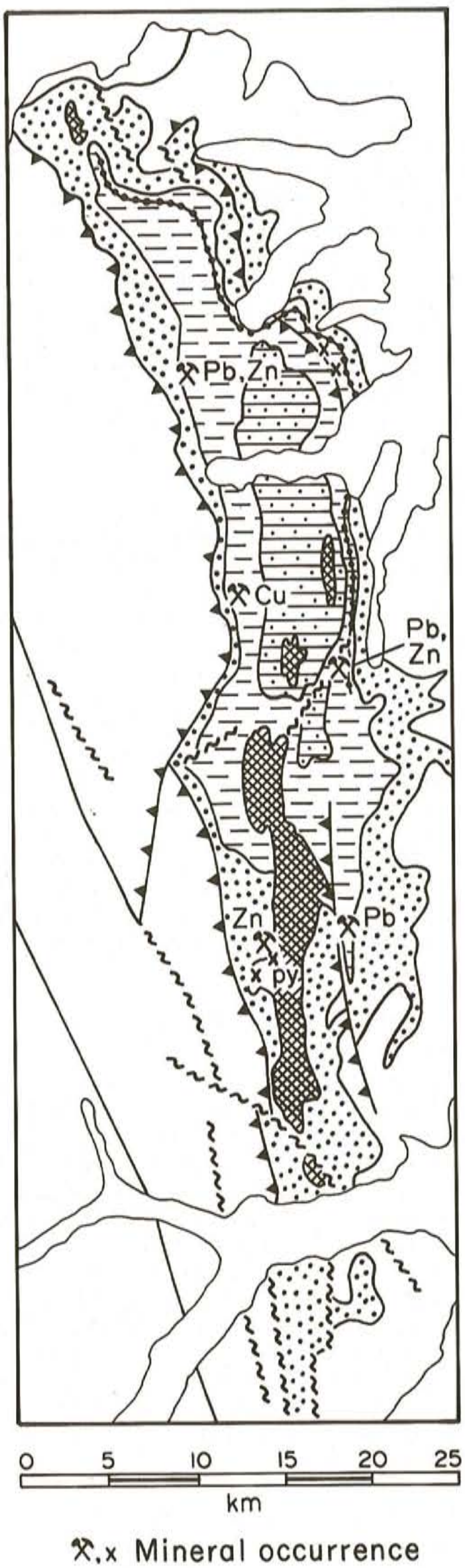
The Letitia Lake Group of central Labrador consists of ca. 1.32 Ga peralkaline volcanic rocks intruded by cogenetic peralkaline syenites and alkaline plutonic rocks (see Figures 6 and 22 for locations). The volcanic rocks are typically quartz–feldspar porphyritic ash-flow tuffs and associated rocks, and contain some pyritiferous zones that appear to represent syngenetic mineralization of VMS type (Wardle and Wilton, 1988). The group is also cut by quartz vein systems, associated with pyrite alteration and minor galena mineralization, which are probably of Grenvillian age. Reconnaissance sampling of both massive sulphides and vein systems has not revealed any significant precious- or base-metal values, although Wilton (*in press*) reported 11.5 ppm Ag in a grab sample from a sulphide-bearing vein. However, regional lake-sediment data reveal local anomalies in Zn, Pb, Cd, Ag $\pm$ As and there would appear to be potential for further exploration.

Blueberry Lake Group

The Blueberry Lake group of western Labrador (Figure 6) is believed to be correlative with the ca. 1.65 Ga Bruce River Group and to be similarly related to the Trans-Labrador batholith. The northern part of the Blueberry Lake group consists of felsic volcanic rocks, predominantly tuffs of latite–rhyolite composition, intercalated with various breccias, sedimentary and intrusive units. These pass westward into a dominantly sedimentary succession of greywacke, slate and conglomerate (Wardle, 1979b). The predominantly subaqueous character of the Blueberry Lake group distinguishes it from the Bruce River Group and suggests that it may have greater potential for volcanic- or sediment-hosted massive sulphide mineralization. Moderate lake-sediment geochemical anomalies in As, Zn, Ni and Pb are present over the group.

PLATINUM GROUP ELEMENTS (PGE)

With the exception of the PGE-enriched Cu–Ni sulphide deposits in the Florence Lake greenstone belt (previously



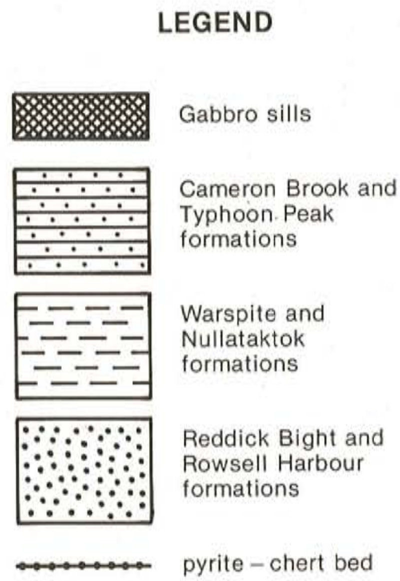


Figure 16. *Geology of the Ramah Group (after Morgan, 1975). Mineral occurrences after MacLeod (1984, 1985).*

mentioned) and some mildly PGE-enriched sulphide showings in the Harp Lake anorthosite intrusion, there are no known PGE occurrences in Labrador. However, comparison of Labrador geology with environments known to be productive elsewhere in the world suggests that there is a significant grassroots potential for PGE exploration. The growing strategic importance of this group of elements coupled with the discovery of a significant new PGE occurrence in the Labrador Trough in adjacent Quebec prompted Wardle (1987) to review possible PGE exploration targets in Labrador. This comprehensive review remains the definitive document on PGE potential in Labrador and the reader is referred to it for further information and references.

Wardle (1987) recognized six bedrock geological environments in Labrador that might host PGE concentrations (Figure 19):

1) Massif-type anorthosite plutons: Large anorthosite plutons of this type are widespread in the Nain, Churchill and Grenville provinces. Small Cu–Ni showings (stratiform zones of disseminated chalcopyrite, pyrrhotite and minor pentlandite) are known in the Harp Lake intrusion, which locally have elevated PGE values. Other massif-type anorthosite plutons have received little attention and their potential is not known.

2) Layered gabbroic plutons: The largest layered intrusion in Labrador is the Middle Proterozoic Kiglapait Intrusion (Morse, 1969) near Nain. Significant analogies can be drawn between the preserved parts of this intrusion and the productive horizons in the Bushveld and Stillwater intrusions (Wardle, 1987) and minor showings of pyrite, pyrrhotite, chalcopyrite are known. No PGE enrichments have been reported. The discovery of stratiform gold and PGE group enrichments associated with sulphides in the Tertiary

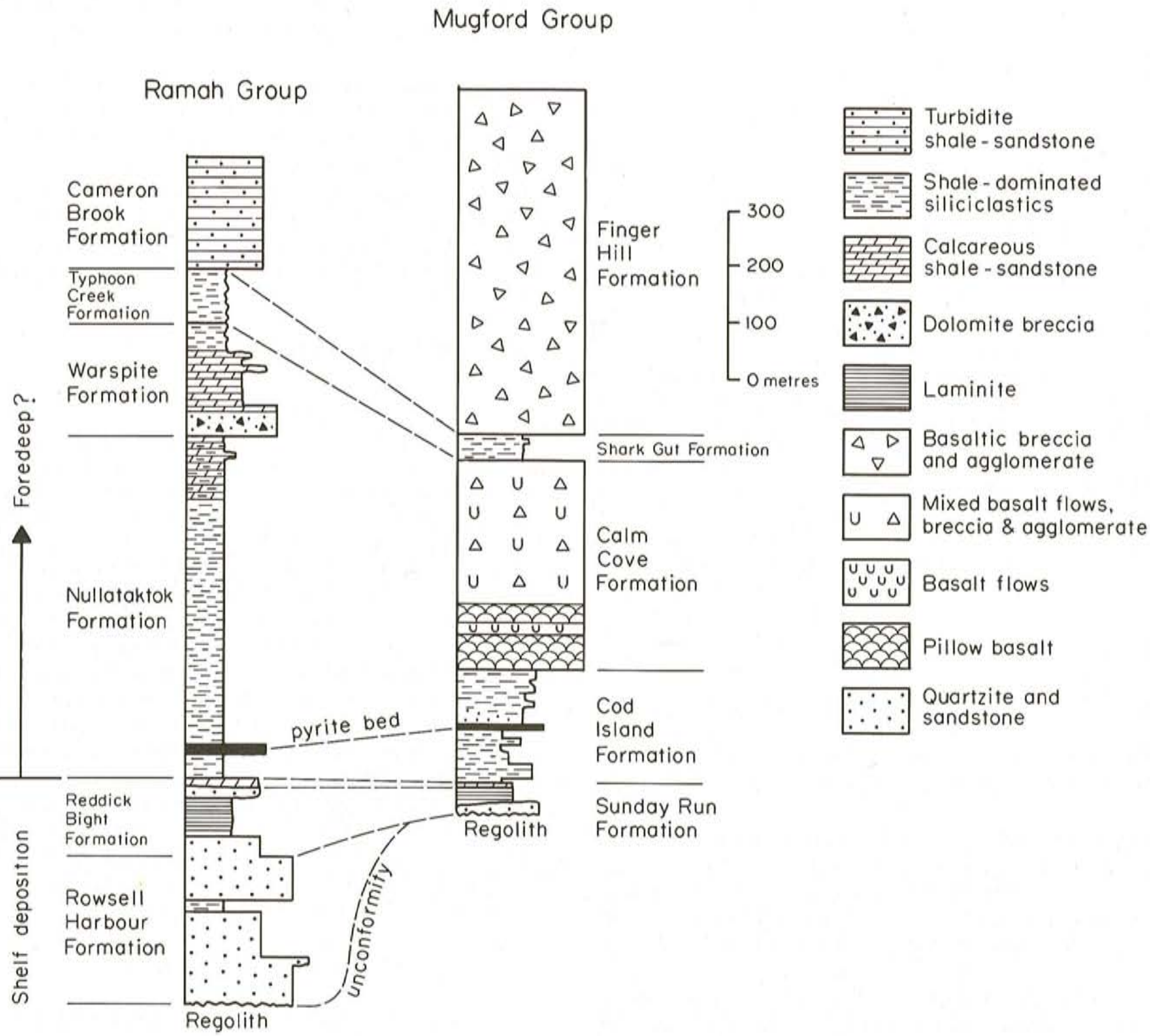


Figure 17. *Simplified stratigraphic sections of the Ramah and Mugford groups (after Smyth and Knight, 1978). Interpretation of rift versus foredeep setting is taken from Hoffman (1987). Gabbro sills, which are abundant in both groups, are not shown.*

Skaergaard intrusion of East Greenland (Neilsen and Schφnwandt, 1990) suggests the possibility that the Kiglapait Intrusion may host similar mineralization. Both the Kiglapait and Skaergaard are classic examples of tholeiitic magma fractionation within a well-defined magma chamber. However, the Skaergaard parent magmas appear to have been more silica-saturated and more oxidized that the Kiglapait magmas (cf. Morse, 1980).

Other minor gabbroic intrusions associated with anorthosite suites occur in the Nain Plutonic Suite, the Harp Lake intrusion and the Atikonak River massif.

3) Massive to weakly layered plutons: This includes widespread intrusions of gabbro and norite within the Grenville Orogen, including the Shabogamo Intrusive Suite, the Michael Gabbro, gabbro-norites of the Red Wine Mountains, and the White Bear Arm gabbro. Minor Cu and Ni mineralization is present locally but no PGE enrichments have been documented.

4) Gabbro-ultramafic sheets and sills: This class comprises high-level intrusions located within or adjacent to supracrustal sequences containing comagmatic volcanic rocks. They include suites ranging from Archean to Middle Proterozoic age in three widely separated areas:

i) Gabbroic and ultramafic sills are widespread in the Quebec portion of the Labrador Trough where a number of significant PGE occurrences, including the Retty Lake deposit

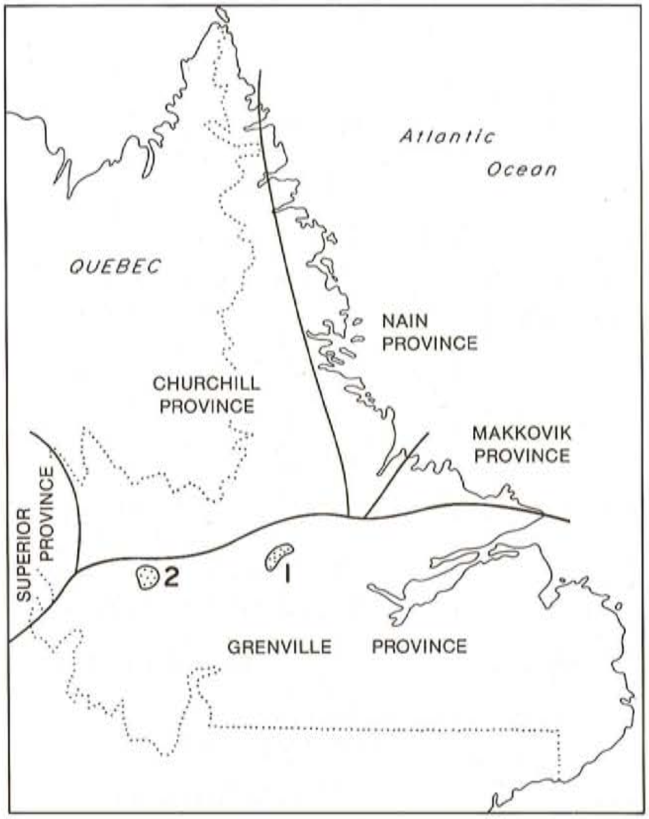


Figure 18. *Target areas for Proterozoic VMS deposits. 1–Letitia Lake Group; 2–Blueberry Lake group.*

near Schefferville, are associated with ultramafic sills. The southern extensions of these sills into Labrador are dominantly gabbroic in composition and host minor magmatic sulphide occurrences. Geochemical investigations (Findlay *et al.*, 1988) have not yielded evidence of PGE enrichment.

ii) Basaltic rocks of the Seal Lake Group were erupted into a transitional shallow-marine to terrestrial environment during a period of anorogenic crustal rifting. Wardle (1987) noted that, in this sense, they are similar to basaltic sequences that host the giant Noril'sk deposits in western Siberia. However, recent geochemical studies of the Seal lake basalts and associated diabase (Wilton, 1989b) have not returned evidence of anomalous Ni sulphide, chromite or PGE concentrations.

iii) Cu–Ni mineralization is known to be associated with ultramafic sills in the Archean greenstone belts of the southern Nain Province (see above) and is locally enriched in PGE.

5) Archean layered anorthosite–gabbro–ultramafic intrusions: These intrusions occur as sheet-like bodies in reworked Archean rocks of the northeastern Churchill Province, and as podiform bodies in the Nain Province. Their presence is reflected in high Ni and Co concentrations in lake sediments and they are geologically akin to the Fiskanaesset Complex in adjacent Greenland, which hosts chromite and associated low-grade PGE mineralization. Wilton and Wardle (1990) have described pyrrhotite and chalcopyrite in sulphide-rich horizons in layered anorthosite at Eclipse Harbour.

6) Hornblende gabbro–diorite–monzonite intrusions: The ca. 1.65 Ga Adlavik Intrusive Suite of eastern Labrador is characterized by late hydrous phases, which locally contain pyrite and chalcopyrite. The fluid-rich nature of these late phases may indicate a potential for deuteric or hydrothermal concentration of PGE, although unpublished data from sulphide-bearing pegmatitic concentrations collected by one of us (A.K.), in 1987, yielded no anomalous concentrations of the PGE.

GRANOPHILE ELEMENTS

Introduction

Granitoid rocks of various ages and petrogenetic affiliations are widespread in all of the orogens of Labrador (Figures 5 and 6). Areas of potential granophile mineralization are shown in Figure 20. A defined potential is indicated in the eastern part of the Trans-Labrador batholith by showings of Mo, U and other granophile elements and in the Strange Lake and Letitia Lake areas by rare-metal deposits in peralkaline rocks and further potential in unexplored areas is indicated by lake-sediment geochemical data (McConnell and Batterson, 1987; McConnell, 1988, 1989; see Figure 4a). The efficacy of geochemistry in granophile-element exploration in Labrador is indicated by the fact that both Letitia Lake and Strange Lake area rare-metal deposits were discovered through drainage geochemical surveys (Brummer, 1960; Zajac *et al.*, 1984, respectively). Potential, in as yet underexplored areas of the Churchill and Grenville orogens, is further suggested by comparison with correlative areas in Scandinavia.

Eastern Makkovik Province

There are numerous showings and deposits of uranium, fluorite, molybdenite and base metals in the eastern part of the Makkovik Province, dominantly within supracrustal rocks of the Upper Aillik Group (Figure 21). Previous models for mineralization in this area (e.g., Gandhi, 1978; Gower *et al.*, 1982) attributed metallogenesis to syn-volcanic processes during formation of the Upper Aillik Group. As a result, granitoid rocks and their surroundings have received very little attention, particularly in the eastern zone of the Makkovik Province. However, recent detailed studies (Wilton, *in press;* MacDougall and Wilton, 1987a; MacKenzie and Wilton, 1987; Wilton and Wardle, 1987) have shown, that many showings are spatially and probably genetically related to late-evolved granitoids in the area (cf. Ryan, 1977). Mineralization includes endocontact mineralization within the granitoid bodies and exocontact mineralization in the country rocks, locally associated with pegmatite and aplite bodies.

Kerr (1987; 1988; *in preparation*) carried out a detailed geochemical and isotopic study of the complex granitoid batholiths in the eastern part of the Makkovik Province and detailed the characteristics of evolved granitoids associated with mineralization. These granitoids show a number of geochemical characteristics indicative of metallogenic 'specialization' including: i) high SiO_2 and depletion in CaO, MgO and FeO; ii) enrichment in incompatible elements; iii) local enrichment in ore elements; iv) extreme depletion in compatible elements; v) decoupling of major- and trace-element variation indicated by disturbance of expected fractionation trends; vi) evidence of volatile activity; and, vii) spatial associations with vein systems, alteration and mineralization. Geochemical features noted above are also shown by several granite bodies that are not known to be associated with mineralization.

One of the best examples of this type of mineralization is a zoned mineral district hosted by a vein swarm around a small stock in the Round Pond area assigned to the ca. 1.65 Ga Monkey Hill Intrusive Suite (Figure 21). MacDougall (1988) described a metallogenic zonation developed around the pluton ranging from proximal Mo–(W)–Cu–F to intermediate carbonate-hosted Zn–Pb to distal U–Zn mineralization. Associated alteration minerals are typical of a skarnoid origin.

Although U, Mo and the base metals are the principal established commodities, other granophile elements such as Sn, W and the rare-earth–rare-metal suite might also be concentrated in this area. MacDougall (1988) reported grains of scheelite associated with granophile sulphide veins in the Round Pond area. Kerr (1988) documented Sn enrichment (116 g/t Sn) in a small endocontact Cu–Pb showing on Burnt Island (Figure 21), and some granitoid suites are enriched in Sn relative to regional background. Many granites in the Makkovik Province have compositions that evolve to weakly peralkaline compositions and analyses of up to 4700 ppm Zr, 400 ppm Y, 1300 ppm La and 1200 ppm Ce have been recorded (Kerr, *in preparation*). Lake sediments in this area are strongly anomalous in Yb and Tb (as strongly as at Strange Lake; Figure 10d) and elevated values of Zn, Pb and other granophile elements; F is greatly elevated in lake waters.

In summary, granites of at least two different ages are associated with mineralization in the eastern Central Mineral Belt. The geochemical characteristics of the mineralized suites are also shared by suites that, as yet, contain no known mineralization. The best exploration potential appears to be in areas that represent high crustal levels where contacts with country rocks are preserved. Regional lake-sediment and water data, as well as locally available detailed geochemical survey data, could aid substantially in target selection in this area as they closely reflect both the local geology and the mineralization (Kerr and Davenport, *in press*).

Rare Metals and Rare Earths in Peralkaline Rocks

The discovery of the Strange Lake Zr–Y–Nb–Be–REE deposit (Figure 6) in 1979 sparked renewed interest in Labrador as a target for rare-metal–rare-earth mineralization. Other rare-metal–rare-earth showings in Labrador include: the Two Tom Lake, Mann #1, Mann #2 and Michelin Nb–Be±Y showings, SW Ten Mile Lake Y showing and the Red Wine North Zr±Y showings, all occuring (with the exception of the Red Wine North occurrence) in the Letitia Lake area (Figure 22), and several small Zr–Nb–Y–REE showings in the Flowers River area (Figure 6) (Miller, 1988). All of these showings are hosted by peralkaline felsic volcanic rocks, (i.e., trachytes, rhyolites) or related subvolcanic intrusions, (i.e., quartz syenites and granites, undersaturated syenites). In addition to known showings, geochemically anomalous concentrations of rare metals in peralkaline volcanic rocks have been reported from the Makkovik area (see above) and from near Fox Harbour on the south Labrador coast (Meyer and Dean, 1988; Figure 20).

The Labrador rare-metal–rare-earth showings are all Middle Proterozoic (Letitia Lake Group, 1327±4 Ma, Hill and Thomas, 1983; Arc Lake Pluton, 1337^{+10}_{-8} Ma, Gandhi *et al.*, 1988; Flowers River Igneous Suite, 1271±15 Ma, Hill, 1982; Strange Lake Complex, 1271±31 Ma, Currie, 1985). They are interpreted to record a crustal uplift-rifting event (Hill and Miller, *in press*), which can be traced throughout Greenland, Scandinavia and into interior North America (Aberg, 1988; Emslie, 1978; Bickford *et al.*, 1986). The magmatic products of this event include peralkaline and alkaline magmas of mafic and felsic compositions, which originated in the mantle or formed by mantle processes and were emplaced into high crustal levels. Rare-metal–rare-earth mineralization is commonly associated with the felsic, highly evolved, phases.

Rare-metal–rare-earth mineralization in Labrador occurs in several modes including: 1) pegmatite–aplite veins and lenses, 2) disseminated zones at or near the contacts of late-stage intrusions and, 3) stratiform disseminated mineralization in near-vent flows (Miller, 1988). The mineralization in all of these modes is thought to result from the concentration of incompatible elements in the roof zones of high-level magma chambers with fluids rich in volatile elements such as F and H_2O. Mineralized veins, pegmatites, small-volume volcanic flows and small late-stage stocks are all fed from this enriched roof zone of the magma chamber.

The Strange Lake deposit was discovered as a result of follow-up work of a F and U anomaly delineated in a regional lake-sediment–water survey (Geological Survey of Canada, 1979). Showings in the Letitia Lake area were discovered as a result of follow-up on a Zn anomaly in stream-sediment survey (Mann #1, Mann #2 and Michelin showings, Brummer, 1960) and through follow-up of an airborne radiometric survey (Two Tom Lake showing; Smith, 1968). Results of recent lake-sediment–water (McConnell and Batterson, 1987; McConnell, 1988) and till geochemical surveys (Batterson, 1989a, b) in both the Letitia Lake and Strange Lake areas indicate that both regional and detailed follow-up lake-sediment and till surveys for elements such as Be and Y are good exploration methods for rare-metal–rare-earth deposits in Labrador.

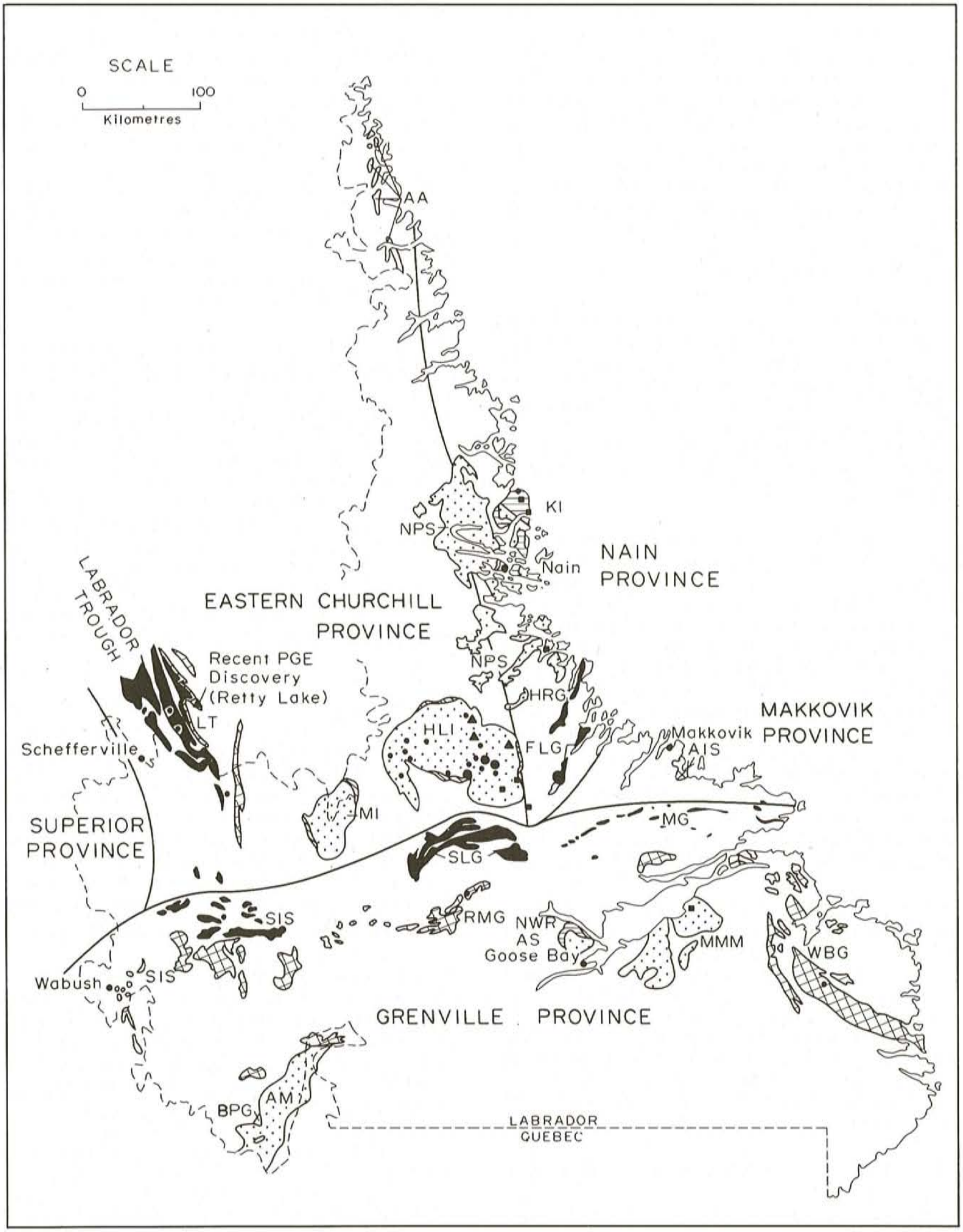


Figure 19. *Potential environments for Platinum Group Element mineralization in Labrador (after Wardle, 1987). Individual units denoted by letter codes are identified in the legend opposite.*

Legend for Figure 19

MASSIF-TYPE ANORTHOSITE PLUTONS

NPS – Nain Plutonic Suite, HLI – Harp Lake Intrusion, MI – Michikamau Intrusion, AM – Atikonak massif, MMM – Mealy Mountains massif

Marginal zone gabbroic rocks

LAYERED GABBROIC PLUTONS

KI – Kiglapait Intrusion, NWRAS – North West River anorthositic suite, BPG – Beaver Pond gabbro

MASSIVE TO WEAKLY LAYERED PLUTONS

Generally overprinted by strong deformation and metamorphic recrystallization SIS – Shabogamo Intrusive Suite, RMG – Red Wine Mountains gabbronorite, MG – Michael Gabbro, WBG – White Bear Arm gabbro.

GABBRO TO ULTRAMAFIC SILLS AND SHEETS

Gabbro

Ultramafites

LT – Labrador Trough, SLG – Seal Lake Group, FLG – Florence Lake Group, HRG – Hunt River group, SIS – Shabogamo Intrusive Suite

ARCHEAN LAYERED ANORTHOSITE – GABBRO – ULTRAMAFIC INTRUSIONS (AA)

HORNBLENDE GABBRO – DIORITE – MONZONITE INTRUSIONS

× AIS – Adlavik Intrusive Suite

SYMBOLS

Prospect	*Showing*	
●	•	*Cu – Ni and Ni mineralization; chiefly chalcopyrite and pyrrhotite including minor pentlandite*
▲		*Cu, Ni mineralization containing accessory PGE values*
	■	*Cu mineralization; chiefly chalcopyrite, pyrrhotite and pyrite*

Rapakivi Granites in the Churchill Province

The Middle Proterozoic granitoid rocks that are associated with the gabbro–anorthosite intrusions of central and northern coastal Labrador, traditionally referred to as adamellites (cf. Wheeler, 1960), are areally extensive, underlying much of the area inland from Davis Inlet and as far north as Okak Bay. They comprise four large composite bodies–Notakwanon, Mistastin, Makhavinekh and Umiakovik (Figure 23)–all exhibiting to some extent the texture, mineralogy and geochemical characteristics of the classic rapakivi granites of the Baltic Shield, which occur in a geologically equivalent environment (cf. Rämö and Haapala, *in press;* Ryan, *in press*).

The rapakivi granites of northern Labrador are virtually unexplored and contain no known showings. However, within the last twenty years, greisen veins, hosting cassiterite, wolframite, Be-minerals and sulphides have been found to be associated with topaz-bearing, geochemically anomalous late-stage granites of the Finnish rapakivi batholiths (Haapala, 1988). In addition, veins carrying granophile and base metals occur in and around the margins of some Finnish batholiths. The geological equivalence of the Labrador and Finnish rapakivi granites, the likelihood that they represent the same or a very similar magmatic event, and the documented metallogenic significance of the latter, suggest that granophile mineralization might be expected to be associated with these rocks in Labrador. In this regard, it is interesting that the Umiakovik body has an associated strong F anomaly in lake water.

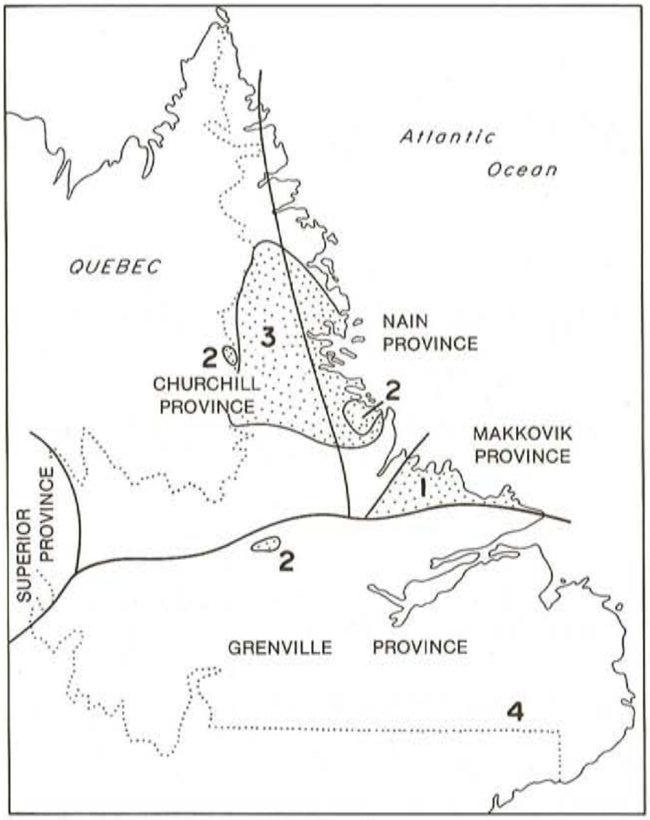


Figure 20. *Target areas for granophile elements. 1–Makkovik Province; 2–rare metals associated with peralkaline rocks; 3–rapakivi granites; 4–southern Grenville Province.*

Grenville Granites

Until very recently, very little was known of the nature or possible economic potential of granitoid rocks in the Grenville Province of Labrador. The extent of middle Proterozoic anorogenic plutonism in eastern Laurentia is presently unknown, mainly because it is most likely to be found in the unmapped area of the southernmost Grenville Province in Labrador. However, recent U–Pb studies in the Pinware terrane (southern Labrador, Figure 6) have identified a granitoid plutonic event at ca. 1.5 Ga, suggesting a correlation with anorogenic plutonism of similar age in Scandinavia and the mid-west U.S.A. In the U.S.A., in particular, such plutonism has been linked with magmatic and hydrothermal Fe and Cu–Fe deposits of the St. Francois terrane in southeast Missouri. This area is also known for Sn–W–Ag–Pb–As–Sb deposits in polymetallic quartz veins, which are considered to be genetically related to the granitic plutonism (e.g., the Silver Mine district; Kisvarsanyi, 1988; Sims *et al.*, 1987).

The likelihood that Grenvillian plutonism is widespread in the southernmost part of the eastern Grenville Province (Gower *et al.*, *in press*, b) suggests a previously unrecognized mineral potential. The granites are enriched in LIL elements and are known to have radio-element anomalies associated with them locally (cf. Gower *et al.*, 1985; Gower and Loveridge, 1987). In addition, lake sediments north and south of Lake Melville carry U anomalies associated with granites and diatexites, and lake waters and sediments over the southern Grenville Province are locally anomalous in F and U+Mo, respectively. In the Sveconorwegian Province in Scandinavia, radio-element anomalies are widespread, especially west of the Mandal–Ustaoset line (Sigmond, 1985), which correlates approximately with the area of extensive Grenvillian plutonism in Labrador. There are widespread Mo anomalies associated with the Scandinavian granites and molybdenite has been reported in late-stage veins within some of the posttectonic granites (e.g., Blomskog granite; Lindh, 1990).

INDUSTRIAL MINERALS

Introduction

Labrador is a storehouse of industrial minerals. Whereas the remoteness of the country has limited the development of these commodities in the past, recent work has shown that the quality of many of these deposits is sufficiently high to warrant serious attention. Exploration in the 1980's has focused on areas with existing infrastructure, road and rail links, (i.e., western Labrador), and on areas with easy access (i.e., the north and south Labrador coast) (Figure 24). The sections below summarize some of the industrial-minerals development opportunities that have been identified in recent years.

Silica in Western Labrador

A reconnaissance study of high-purity quartzites of the Wishart Formation (Figure 25) was carried out in the vicinity of Labrador City by Dean and Meyer (1985). Results of a chip-sampling program (Meyer and Dean, 1986) identified several prospects, one of which was drilled in 1986 (Meyer and Dean, 1987). Geochemical analyses of the drill core show that the quartzite meets requirements for a variety of silica-based products. The availability of cheap hydroelectricity from Churchill Falls, means that the economics of producing commodities such as silicon metal in western Labrador could be very attractive (Fenco-Lavalin, 1988).

Drilling was also carried out on a unique deposit of friable quartzite (Fermont Highway silica sand deposit) believed to have resulted from deep Cretaceous weathering of the quartzites (Meyer and Dean, 1987). This deposit, which could be hydraulically mined, has very high whiteness, and preliminary results show that it would require little processing to achieve total impurity levels of less than 250 ppm.

Graphite–Western and Northern Labrador

The discovery of the Lac Knife graphite deposit near Fermont, Quebec, by Mazarin Incorporated sparked exploration for graphite in western Labrador. This large-flake deposit, which averages 16 percent graphite, occurs in fine-

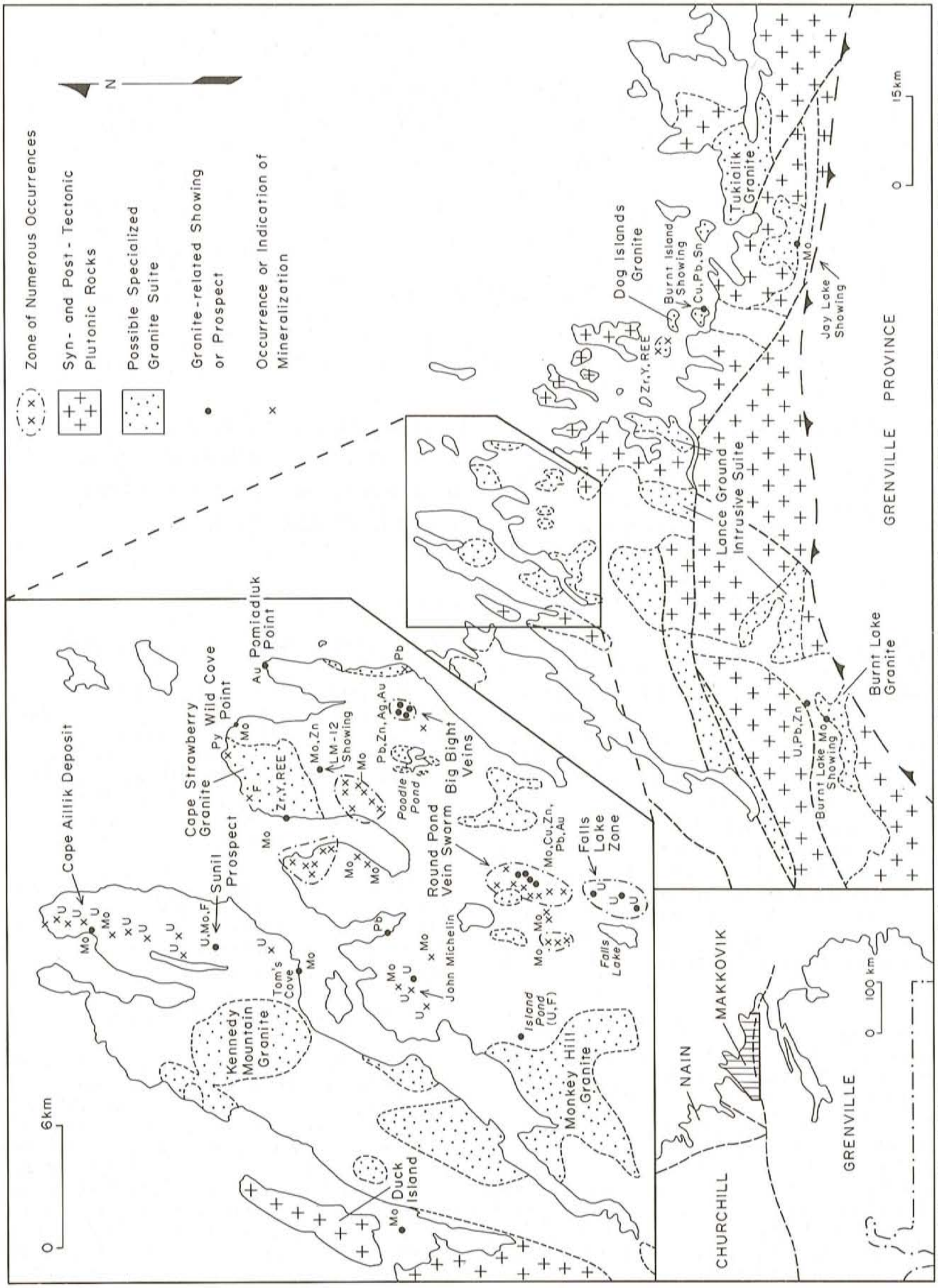


Figure 21. *Granitoid plutons and associated mineral occurrences of the Makkovik Province. Inset at top left shows details of the geochemically specialized granitoid suites and mineral occurrences of the Makkovik area.*

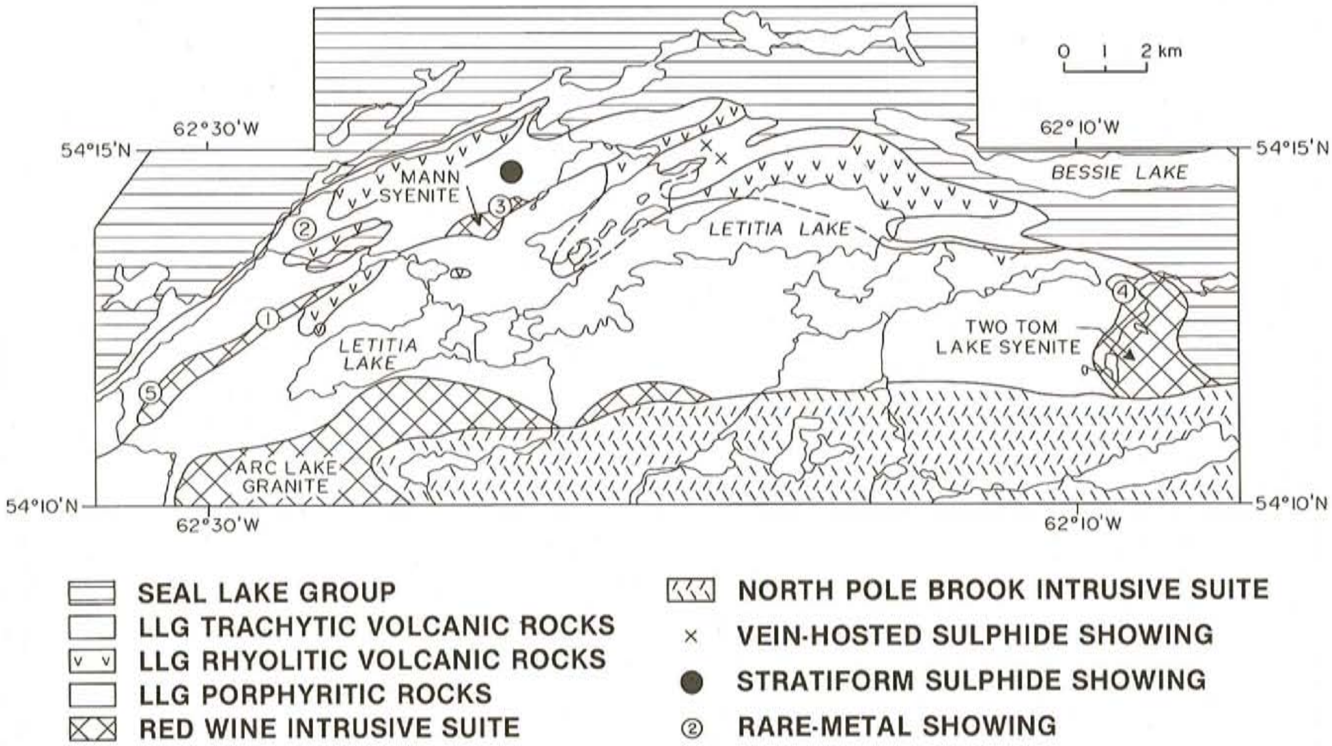


Figure 22. *Geology and mineral occurrences of the Letitia Lake Group.*

to medium-grained quartzofeldspathic gneiss of the Menihek Formation in the upper Knob Lake Group. These metasediments can be traced northeastward into Labrador, where there are a number of graphite showings (Figure 25). A geophysical and prospecting survey carried out in the Labrador City–Wabush area in 1989 by the Newfoundland Department of Mines and Energy (Meyer, 1990), rediscovered one of these showings, the Mart Lake graphite prospect. A 15-m-long trench on this prospect returned an average of 42 percent carbon, although the flake size is small and fine grinding would be required to achieve the desired purity level of 90 percent or greater. There are many significant untested conductors on this property, as well as relatively untested graphite prospects elsewhere in the area. Furthermore, there is a considerable exploration potential for undiscovered deposits.

A little-known and short-lived graphite mining operation was carried out near Saglek in northern Labrador during World War II (Carr, 1958). The 'lump' or vein-type' graphite is hosted by mylonitic Tasiuyak quartz–feldspar–garnet–graphite gneiss, and is thought to be similar to deposits mined in Sri Lanka. The 30- to 90-cm-thick lens that was mined, is exposed over 8 m (Meyer and Dean, 1988). Further occurrences of graphite have been reported in the same geological unit immediately north of the Fraser River (McConnell, 1984) and there would appear to be a considerable exploration potential for larger, more important deposits in the area (Douglas, 1953).

Refractory Minerals–Western Labrador

There are many kyanite–garnet–muscovite prospects in the Attikamagen Formation in the Labrador City–Wabush area (Figure 25). One of the best prospects occurs at the south end of Flora Lake (Rivers, 1978; Meyer and Dean, 1988) where kyanite–garnet–mica–quartz schists contain up to 20 percent kyanite, 10 to 20 percent garnet and 10 to 15 percent mica (dominantly muscovite). There is considerable potential for other high-grade deposits to be found in the area.

There is only one producer of kyanite in North America at the present time, and there is strong growth in garnet and muscovite markets (Metals Economics Group, 1988). Thus, there is good economic potential for one operation to produce these three industrial minerals.

Dimension Stone–North Labrador Coast

In 1986, the Department of Mines and Energy sampled three dimension-stone prospects in the Nain anorthosite, on the northern Labrador coast (Meyer and Dean, 1987). Recent interest by a major Italian stone company has focussed on one of these prospects at 10-Mile Bay, where a uniformly medium-grained, light-grey anorthosite, with up to 20 percent of the labradorite crystals showing flashes of blue on a cut surface, outcrops at tidewater. A 10-tonne block was quarried by the Labrador Inuit Development Corporation in the fall of 1990 and shipped to Italy. If tests on the anorthosite block are satisfactory, development of the deposit may follow.

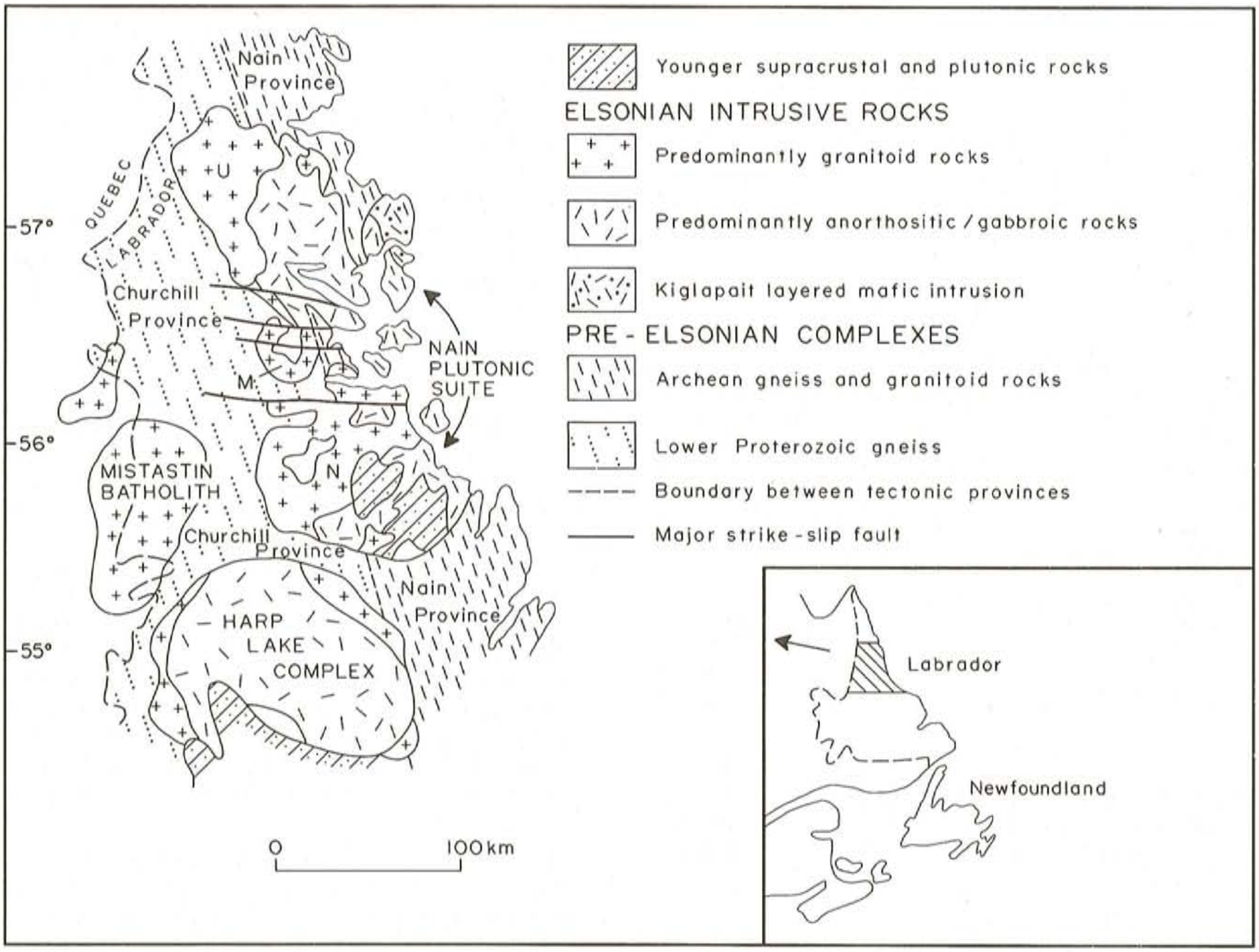


Figure 23. *Rapakivi granites of northern Labrador. The Elsonian granitoid rocks of this area have some or all of the characteristics of the Rapakivi suite. U–Umiakovik; M–Makhavinekh; N–Notakwanon plutons.*

Anorthosite is widespread on the many islands and fiords of the north Labrador coast between Davis Inlet and the area north of Nain. The establishment of a dimension-stone quarry in the Nain area, and shipping of rough block to European processing plants, could open up the entire Labrador coast south of Nain for exploration.

Mica–Southeastern and Western Labrador

Muscovite-bearing pegmatites have been reported from the southeast Labrador coast (Gower *et al.*, 1986b, 1987), and from roadcuts in western Labrador (Meyer and Dean, 1988). One of the southern Labrador pegmatites is 10 m wide, has an exposed strike length of 50 m (Gower *et al.*, 1985), and contains free-splitting books of sheet muscovite up to 30 cm in diameter and 15 cm thick (Meyer, 1990). During regional mapping of the area, numerous other pegmatites were mapped by Gower *et al.* (1986b). The market for sheet muscovite is small, but prices range up to C$2000 per kilogram.

Ti-Sands–Lake Melville

Investigations into the heavy-mineral placer potential in the Lake Melville area and the coastal zone between Groswater Bay and Sandwich Bay, were carried out in 1990 (Emory-Moore and Meyer, *in preparation*). Numerous rivers entering these areas drain hinterlands underlain by gabbro–anorthosite massifs containing disseminated ilmenite. Black sand lenses and laminations are visible in the extensive postglacial deltaic, estuarine and littoral sands. Preliminary investigations suggest that the reworked postglacial sediments in modern beach environments exhibit the highest placer potential. The highest concentration of heavy minerals encountered during the sampling program occurred along a 20-km-long coastal-beach system north of Cartwright, with up to 50 percent heavy minerals over a 1 m thickness. Detailed mineralogical analyses are now underway to evaluate the potential for obtaining low-alkali TiO_2 concentrates from these deposits.

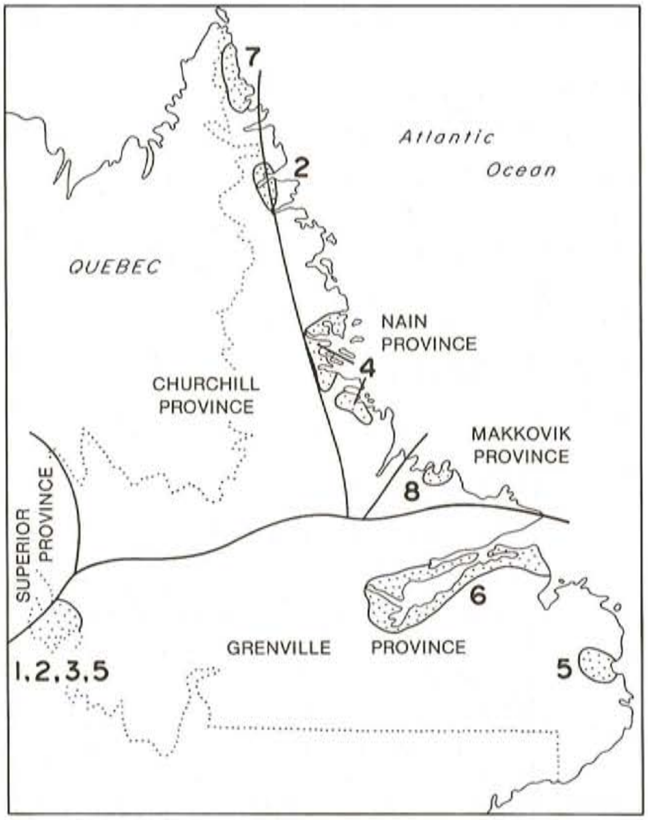


Figure 24. *Location of main industrial mineral prospects in Labrador. 1–silica; 2–graphite; 3–refractory minerals; 4–dimension stone; 5–mica; 6–Ti-rich sands; 7–chromite; 8–diamonds.*

Chromite–Northern Labrador

Podiform, sill-like anorthosites occur in the northern part of the Nain Province and are reflected in widespread Ni anomalies in stream sediments. These bodies, mapped by Taylor (1979), are believed to be Archean in age, as they are cut by early Proterozoic dykes (Wilton and Wardle, 1990), inviting a comparison with the mid-Archean Fiskenaesset Complex of western Greenland, a layered anorthosite intrusion that was dismembered by ca. 2.9 to 2.8 Ga magmatism and contains seams of chromite (Ghisler, 1976). Wilton and Wardle (1990) described examples of these anorthosites at Noodleook (Ekortiarsuk) Fiord and Eclipse Harbour. Although the presence of chromite was not confirmed in the field, subsequent laboratory studies (D. Phillips, personal communication, 1990) have recently found up to 1.2 percent Cr in ultramafic samples from Noodleook Fiord.

Diamond Potential–Labrador Coast

Various occurrences of alkaline mafic dykes are known from the Labrador coast. The most extensive development occurs in the Aillik Bay area of the Makkovik Province (Foley, 1989) where alkaline–ultramafic lamprophyres form a system of cone sheets and radial dykes thought to be related to an intrusive centre under the Labrador Sea. Lamprophyric dykes are thought to have formed ca. 0.6 to 0.57 Ga, in association with the St. Lawrence rift system, whereas the ultramafic lamprophyres and carbonatites are more likely Cretaceous (Foley, 1989). Small kimberlite–alnöite pipes and dykes also occur in the Saglek area of the northern Nain Province (Collerson and Malpas, 1977) and also are likely of Cretaceous age and related to opening of the Labrador Sea. The kimberlitic affinity of these various alkaline rocks suggests that they may be worth prospecting for their diamond potential.

CONCLUSIONS

The exploration environments that have been highlighted briefly in this paper represent some of the grassroots targets that Labrador has to offer. Our presentation of the mineral potential of this area is, to some extent, coloured by the state of our knowledge (e.g., the graphite potential of western Labrador has been given a significant boost by the recent Lac Knife discovery) and by the market interest in various commodities (i.e., although we have not emphasized the uranium potential, there are a number of prospective environments that could be quickly identified if there were renewed interest in uranium exploration). As geological mapping and related regional studies continue in this area, new targets will undoubtedly be identified and a better focus for exploration related to known targets will be achieved.

Exploration in Labrador has traditionally suffered from the remoteness of the country and from a perception (in part based on inadequate geological information) that there are no prospective environments. In fact, the environments are there and the lack of major non-ferrous mineral deposits in Labrador may be largely a function of the lack of modern exploration. There is considerable potential for a variety of deposit types related to lower grade rocks (e.g., the Central Mineral Belt, eastern Labrador granitoid rocks) in which current deposit models could be applied in a relatively straightforward manner. Although it is true that much of Labrador is at relatively high metamorphic grades, making the application of some deposit models more speculative, some deposit types actually require high-grade metamorphism (e.g., refractories, graphite) and pre-metamorphic deposits that might occur in these areas (e.g., Besshi-type or SEDEX deposits) could have survived the variably intense deformation and metamorphism more or less intact. Although exploration for these deposits using geological models will certainly be more difficult in relatively high-grade, deformed terranes, it seems likely that, as the easily found large deposits in lower grade terranes are all discovered, exploration will need to be focused in the more geologically difficult regions. Armed with new geological concepts and remote sensing techniques, and the need to meet an ever increasing demand for metals from ever decreasing resources, it may well be that explorationists will find a minerals storehouse in Labrador that will provide important resources for the province well into the 21st century.

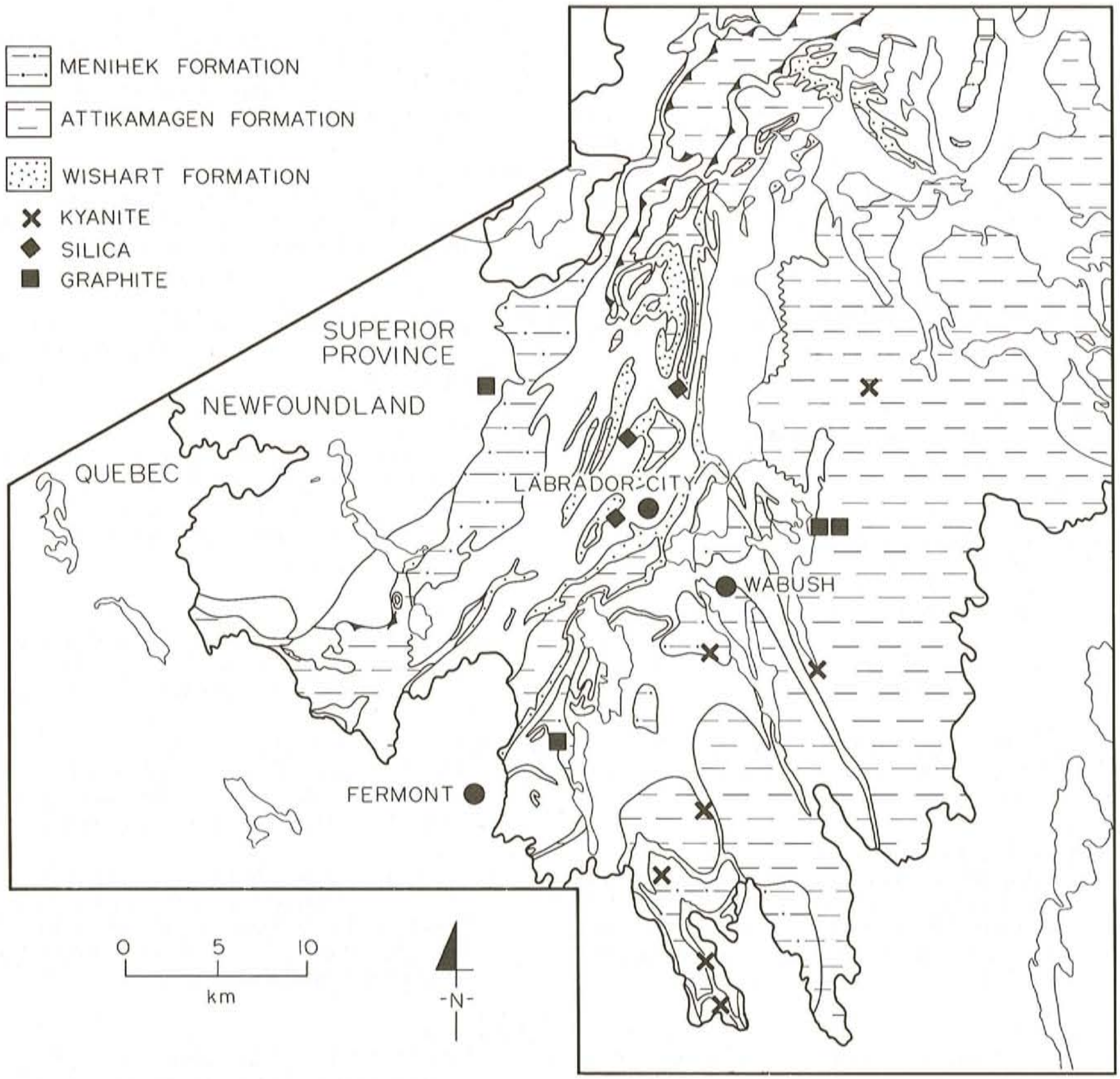


Figure 25. *Industrial minerals in western Labrador and distribution of geological units with further industrial-minerals potential.*

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