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PLATINUM-GROUP-ELEMENT POTENTIAL IN LABRADOR

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ABSTRACT

Exploration for Platinum-Group Elements (PGE) is increasing in most areas of Canada, including Labrador. In the past, Labrador has had only a minimal level of exploration for these metals, and as yet significant PGE occurrences have not been discovered. However, by comparison with environments elsewhere in the world, the potential for discovery of PGE would appear to be at least equal to that of other areas of the Canadian Shield. PGE, although overwhelmingly associated with mafic plutonic rocks, may be sought in a variety of mineralization environments, ranging from magmatic to hydrothermally remobilized.

The most obvious potential in Labrador is for magmatic mineralization in either layered gabbroic intrusions or in association with Ni-sulfide deposits in ultramafic rocks. Examples of suitable layered gabbroic complexes in Labrador are the Kiglapait Intrusion and Archean layered gabbro–anorthosites of northern Labrador, and the layered gabbroic parts of massif-type anorthosite suites, in particular the North West River anorthositic suite and Harp Lake intrusion of southern and central Labrador.

The recent discovery of PGE mineralization in the Québec part of the Labrador Trough will, no doubt, prompt a re-examination of the gabbroic and ultramafic sills of this belt. Ultramafic–Cu–Ni-sulfide associations are also known from the Archean Florence Lake belt of eastern Labrador and, together with the similar Hunt River belt, should also be explored for PGE.

The high-level gabbro-sill swarm of the Seal Lake Group, and the possibly equivalent Shabogamo and Michael gabbro suites, represent an intrusive environment similar to that of the Noril'sk intrusions and could be explored for similar Ni–PGE potential.

The Adlavik Intrusive Suite of eastern Labrador is suggested as a candidate for hydrothermal PGE mineralization. Other targets for hydrothermal mineralization in Labrador are difficult to define other than in a very general fashion, but hydrous shear zones within metagabbroic complexes that occur largely within the Grenville Orogen probably represent the best starting point.

INTRODUCTION

Recent years have seen a considerable upsurge in exploration interest for the Platinum-Group Elements (PGE), fueled by price increases and anticipation of shortages in the supply of these strategically important metals. Exploration in the 1960s and early 1970s resulted in the discovery of several Ni–Cu prospects in greenstone belts of eastern Labrador and the Harp Lake intrusion of central Labrador. Minor PGE values were discovered in association with sulfide mineralization in the Harp Lake intrusion, and represent the only published values recorded for these elements from Labrador to date. Exploration of other areas was minimal and considerably impeded by a mineral-land-tenure system that tied up large areas of land in long-term mineral concessions.

The past year has seen the inception of reconnaissance PGE exploration programs by industry in northern and central Labrador, and, together with the recently announced discovery of PGE mineralization in adjacent Québec, has prompted this paper on potential PGE-mineralization environments in Labrador.

PGE-MINERALIZATION ENVIRONMENTS

The PGE have transitional siderophile (oxide) to chalcophile (sulphide) behaviour and are overwhelmingly associated with mafic and ultramafic plutonic rocks (Crocket, 1979). They may be divided into two groups on the basis of their chemical behaviour. The first group consists of osmium (Os), iridium (Ir) and ruthenium (Ru), which are strongly siderophile, have higher melting points, and tend to occur as alloys of oxide inclusions in very early crystallizing silicate and oxide phases, such as spinel, olivine or chromite. Not surprisingly, therefore, they are nearly always found in association with ultramafic rocks. The second group of the PGE, namely the more economically important elements, platinum (Pt), palladium (Pd) and rhodium (Rh), are more chalcophile and tend to concentrate in gabbroic rocks, though in the presence of a sulfide phase they will also occur in ultramafic rocks. The behaviour of the PGE, in particular Pt, Pd and Rh, is generally, though not uniformly (see Heimstra, 1985), regarded as being incompatible with respect to crystallization of major silicate or oxide phases. However, the PGE will partition strongly into a sulfide phase (Naldrett and Cabri, 1976; Campbell and Barnes, 1984; Naldrett *et al.*, 1979), and the presence of such a phase, generally as an immiscible sulfide melt, appears to be one of the most important factors governing the development of PGE concentration, regardless of whether the parent magma is of ultramafic or gabbroic composition.

Approximately 99 percent of the world's production of PGE is estimated to come from magmatic sulfide deposits (Naldrett and Duke, 1980), dominantly associated with stratiform layered mafic complexes. These may be divided into two types: those in which PGE are the most important products (primary PGE producers); and those in which PGE are produced as by-products of Ni or Ni–Cu ore (secondary PGE producers).

Deposits in which PGE Form the Primary Ore Minerals

This type of mineralization is hosted by plutons of dominantly gabbroic composition, of which the largest single example, by far, is the Early Proterozoic Bushveld Complex of South Africa (Vermaak, 1976). It contains PGE (predominantly Pt) in the Merensky Reef, UG–2 chromite layer and Platreef. The Merensky Reef hosts the greatest volume of PGE ore and is the type example of a stratiform magmatic PGE deposit. The Bushveld Complex, together with the other major example of this class, the Early Proterozoic Stillwater Complex of Montana, (Conn, 1979; Irvine *et al.*, 1983), form large, cyclically layered intrusions of overall gabbroic composition. Both have lower ultramafite zones (Irvine *et al.*, 1983) composed largely of alternating layers of harzburgite and bronzitite with thin sporadic chromitite layers. At intermediate levels, norite and anorthosite predominate, and in the upper levels two-pyroxene gabbro (and in the Bushveld, granophyre and felsite) forms the dominant rock type. Mineralization occurs 400 to 600 m above the ultramafites and is closely associated with anorthosite, bronzitite, norite, and (in the Bushveld) chromitite seams. The mineralized 'reefs' are distinguished by enrichment in disseminated Fe, Ni and Cu sulfides.

PGE have also been produced from zoned Alaskan-type ultramafic bodies, largely from the Ural Mountains, USSR, but also from placer deposits associated with similar bodies in Alaska–British Columbia (St. Louis *et al.*, 1986). This type of intrusion is distinguished by dunite cores and concentric outer zones of clinopyroxenite and hornblendite. In contrast to the anorogenic layered intrusions, the Alaskan-type bodies are found within orogenic zones. Older PGE-mineralized analogues have been suggested to include the Archean Lac des Isles Complex of Ontario (Sutcliffe, 1986).

Deposits from which PGE are Produced as By-products of Ni-Sulfide Ore

Examples of this class abound and include several different types of intrusion (Naldrett and Cabri, 1976).

1) *Irruptives produced by astrobleme impact.* The only known example of this is Sudbury, Ontario, where PGE are produced as by-products from Ni-sulfide ores that separated from a gabbroic magma.

2) *Layered mafic–ultramafic–volcanic complexes within the basal parts of Precambrian greenstone belts.* Two types are generally recognized: a) those associated with komatiitic flows in a peridotite–volcanic association, e.g., Kambalda, Western Australia (Gresham and Loftus-Hill, 1981) and Munro Townships, Ontario (Crocket and MacRae, 1986), and b) dunite-associated deposits, also typified by Western Australian Ni deposits (Marston *et al.*, 1981).

3) *High-level, tholeiitic intrusions associated with flood basalts.* Examples of this class are Permian volcanic and intrusive rocks of the Noril'sk area, Siberia (Glazkovsky *et al.*, 1977, page 3); and the Duluth Complex of the Middle Proterozoic Keweenawan rift zone, U.S.A.

The concentration of PGE by sulfide scavenging is probably the single most important factor in concentrating PGE into Ni- or Ni–Cu-sulfide deposits, and also plays a vital role in PGE-dominant ore formation. For example, Vermaak (1976) has proposed that the concentration of PGE in the Merensky Reef resulted from increases in sulfur fugacity following iron depletion of the magma by chromite settling. Other authors (e.g., Barnes *et al.*, 1985) have pointed out the important effect of delaying the development of an immiscible sulfide phase, therefore allowing Pt, Pd and Rh to concentrate as incompatibles in the fractionating magma. The appearance of plagioclase cummulates, as represented by anorthosite or leucogabbro layers, is also widely recognized as an inherent feature of zones containing PGE mineralization. Plagioclase fractionation may, therefore, play an important role in concentrating PGE within the remaining liquid fraction.

However, simple, closed-system fractional crystallization of a magma may be inadequate to account for economic PGE enrichment. Todd *et al.* (1982), Irvine *et al.* (1983) and Naldrett *et al.* (1985) have invoked mixing of two parental magmas followed by development of density stratification and resultant double-diffusive convective magma mixing to account for the sudden development of a sulfide-bearing phase in the Stillwater and Bushveld magma chambers. In a modification of this model, Naldrelt *et al.* (1986) envisage structures such as the Merensky reef to have originated by lateral spreading from downspouts of dense, sulfide-rich magma–the sulfide-rich magma having been formed by mixing of ultramafic and anorthositic parental magmas at higher levels in the magma chamber. There is also evidence that the Bushveld magmas were initially enriched in PGE (Sharpe, 1982) compared to other layered complexes, though whether this was achieved by melting of an enriched source region or by fractionation at some deeper crustal level is unknown. Others (e.g., Crockett, 1979; Davies and Tredoux, 1985) have been unable to find evidence of prior PGE magma enrichment.

There is now, also, considerable evidence pointing to the mobility of PGE under low-temperature, deuteric or hydrothermal conditions, particularly those in which chloride-rich fluids are present (Barnes *et al.*, 1985). The Merensky and J–M reefs of the Bushveld and Stillwater intrusions respectively are characterized by pegmatitic textures and the presence of volatile-rich minerals such as biotite and apatite. Mathez *et al.* (1985) and Johan and Watkinson (1985) have suggested that PGE in late-stage, fractionated melts may be complexed and transported by chloride-rich fluids, and it has even been suggested (von Gruenewald, 1979) that large-scale features such as the Merensky Reef may originate from such late-stage magmatic-fluid enrichment. More definitive examples of deuteric remobilization appear to be the cross-cutting platiniferous dunite pipes of the eastern Bushveld (Stumpfl and Rucklidge, 1982), which carry PGE in pegmatitic zones. A low-temperature fluid phase also appears to have been responsible for transportation and precipitation of PGE in gabbroic pods of the Coldwell Complex, Ontario (Watkinson and Dahl, 1986), and the Koillismaa Layered Igneous Complex of Finland (Piispanen and Tarkian, 1984).

Evaluation of these models is beyond the scope of this paper. There is no uniform model for the development of magmatic PGE deposits, and in particular, there is strong disagreement concerning the role of primary-magmatic versus deuteric or hydrothermal processes in ore formation (e.g., Naldrett *et al.*, 1986). Theoretical considerations aside, the chief empirical factors required for PGE mineralization appear to be: 1) in all rocks, the presence of a concentrated sulfide phase; 2) in gabbroic rocks, the development of strong fractionation, in particular plagioclase fractionation as indicated by cyclical layering, ranging from ultramafic (including chromitite) to anorthosite in composition. PGE mineralization in ultramafic rocks appears favoured by primitive (e.g., komatiitic) compositions, but in gabbroic plutons the overall composition, whether it be alkali basalt or tholeiite, does not appear to be critical.

Hydrothermal and Metamorphic Environments

In addition to deuteric mobilization, there is also evidence, albeit restricted, that PGE may be able to move considerable distances in hydrothermal environments. The best known example of this is the Messina deposit of South Africa (Mihálik *et al.*, 1974), which contains PGE in association with Cu ore in a propyllytic alteration zone associated with a granite intrusion. The PGE also appear to have the capacity to become mobile in metamorphic environments; for example, the Hitura Ni deposit of Finland (Häkli *et al.*, 1976) and Unst ophiolite of Scotland (Gunn *et al.*, 1985) contain their highest PGE values in serpentinized ultramafite. Häkli *et al.* (1976) postulate that transport occurred in chloride brines. The New Rambler deposit of Wyoming (McCallum *et al.*, 1976), which contains vein-hosted PGE in association with Cu in sheared metagabbro, may be a further example of metamorphic remobilization, although a magmatic-hydrothermal origin is also possible. Similar hydrothermal alteration along shear zones also has been described by Rowell and Edgar (1986) from the Wanapite Intrusion, Ontario.

The mobility of the PGE appears to extend even into the environment of low-temperature basinal brines and ground waters. The Zechstein Kupferschiefer of Poland contain marked concentrations of PGE and Au in organic-rich black shales (Kucha, 1982), indicating the mobility of the elements in what was presumably a chloride-rich diagenetic environment. Fuchs and Rose (1974), Bowles (1985) and Stumpfl and Tarkian (1976) have also provided evidence indicating the mobility of PGE in ground waters, particularly acidic, chloride-rich waters. Discovery of the Stillwater J–M reef was based in part on successful soil geochemical prospecting for Pt and Pd (Fuchs and Rose, 1974; Conn, 1979); therefore, the surface mobility of the PGE clearly has important economic ramifications.

Placer Deposits

Placer deposits, notably developed adjacent to Alaskan-type and Alpine-type ultramafic bodies in mountainous terranes, such as the Cordillera of the northern United States and Canada, have, in the past, provided small but economically viable sources of PGE.

POTENTIAL PGE ENVIRONMENTS IN LABRADOR

Mafic plutons in Labrador range in age from Archean to Middle Proterozoic, represent a range of crustal levels, and are preserved in a considerable variety of deformational states. Figure 1 shows the location and classification of the major plutonic suites discussed in this section. The classification scheme is based largely upon bulk composition, degree of internal fractionation (as represented by development of layering and compositional range) and morphology. Age is considered only where a particular class appears to be time specific. This scheme, although not rigorous, permits comparisons with the mineralized plutonic environments discussed above.

Description of individual plutonic suites and mineral occurrences are necessarily brief. For further information regarding mafic plutonic suites of Labrador the reader is referred to Greene (1974) and Emslie (1978). Details of mineral occurrences are available *in* Douglas (1976), the Mineral Assessment Report Library (Mercer, 1986) and the Mineral Occurrence Data System (O'Driscoll, 1986).

Massif-Type Anorthosite Plutons (Class 1)

This class is predominant in Labrador and includes the classic 'Elsonian' plutons of central and northern Labrador (Emslie, 1978). Anorthosite suites in the Nain Province and Churchill Orogen are fresh, posttectonic intrusions that have lopolith or funnel-shape profiles. Intrusion ages range between 1450 and about 1400 Ma, and bulk composition varies between leucotroctolite, leuconorite, leucogabbro and anorthosite. The Harp Lake and Michikamau intrusions possess thin marginal zones of layered troctolite, olivine gabbro and norite. The Nain Plutonic Suite is more complex and consists of a number of gabbroic to anorthositic intrusions, some of which are layered and considered under Class 2 (Figure 2). All of the anorthosite intrusions in the Nain Province and Churchill Orogen are associated with consanguinous suites of monzonite and syenite, proposed by Emslie (1978) to have been derived by contemporaneous melting of lower crust during anorthosite intrusion. Granitoid

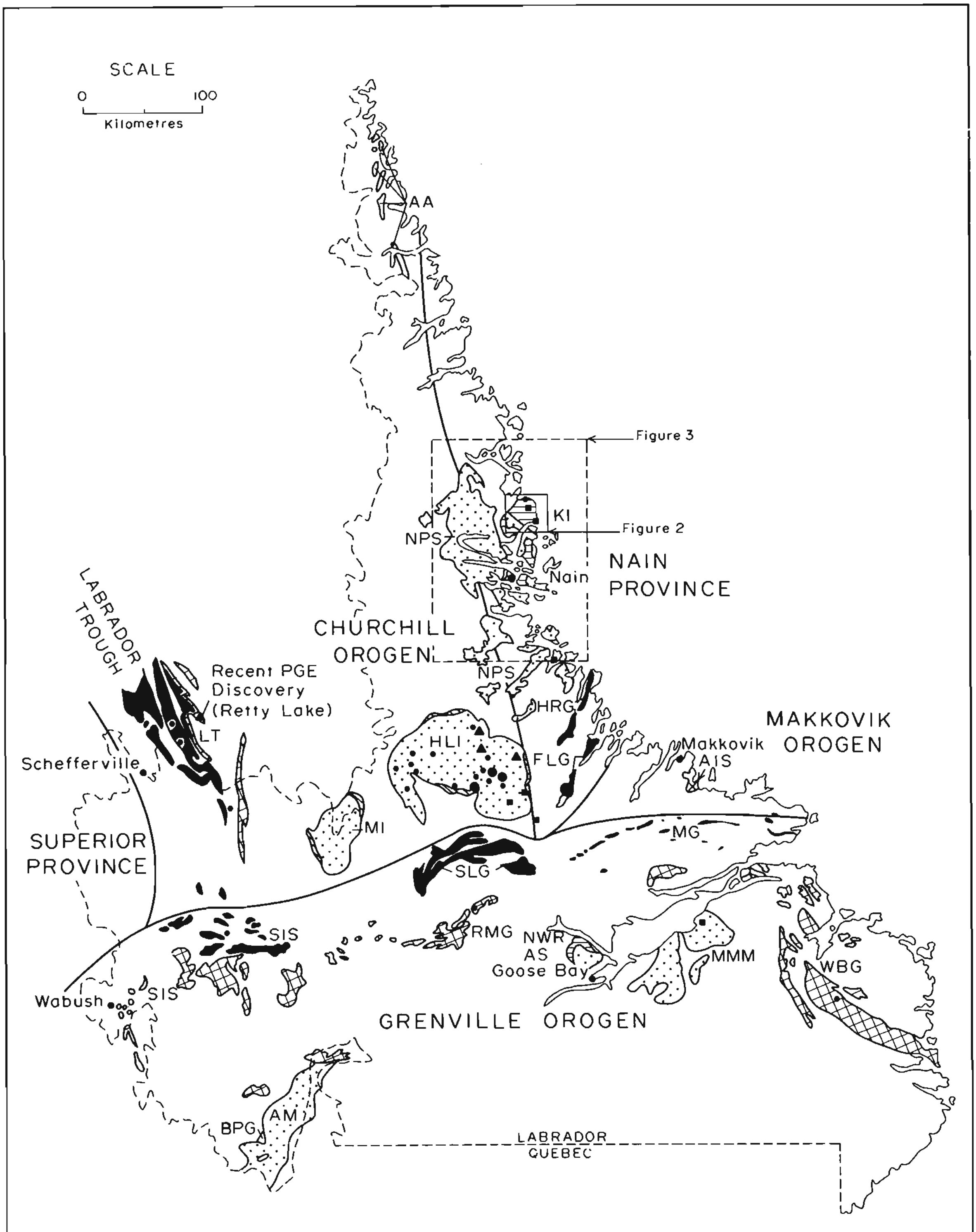

Figure 1. *Mafic intrusive suites of Labrador and associated mineralization; intrusions are classed according to overall composition, degree of internal differentiation, and morphology.*

LEGEND *(Figure 1)*

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*

rocks in the Nain Plutonic Suite (Wheeler, 1960; Morse, 1971) occur partially as roof caps to anorthosite, whereas in the more southerly Harp Lake and Michikamau intrusions they occur as partial annular rims. This difference may indicate the existence of progressively deeper erosion levels to the south.

Anorthosite suites within the Grenville Orogen are variably deformed and recrystallized, and have intrusion ages varying between 1650 and 1150 Ma. The major suites are the Mealy Mountains anorthosite (Emslie, 1976) and the Atikonak massif anorthosite (Emslie *et al.*, 1986), which consist of massive to moderately layered leucogabbro, leuconorite, leucotroctolite and anorthosite. The North West River anorthositic suite, a smaller intrusion, possibly related to the Mealy Mountains anorthosite, forms the upper structural level of a shallow, south-dipping thrust slice known as the Cape Caribou River allochthon (Ryan *et al.*, 1982; Wardle and Ash, 1984). The suite is internally divided into an upper anorthosite component and a thick lower series of layered gabbros and their amphibolite equivalents. It is equivocal as to whether the North West River suite should be classed with the massif-type plutons or the layered gabbroic plutons (Class 2); it has characteristics of both.

As a rule, massif-type anorthosites are not associated with economic Ni-sulfides or PGE deposits. However the Harp Lake intrusion (Emslie, 1980) of central Labrador contains numerous small Cu–Ni-sulfide showings and prospects discovered during Ni exploration by Kennco in the early 1970's (McAuslan, 1973a,b; Jones, 1975). These form stratiform zones of disseminated chalcopyrite, pyrrhotite and minor pentlandite over strike lengths of up to 650 m in leucogabbroic rocks. Cu values range from 0.03 to 0.07 percent and Ni from 0.12 to 0.32 percent. PGE values were detected at several showings with maximum values of 185 micrograms/tonne Pt and 150 micrograms/tonne Pd (Jones, 1975). Douglas (1976), in her compilation report of mineral

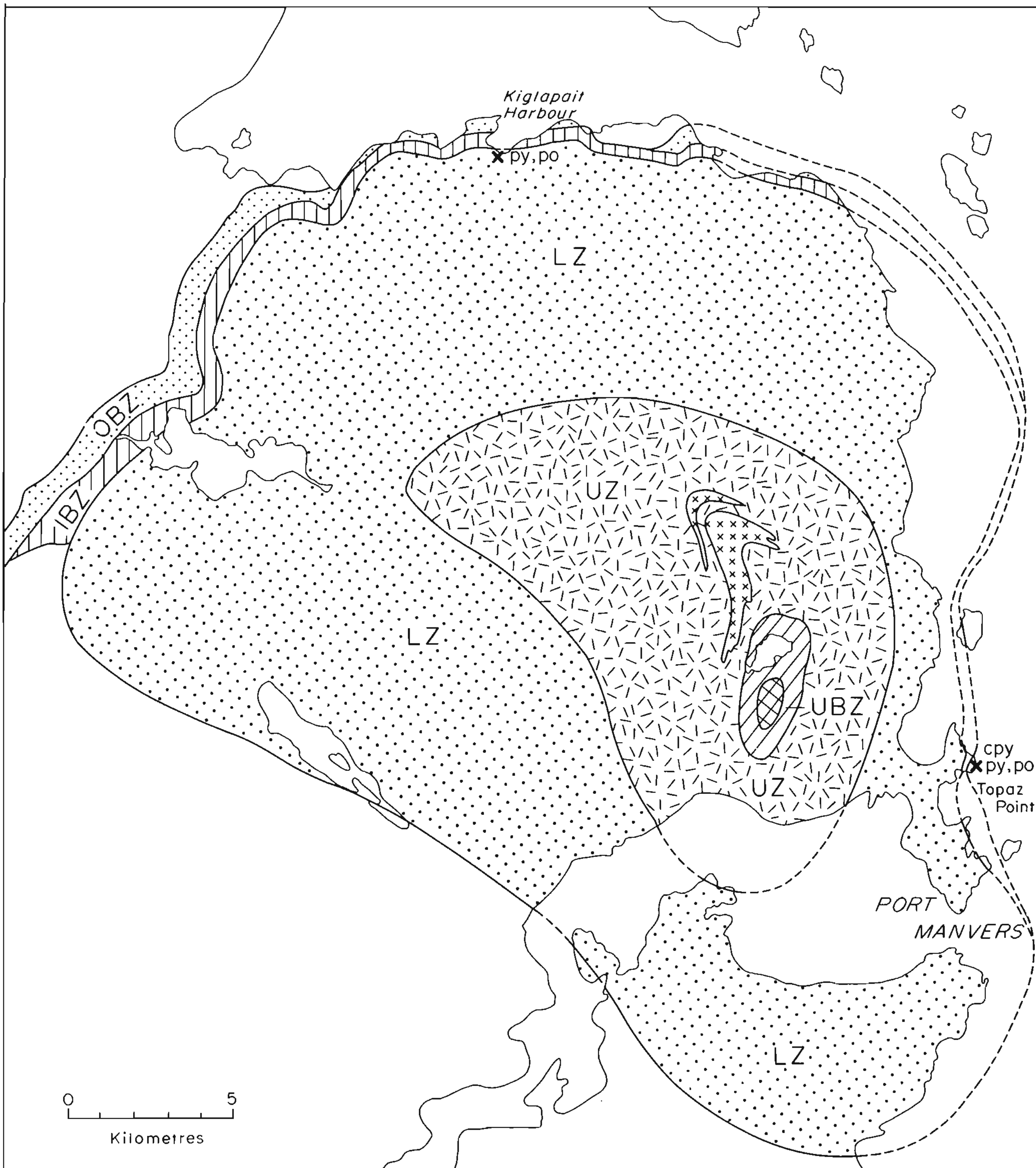

Figure 2: *Geology of the Kiglapait Intrusion (simplified after Morse, 1969); for location see Figure 1.*

LEGEND *(Figure 2)*

UPPER BORDER ZONE

Medium grained massive troctolite to olivine gabbro

Gray gabbro, olivine gabbro and ferrodiorite

UPPER ZONE

Layered and laminated olivine gabbro (base) through ferrodiorite to ferrosyenite (top)

Ferrodiorite to ferrosyenite

LOWER ZONE

Layered and laminated medium to coarse grained troctolite, including dunite and leucotroctolite; pyroxenite lenses common near base

INNER BORDER ZONE

Massive, medium to coarse grained, subophitic olivine gabbro

OUTER BORDER ZONE

Fine to medium grained, granular, banded gabbro, olivine gabbro and pyroxenite

occurrences in Labrador, notes values of 15 to 30 ppm Pt from the Dart Creek showing. (The source of this information could not be found; however, it is likely that it is the Kennco work, and that 'ppm' quoted by Douglas is a typographical error for ppb.)

Emslie (1980) has suggested that anorthosites such as the Harp Lake intrusion are generally too fractionated to have significant potential for either Ni-sulfide or PGE mineralization. However, as noted in the introduction, the concentration of Pt, Pd and Rh may be favoured by prolonged fractionation, provided that sulfide phase separation can be sufficiently delayed.

Other massif-type anorthosite plutons in Labrador have received but cursory exploration, and contain only a few, minor sulfide showings (Figure 1).

Layered Gabbroic Plutons (Class 2)

By analogy with the Bushveld and Stillwater complexes, this class of pluton appears to hold the most obvious potential for PGE mineralization. The largest example in Labrador is the Kiglapait Intrusion (Morse, 1969) of ca. 1400 Ma age, and which is probably closely related to the adjacent Nain Plutonic Suite (Figure 1, Figure 2). The intrusion (Figure 2) ranges in composition from troctolite through olivine gabbro and anorthosite to ferrodiorite and ferrosyenite. The bulk composition is high-alumina low-K tholeiite. The intrusion was prospected by Kennco (Barr, 1970), who reported vein-hosted, pyrite–pyrrhotite–chalcopyrite mineralization from the contact zone at Topaz Point, and lenticular masses of pyrite–pyrrhotite (with 0.5 percent Cr) from marginal gabbro at Kiglapait Harbour. The upper zone of the intrusion (Figure 2) also contains a titanomagnetite-rich ferrodiorite horizon containing minor, localized Cu mineralization (Barr, 1970). No PGE values were detected. By analogy with the Bushveld–Stillwater environments, the layered series represented by the upper and lower zones in Figure 2 appears to hold the best potential for PGE mineralization. Those rocks occur high in the intrusion (as is the case with the Merensky and J–M reefs), are marked by plagioclase fractionation and include a range of compositions from troctolite to ferrodiorite and ferrosyenite. Significantly, apatite is also locally present as a cummulate phase (1 to 7 percent) together with biotite, indicating the presence of a volatile-enriched fluid phase. The area of the Kiglapait Intrusion was acquired and explored for PGE in 1986 by Platinum Exploration Canada Inc., but results are not yet available.

Smaller, layered intrusions occur within the Nain Plutonic Suite (Morse, 1976, page 46), where they range in size from less than 1 km² to partially exposed bodies conjecturally greater than 400 km² in area (Figure 3). Composition varies from gabbro to monzonite and quartz monzonite. The major gabbroic intrusions are the Barth Island layered structure and the Bridges, Hettasch and Tigalak-Newark island intrusions.

Other minor gabbroic intrusions associated with anorthosite suites have been described from the Harp Lake intrusion (Emslie, 1980) and Atikonak River massif (Emslie *et al.*, 1986). The latter contains two intrusions, one of which, the Beaver Pond gabbro, has pyroxene and oxide-rich pods containing sulfide mineralization, including pyrrhotite and chalcopyrite (Emslie *et al.*, 1986).

Massive to Weakly Layered Plutons (Class 3)

This class is prominent within the Grenville Orogen and consists of gabbro and norite, together with their leucocratic varieties, and lesser amounts of anorthosite. The class includes the partially deformed and recrystallized Shabogamo Intrusive Suite (Fahrig, 1967; Rivers, 1980);

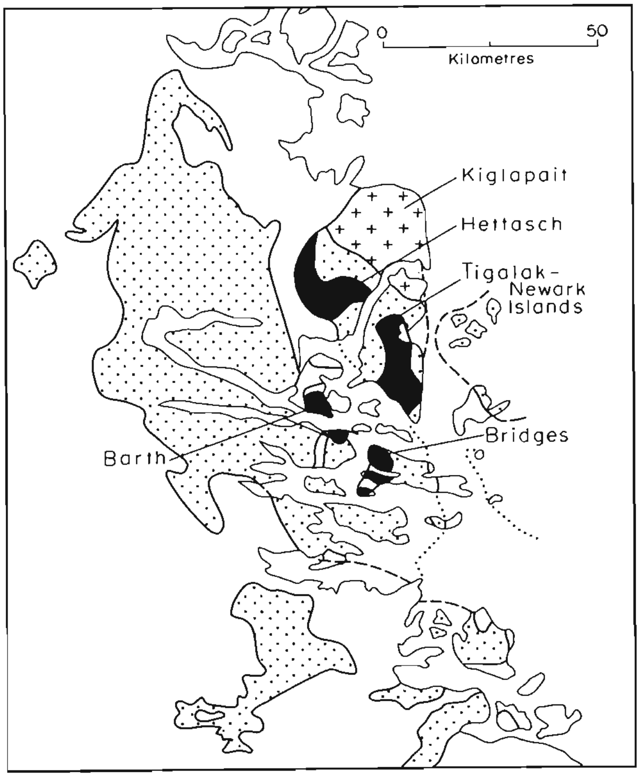

Figure 3: *Layered gabbroic intrusions of the Nain Plutonic Suite (after Morse, 1976); layered intrusions are indicated by name. (For regional location see Figure 1.)*

Michael Gabbro (Emslie, 1983); gabbro–norites of the Red Wine Mountains area (Emslie *et al.*, 1978), and the White Bear Arm gabbro (Gower *et al.*, *this volume*). These suites range from ca. 1650 Ma to 1400 Ma or even younger. Some of them may be genetically related to anorthosite-suite intrusion. A widespread mass of gabbroic rocks also occurs in an area extending southwest of the Mealy Mountains anorthosite (Greene, 1972). Neither the age nor composition of this suite is reliably known, but where examined in detail (Wardle and Crisby, *this volume*) the suite, has been shown to be considerably less extensive than previously thought, and to consist of myriad gabbroic enclaves in granitoid intrusions.

Compositional layering in this class is generally only weakly developed, and the plutons occur as a variety of sheets, stocks and irregular masses, probably representing intrusion at a range of crustal levels. Individual plutons are typically recrystallized, either to coronitic textures, or to amphibolite–granulite-facies metamorphic assemblages.

Only minor mineralization is associated with this class of intrusion. The White Bear Arm gabbro contains a mineralized gossan zone at Mountain Brook, which has yielded assay values of 0.13 percent Ni and 0.15 percent Cu (Douglas, 1976, page 14).

Gabbro–ultramafic sheets and sills (Class 4)

These are high-level intrusions located within or adjacent to supracrustal sequences including comagmatic volcanic rocks. They range in age from Archean to Middle Proterozoic; some may be high-level equivalents of gabbroic intrusions included in Class 3. The 'type example' of this class is found on the eastern margin of the Labrador Trough (Figure 1) where Lower Proterozoic graywacke, shale and pillow lavas are intruded by approximately 6000 m of gabbro and ultramafic sills. The sills, of overall oceanic-tholeiite composition, are typically massive and undifferentiated (the 'normal gabbro sills' of Baragar, 1967). However, on the easternmost side of the trough, they possess central zones of anorthositic gabbro exhibiting glomeroporphyrytic texture, and are typically spatially associated with both peridotite sills and composite peridotite–gabbro sills in which gabbro forms a thin, discontinuous upper layer. Fahrig (1962) and Baragar (1967) have proposed a mechanism of dynamic differentiation during magma flow, rather than fractional crystallization, to account for the development of layering. Presumably, however, the presence of large plagioclase glomerocrysts in the anorthositic gabbros hints at fractional crystallization processes that have occurred at deeper crustal levels.

The gabbroic sills of the Labrador Trough contain few sulfide (pyrite–pyrrhotite–chalcopyrite) showings of known magmatic origin, and most of these are in the Howse Lake area (Douglas (1976). Ultramafic sills, largely exposed in Québec, contain several Cu–Ni showings in serpentinized peridotite, one of which, in the Retty Lake area (Figure 1), has recently yielded encouraging Pt assay values of up to 6.4 grams/tonne over 2.5- to 3-m intersections (Avison *et al.*, oral presentation at the Séminaire d'information sur les activités de la direction générale de l'exploration géologique et minérale du Ministere de l'Energie et des Ressources, Québec, City, December, 1986).

The Middle Proterozoic Seal Lake Group of central Labrador represents another example of sill-swarm development. The group consists of interbedded red beds, shale, quartzite and subaerial basalt flows intruded by numerous diabase and gabbro sills of alkali basalt to tholeiite composition (Brummer and Mann, 1961; Baragar, 1981). The shales, and locally the volcanic rocks of the group, are host to numerous occurrences of native copper and chalcocite (Brummer and Mann, 1961; Ghandi and Brown, 1975). However, there are few occurrences described from intrusive rocks.

The Seal Lake Group basaltic rocks were erupted into a transitional shallow-marine–terrestrial environment during a period of anorogenic crustal rifting (Baragar, 1977). In this sense they are similar to the Permo-Triassic Noril'sk volcanic rocks of the Siberian Platform. Both are also dominated by olivine-basalt compositions. Ni-sulfide and associated PGE mineralization occurs within high-level stratiform intrusions in the Noril'sk area, and by analogy the Seal Lake Group may have similar potential. High-level sills of the Shabogamo Intrusive Suite (Fahrig, 1967; Rivers, 1980), which may be time equivalent to the Seal Lake Group sills (Emslie, 1983), also intrude supracrustal sequences along the northern margin of the Grenville orogen. To the south, rocks of the Shabogamo Intrusive Suite are exposed at progressively deeper crustal levels and are included in Class 3.

The last examples of high-level sheets and sills discussed here are the Archean Florence Lake and Hunt River 'greenstone belts' of the Nain Province (Figure 1). The

Florence Lake group (formerly known as the Ugjoktok supracrustal rocks; Sutton *et al.*, 1972) is a succession of mafic to intermediate volcanic and associated sedimentary and intrusive rocks preserved at low to medium metamorphic grade (Ermanovics and Raudsepp, 1979). The intrusive rocks comprise ultramafites and amphibolites and are locally serpentinized. Several Ni-sulfide showings are known, chief of which is the Baikie showing located in talc–chlorite schist of the Schist Lakes formation. It is unclear, however, whether the host rocks to these showings are derived from intrusive or extrusive (possibly komatiitic?) rock types. Comparisons could be made with Western Australian Kambalda-type deposits; however, there is an apparent scarcity of ultramafite, particularly komatiitic rocks, in the Labrador situation. The Florence Lake group has been fairly thoroughly prospected, at least for its Ni–base-metal–Au potential (e.g., Westoll, 1971). The Hunt River belt consists of metabasalt, amphibolite, variegated schist, felsic gneiss and ultramafic rocks (Ermanovics and Korstgard, 1981), generally at amphibolite facies. The group is not known to host sulfide mineralization, but by comparison with the Florence Lake group has received relatively little exploration attention.

Archean Layered Anorthosite–Gabbro–Ultramafite Intrusions (Class 5)

This class of intrusion occurs principally as sheet-like intrusions within reworked Archean gneisses of the northeastern Churchill Orogen (Taylor, 1979), but also as small podiform bodies scattered throughout the Nain Province, and its reworked extensions in Proterozoic orogens. The intrusions are considered in a separate class from the massif-type anorthosites in view of their overall gabbroic, as opposed to leucogabbroic, composition, and their general highly deformed and recrystallized nature. In their original state, they were probably similar to the layered intrusions of Class 3 and conceivably have similar PGE potential. No mineralization is known from this class of intrusion in Labrador, a feature which is at least in part due to the remote northern location and consequent lack of exploration.

By comparison, the rifted extension of the Nain Province, as seen in west Greenland, contains the well studied Fiskanaesset Complex of layered leucogabbro and peridotite (Windley *et al.*, 1973; Myers, 1975), which hosts subeconomic chromite and associated low-grade PGE mineralization. PGE values are associated with both chromitite layers in ultramafic rocks and, perhaps more significantly, with sulfide-bearing anorthosite and leucogabbro (Page *et al.*, 1980). By comparison, the anorthosites of Labrador, which may hold similar potential, have barely been explored.

Hornblende Gabbro–Diorite–Monzonite Intrusions (Class 6)

This class of hydrous gabbroid is represented chiefly by the Adlavik Intrusive Suite (Figure 1) of eastern Labrador, which forms part of the extensive ca. 1650 Ma Trans-Labrador batholith (Gower and Owen, 1984). Other smaller but similar gabbroic intrusions occur along the northern margin of the Grenville Orogen (Gower and Owen, 1984; Wardle, 1985). The Adlavik suite, as described most recently by Gower *et al.* (1982) and Kerr (1986) consists of clinopyroxene-, hornblende- and biotite-bearing cummulate gabbro; diorite and monzodiorite, including pegmatitic and appinitic phases; and a variety of monzonites and syenites. Pegmatitic gabbros, interpreted by Kerr (1986) as late phases of the Adlavik suite, locally contain minor pyrite and chalcopyrite, and are presumed to result from late-stage hydrothermal fluid activity.

This type of hydrous mafic intrusion is not known to host primary-magmatic sulfide or PGE deposits. However, its fluid-rich nature may indicate significant potential for deuteric or hydrothermal PGE concentration.

Placer Environments (Class 7)

This potential class of deposit has to be considered in association with any of the above igneous suites. Nearly all of the mafic plutonic suites of Labrador form sparsely vegetated, upland areas subject to active erosion. Heavy-mineral concentrations, chiefly of illmenite and magnetite, are common constituents of glaciofluvial sands in the vicinity of these suites, and may offer valuable exploration guides, not only to the location of bedrock mineralization, but also to placer PGE deposits.

SUMMARY

Platinum-Group Elements, in Labrador, as elsewhere, may be reasonably expected to reside in mafic plutonic suites, with the notable exception of placer deposits. Within the overall environment of mafic plutons, PGE may be sought in a range of magmatic, deuteric or hydrothermal environments. With regard to magmatic deposits, exploration can be directed either toward further searches for Ni- or Ni–Cu-sulphide deposits containing by-product PGE mineralization, or toward independent PGE mineralization. Prospective targets for Ni-sulfide-associated PGE mineralization include the gabbro–ultramafic sills of the Labrador Trough, the Ni-bearing ultramafic rocks of the Florence Lake group, and the mixed ultramafic–gabbroic rocks of the Hunt River belt. By analogy with the Noril'sk intrusions, PGE, possibly in association with Ni sulfides, could also be sought in the Seal Lake Group sill swarm and the possibly equivalent Shabogamo and Michael gabbros.

The most obvious potential for discovery of independent PGE mineralization resides in layered gabbroic complexes such as the Kiglapait Intrusion of northern Labrador, the layered parts of the massif-type anorthosite intrusions (in particular the Harp Lake intrusion), the Archean layered gabbro–anorthosite–ultramafite plutons of northern Labrador, and the basal gabbros of the North West River anorthositic suite. The smaller layered bodies of the Nain and Atikonak anorthosite suites may also be worthy of exploration attention.

The potential for hydrothermal PGE mineralization in Labrador is difficult to adequately assess, other than in a general fashion. The Adlavik Intrusive Suite with its obvious fluid-rich character is a potential host for hydrothermal mineralization of magmatic origin. Otherwise, attention might be given to hydrous shear-zone environments in metagabbroic massifs, such as the White Bear Arm gabbro and some of the other gabbroic bodies lying along the northern margin of the Grenville Orogen.

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Note: Mineral Development Division file numbers are included in square brackets.