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A REVIEW OF KIMBERLITIC AND ULTRAMAFIC LAMPROPHYRE INTRUSIVES FROM NORTHERN LABRADOR

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ABSTRACT

Four ultramafic lamprophyre to kimberlite intrusive sites have been recognized in the Archean Nain Province of northern Labrador. Two sites are located within the Hopedale Block, at (1) capes Aillik–Makkovik and (2) Ford's Bight, and two are located within the Saglek Block, in the (3) Saglek and (4) northern Torngat Mountains areas. To date, no diamonds have been found in either intrusive site, but geochemical analysis has been, at best, rudimentary. Group 1 has been previously described as kimberlitic, at least in part, but, to date, no detailed geochemical evaluation of diamond indicator minerals has been completed. The intrusive rocks of Group 2 have only recently been identified as part of a possible kimberlite diatreme; there are no whole-rock or mineral geochemical data yet derived for this suite. The Group 3 suite has been defined as kimberlitic for some time, but spatial and geochemical data have been restricted to unpublished reports. Group 4 dykes were originally classified as ultramafic lamprophyres, but mineral assemblages of some dykes indicate that they are macrocrystal hypabyssal phlogopite–perovskite archetypal kimberlites, whereas the remainder are olivine–phlogopite–calcite ultramafic lamprophyres, possibly melilitites. Sample size, however, was very small for definitive determinations, and one kimberlite has a strike extension classified as lamprophyre. Within the kimberlites, the following minerals were identified: (1) lherzolitic, eclogitic and megacrystal garnets (megacrystal garnets were also found in some of the lamprophyres), (2) clinopyroxenes, which plot in Fipke's diamondiferous CPX domain (as does one lamprophyre), (3) orthopyroxenes with < 1% to 1.5 % Al_2O_3, and (4) olivines with Fo contents of ~ 88-92 (some of the lamprophyres have two populations of olivine with clusters of similar high Fo values). Orthopyroxene and clinopyroxene geothermobarometers suggest a possible harzburgite chemistry for some mineral separates, and also that the postulated geotherm for the intrusive history of the dykes is permissive of diamond stability.

Ages for the different suites are: ca. 1200 to 1130 Ma and ca. 700 Ma for Group 1, 197 to 145 Ma for Group 2, and ca. 1259 Ma for Group 3. Group 4 have not been dated but may be correlative with ca. 546 Ma dykes in the Abloviak Shear Zone of Québec.

INTRODUCTION

Kimberlitic and ultramafic lamprophyric intrusions have been reported from (1) capes Aillik–Makkovik, (2) Ford's Bight, (3) Saglek, and (4) the northern Torngat regions of coastal Labrador (Figure 1). A number of petrological studies, mainly as post-graduate theses, have been done on the dykes in the capes Aillik–Makkovik region (e.g., King, 1963; Hawkins, 1976; Foley, 1982).The Ford's Bight system has been previously recognized as an intrusive breccia (King and MacMillan, 1975), but recently it has been suggested that the breccia might represent a diatreme (Wilton *et al.*, 2001b) and there has been no geochemical work (either mineral or whole rock) completed. The Saglek dykes have been reported on since 1977, but actual information on them remains sketchy and is based on a single published abstract (Collerson and Malpas, 1977). The Torngat dykes have only recently been documented as kimberlites (Wilton, 2000b; Wilton *et al.*, 2001a) and have had preliminary mineral chemistry completed on diamond indicator minerals, such as garnet; this geochemical work is reported here.

This project was initiated to (geochemically) examine known, or postulated, kimberlite and ultramafic lamprophyres from northern Labrador. The ultimate aim of the research is to evaluate and compare their relative economic significance. The data will also be important from a broader

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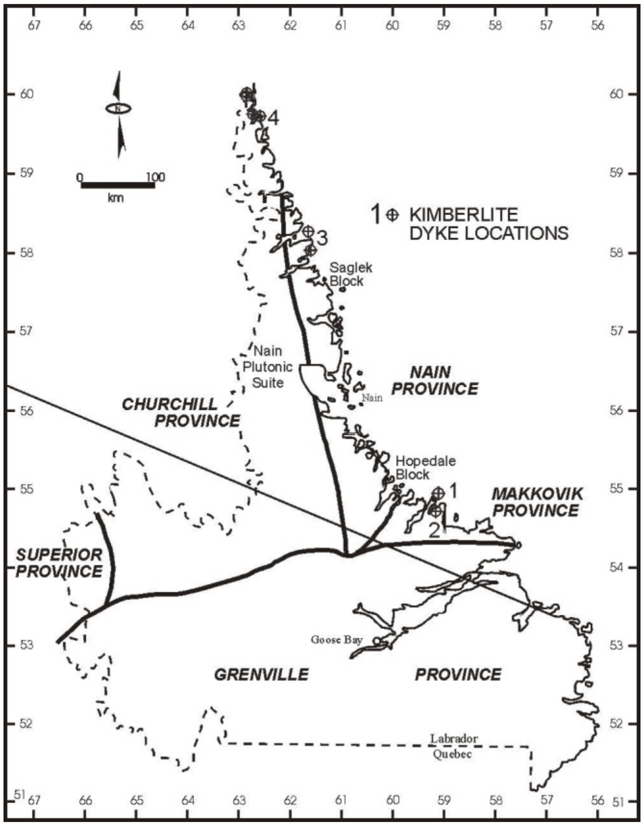

Figure 1. *Location of kimberlite and ultramafic lamprophyre dykes in Labrador.*

scientific perspective as it will provide spatial and temporal information on mantle compositions beneath the Nain Province. The geochemical studies will involve (a) high-precision X-Ray Fluorescence (XRF) analyses of whole rocks, (b) Sm–Nd and Rb–Sr isotope analyses, (c) Laser Ablation Microprobe Inductively Coupled Mass Spectrometer (LAM-ICP-MS) and electron microprobe analyses of mineral phases, and (d) LAM-ICP-MS (and possibly Thermal Ionization Mass Spectrometer (TIMS)) age dating of suitable mineral phases.

THE CAPES AILLIK–MAKKOVIK DYKES AND PIPES

The capes Aillik–Makkovik dykes and pipes have been described by King (1963), Hawkins (1976), Foley (1982) and Malpas *et al.* (1986). Foley (*op. cit.*) and Malpas *et al.* (*op. cit.*) proposed the name allikites for some dykes that would have been termed "central-complex kimberlites". These authors also derived whole-rock geochemical data on the dykes and limited major oxide data on pyroxene, olivine, mica, K-feldspar, and magnetite phases. McConnell and Ryan (1995) report a 585 ± 2 Ma U–Pb date for perovskite from an aillikite dyke. The K–Ar dating of the dykes indicates two distinct emplacement events at ca. 1200 to 1130 Ma and ca. 700 Ma (Collerson, 1993). The earlier work does not seem to have distinguished the dykes–pipes on the basis of this different chronology, and Collerson (*op. cit.*, p. 36) admits that "the terminology used to classify the dikes has been confusing". Ryan and McConnell (1995) provided an appendix on "Nomenclature of Lamprophyric Rocks at Aillik Bay". To date there have been no major-element geochemical analyses carried out on indicator minerals for comparison with diamond field discrimination diagrams (*cf.*, Fipke *et al.*, 1995), no Ni or other trace-element thermometry calculations, and no pyroxene geobarometry determinations for these dykes.

THE FORD'S BIGHT DIATREME

King and McMillan (1975, p. 44) reported a "flat-lying breccia ‘bed'" cut by "lamprophyre" dykes at Ford's Bight, ~20 km southeast of the Cape Makkovik dykes. They also reported microfossils from the breccia that were dated as being between Early Jurassic (< 197 Ma) and Early Cretaceous (> 145 Ma). Re-mapping of the "bed" in 2001 (Wilton *et al.*, 2001a) suggests that it represents a very large diatreme with some kimberlitic characteristics, including ultramafic inclusions. The diatreme crops out intermittently over a lateral distance of at least 500 m in the low-tide portions of a beach on the southeast side of the bight (Plate 1); King and McMillan (1975) report that the outcrops are exposed for 2 km. Fragmental rocks are present as separate isolated blocks in the beach sand, but the full extent of the diatreme is not visible and the contacts with country rock are not exposed. The diatreme is apparently intrusive into proximal ca. 1860 Ma Upper Aillik Group felsic volcanic rocks (Scharër *et al.*, 1988) and it consists of heterolithic breccia cut by lamprophyre dyke material (Plate 2). Lamprophyre also generally constitutes the groundmass to the breccia.

Fragments in the diatreme range up to 15 cm across, but generally average 3 to 8 cm. The fragments are angular to very well rounded, and range from ultramafic rocks to lamprophyre, to white-weathering Upper Aillik Group felsic volcanic rocks (Plate 3). These latter fragments are locally sourced, yet typically are the best rounded, indicating that they were probably abraded in a high-pressure, explosive, volcanic environment as opposed to a detrital weathering environment. King and McMillan (*op. cit.*) report fragments, up to 30 to 50 cm in diameter, of "quartzite" (Upper Aillik Group felsic volcanic rocks) in breccia. Carbonate is present as cement to some portions of the breccia and also as amygdules within lamprophyre fragments and dykes. There are no geochemical data for this latest event at Ford's Bight.

Plate 1. *Scattered subcrop exposures of the Ford's Bight diatreme.*

Plate 2. *Ultramafic lamprophyre (kimberlitic ?) dyke in the Ford's Bight diatreme.*

If the mid-Mesozoic fossil age of the diatreme matrix is correct (i.e., 197 to 145 Ma), then there were possibly three periods (1200 to 1130, 700 (or 585) and 197 to 149 Ma) of kimberlitic intrusion in this region.

THE SAGLEK DYKES AND PIPES

Collerson (1993) reported that kimberlite dykes and pipes are present at two localities in the Saglek Fiord region of northern Labrador; these were Big Island and White Point. McConnell and Ryan (1996), however, suggest that the White Point breccias are not kimberlite pipes. B. Ryan (written communication, 2002) describes the White Point examples as basaltic–diabasic breccia dykes that have a chloritic rock flour matrix. According to Collerson (*op. cit.*) the dykes are 1 to 2 m wide and 200 to 500 m long. He reported (i) that the dykes have similar geochemical compositions to published data on kimberlites, (ii) that the mineral chemistry for olivines and phlogopites indicates that these minerals plot in fields for kimberlite and micaceous kimberlite, respectively, and (iii) that K/Ar isotopic analyses indicate an emplacement age of ca. 1259 ± 16 Ma for these dykes. These Saglek dykes were the objects of extensive sampling and mapping by the Diamond Field Resources–Archean Resources joint-venture project in 1993, but no data from that investigation have been published.

Plate 3. *Carbonate-cemented breccia in Ford's Bight diatreme containing fragments of Upper Aillik Group felsic volcanic rocks (white) and lamprophyre (black).*

THE TORNGAT DYKES

Wardle *et al.* (1994) reported a series of dykes in the Torngat Mountains of northernmost Labrador and Killiniq Island (southernmost Nunavut), which they suggested were part of the kimberlite–lamprophyre clan (Figure 2). They described the dykes as dark-grey to black, recessively weathering ultramafic lamprophyres, having local olivine nodules, and, while noting that their absolute age was unknown, grouped them as Phanerozoic dykes.

Ryan (1993) noted the geological correlation between western Greenland and northern Labrador and suggested that diamondiferous kimberlitic dykes similar to those of western Greenland may be present in Labrador. He suggested that the ultramafic lamprophyres reported by Wardle *et al*. (1994) might actually be kimberlites.

Digonnet *et al.* (1996) completed detailed examinations of similar posttectonic mafic dykes in the Abloviak shear zone to the south of the northern Torngat dykes and described the dykes as kimberlites. Their work included age dating, which indicated a common Early Paleozoic age with the Greenland dykes, and Nd isotope work, which indicated ϵNd values likewise similar to those in the Greenland examples. Digonnet *et al.* (2000) provided more detailed data on the dykes, terming them ultramafic lamprophyres, and specifically, aillikites. They concluded (*op. cit.*, p. 531) that "a significant diamondiferous alkaline province is present in northeastern North America".

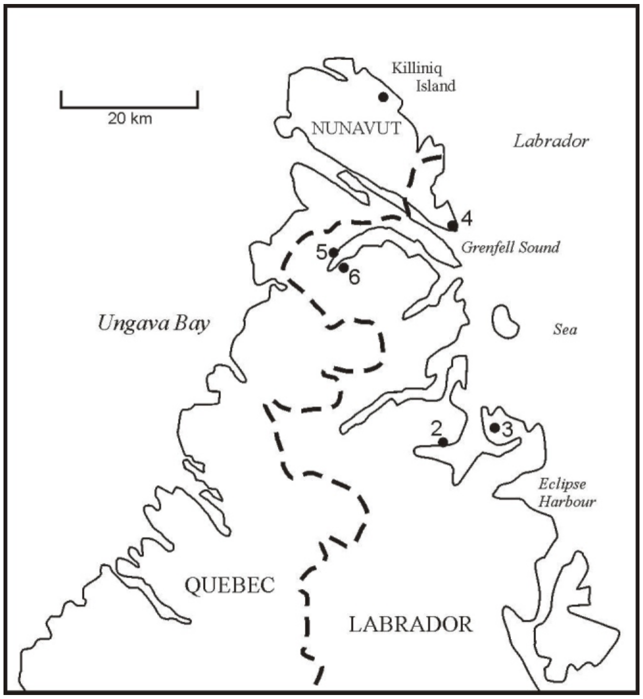

Figure 2. *Location of ultramafic lamprophyre dykes in northern Labrador (from Wardle* et al.*, 1994); dyke numbers are those assigned by Copper Hill Resources Inc. (Wilton, 1998); dyke #1 not shown.*

Digonnet *et al*. (1997) reported finding a gem-quality macrodiamond within one of these Ungava Bay dykes. Extensive exploration work by Twin Mining Ltd. (Davis *et al*., 2001) has indicated that a number of, what they termed, kimberlitic dykes in the Abloviak shear zone are diamondiferous.

Copper Hill Resources Inc. of St. John's, Newfoundland, staked five dykes as mapped by Wardle *et al.* (1994) in Labrador (Figure 2). These dykes are termed the Mount Ikordlearsuk dyke (Dyke 2), the Iselin Harbour dyke (Dyke 3), the Tunnissugjuak Inlet dykes (Dykes 5 and 6), and the Grenfell Sound dyke (Dyke 4). Exploration work on these dykes was conducted by Wilton (1998; 2000a) and Wilton and Taylor (1999), and was limited to reconnaissance mapping and whole-rock, stream-sediment and soil sampling. The main objectives of the exploration programs were to (i) determine the precise locations of dykes as shown on the map of van Kranendonk and Wardle (1995), (ii) to examine their size and nature, and (iii) to ascertain if they have any characteristics in common with kimberlites. Due to the reconnaissance nature of the exploration, sample size was restricted to < 20 kg for whole-rock samples and < 3 kg for steam-sediment and soil samples. The rock samples were sent to the Kennecott Canada laboratories where Dykes 3 and 5 were subsequently identified as being kimberlitic (Masun, 1999; Wilton, 2000b).

Grenfell Sound Dyke (Dyke 4)

Wardle *et al.* (1994) indicated the presence of an ultramafic lamprophyre at Grenfell Sound, but it is not shown on a subsequent map by van Kranendonk and Wardle (1995). The latter shows the area to be underlain by buff-weathering granulite-facies gneiss (Unit *Agn*), supracrustal gneiss (Unit *Ams*) along the SW corner, and a mafic gneiss (Unit *Amf*) along the northeast. During the 1998 exploration program (Wilton and Taylor, 1999), an ultramafic dyke, up to 1.5 m wide, exhibiting quartz-filled tension gashes, and having pyroxene crystals up to 1 cm across, was found to intrude the gneisses at this location, but the dyke is not an ultramafic lamprophyre. It is instead a pretectonic, amphibolitized pyroxenite.

Tunnissugjuak Inlet Dykes (Dykes 5 and 6)

The map of van Kranendonk and Wardle (1995) indicated lamprophyre dykes (Unit *Ud*) in this area are hosted by homogeneous, massive to foliated, orthopyroxene-bearing granodiorite–tonalite, or enderbite (Unit *Pigd*; Figure 3a).

The two dykes are exposed along opposite shorelines of the inlet (Plate 4), and Wilton (1998) suggested that the dyke exposures probably constitute a single dyke. The southeastern dyke is 1 m wide and contains numerous cavities wherein crystals and/or xenoliths are weathered out. Carbonate veinlets are abundant, and carbonate is present in the groundmass. Xenoliths of glassy material, up to 1.5 cm in diameter, are widespread. The northwestern dyke is on the order of 3 m wide and has very abundant xenoliths (including eclogite? - Plate 5) and xenocrysts (some of which are spinel). Carbonate is quite common.

Mount Ikordlearsuk Dyke (Dyke 2)

The map of van Kranendonk and Wardle (1995; Figure 3b) shows this dyke (Unit *Ud*) as being intruded into Unit Apanl (granoblastic amphibolitic gneiss) with enclaves of Unit *Agn* (buff-weathering granulite-facies gneiss). There is a small sliver of Unit *Pspg* (paragneiss and metasedimentary migmatite) along the western boundary. Although, the aforementioned map shows the dyke along a scree slope; Wilton and Taylor (1999) found that, in fact, it crops out along the shoreline. The dyke is perpendicular to the fabric of the host amphibolitic gneiss and ranges from 0.4 m wide to <1 cm. The dyke and smaller dykelets parallel a well-defined cleavage within the host gneiss but none are deformed and the dykes are clearly the youngest rocks in the area (Plate 6). Along some vertical surfaces the dyke exhibits an explosive (brecciated) texture with the host rock (Plate 7). The dyke contains carbonate amygdules (3 to 5

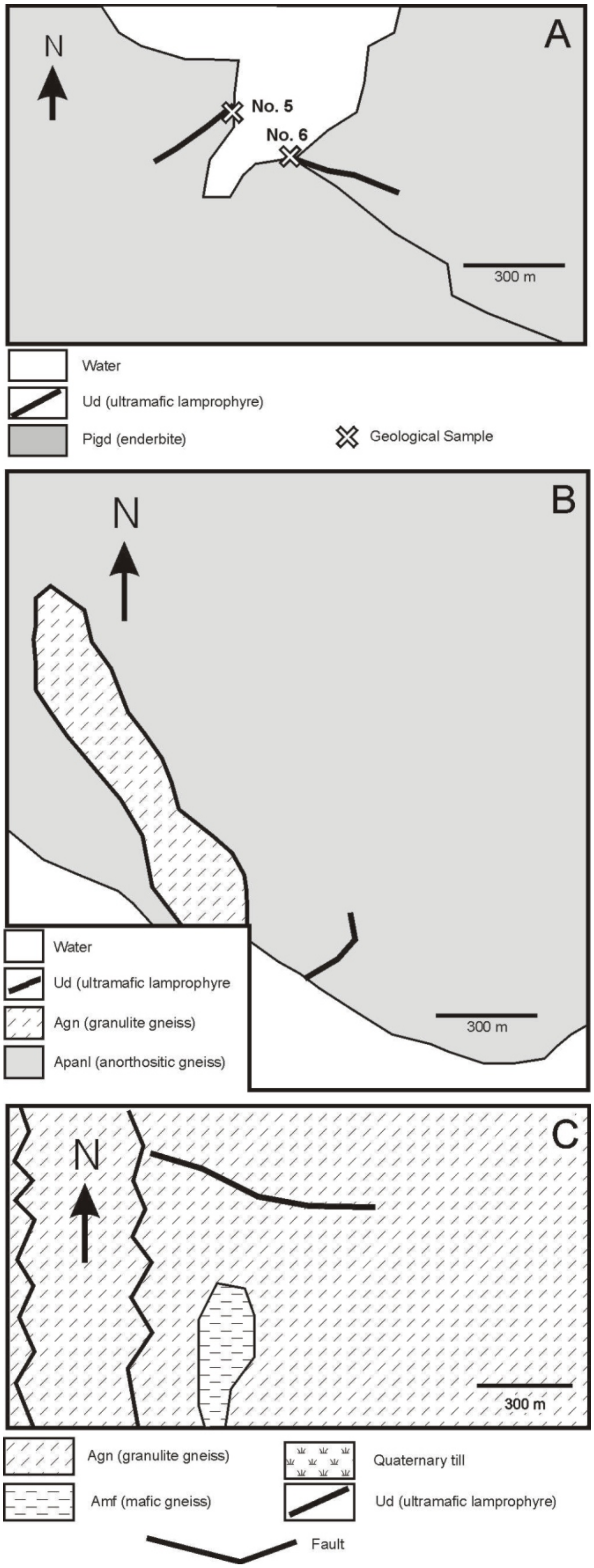

Figure 3. *(a) Geological setting of the Tunnissugjuak Inlet dykes; (b) Geological setting of the Ikordlearsuk Mountain dyke; (c) Geological setting of the Iselin Harbour dyke (from van Kranendonk and Wardle, 1995).*

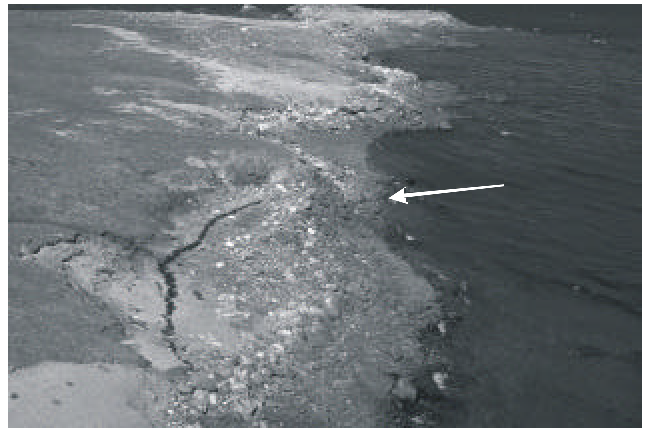

Plate 4. *Outcrop of Dyke 5 on shoreline of Tunnissugjuak Inlet (black, centre).*

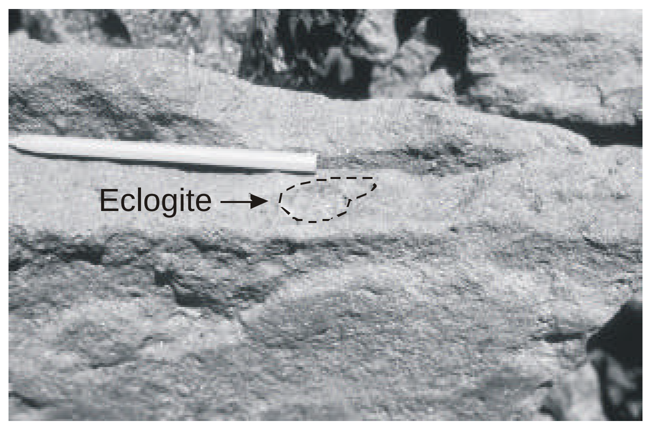

Plate 5. *Ecolgitic xenolith (below right end of pen) in Dyke 6, Tunnissugjuak Inlet.*

mm in diameter), olivine phenocrysts(?)/macrocrysts(?), rare sulphides, glass, and garnet xenocrysts. There are also wall rock and other xenolithic inclusions.

Iselin Harbour Dyke (Dyke 3)

This dyke according to van Kranendonk and Wardle (1995; Figure 3c) has been intruded into an area underlain by buff-weathering granulite-facies gneiss (Unit *Agn*) having small enclaves of mafic gneisses (Unit *Amf*). This 0.5-km-long, east–west-trending ultramafic lamprophyric dyke

Plate 6. *Ultramafic lamprophyre dyke at location 2; the dyke cuts the host gneissic fabric and and has a chilled rim.*

Plate 8. *Weathered fracture in which Dyke 3 is located (photograph was taken on a foggy day).*

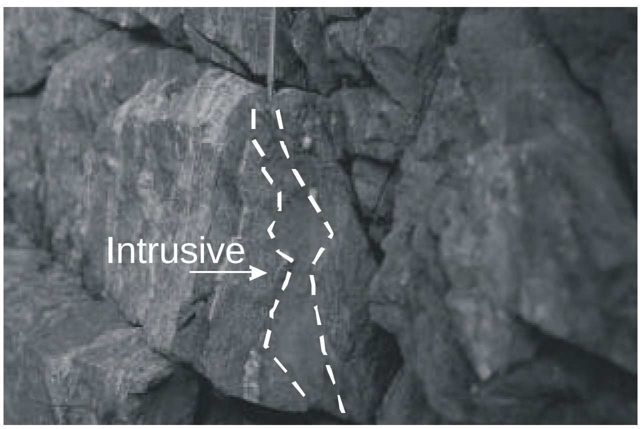

Plate 7. *Explosive pipe-like intrusion of Dyke 2 (to right of pen and amphibolite layer).*

Plate 9. *Olivine macrocrysts in soil developed on Dyke 3.*

(Unit *Ud*) (Wilton and Taylor, 1999) is actually located 150 m to the south of where it is plotted on the van Kranendonk and Wardle (1995) map. The dyke occurs within a 2-m-wide, roughly east-west-trending, fracture zone that runs for at least 750 m (Plate 8) and is orientated perpendicular to the fabric of the host gneiss. The dyke is not exposed within the fracture zone, but its presence is indicated by frost-heaved subcrop. Its subcropping form and variable lateral nature imply the dyke may actually be pipe-like. The dyke rock contains numerous olivine and garnet macarocrysts and the soil immediately overlying the dyke contains abundant olivine macrocrysts (Plate 9).

Petrographic Analyses

Masun (1999) conducted petrographic examination of whole-rock samples from the different dykes of the northern Torngat area, and according to his work, the dyke from the southern shore of Tunnissugjuak Inlet (Dyke 6) and the dyke from Iselin Harbour (Dyke 3) are "oxide-rich, uniform-to-segregation-textured macrocrystal hypabyssal phlogopite perovskite archetypal kimberlites" (Masun, 1999, p. 1). The samples from the northern shore of Tunnissugjuak Inlet (Dyke 5)and Ikordlearsuk Mountain (Dyke 2), on the other hand, are "olivine phlogopite calcite ultramafic lamprophyre, possibly melilitite" (*op. cit.*, p. 2).

Kivi (1999a) described mineral processing and heavy-mineral segregation carried out on the whole-rock samples; 547 microprobe analyses were carried out on some of the mineral separates. Minerals identified and separated from the kimberlites (Dykes 3 and 6) include olivine, enstatite, clinopyroxene, pyrope (peridotitic) garnet, pyrope–almandine ss garnet (eclogitic garnet Type II), megacrystic garnets, ilmenite and chrome spinel. The other dykes contain olivine, ilmenite, megacryst suite garnet, and chrome diopside. Kivi (*op. cit.*, p. 4) concluded that Dyke 3 "had the most promising chemistry, followed by Dyke 6. The lamprophyres are also likely deep sourced, but do not contain significant amounts of mantle xenocrysts".

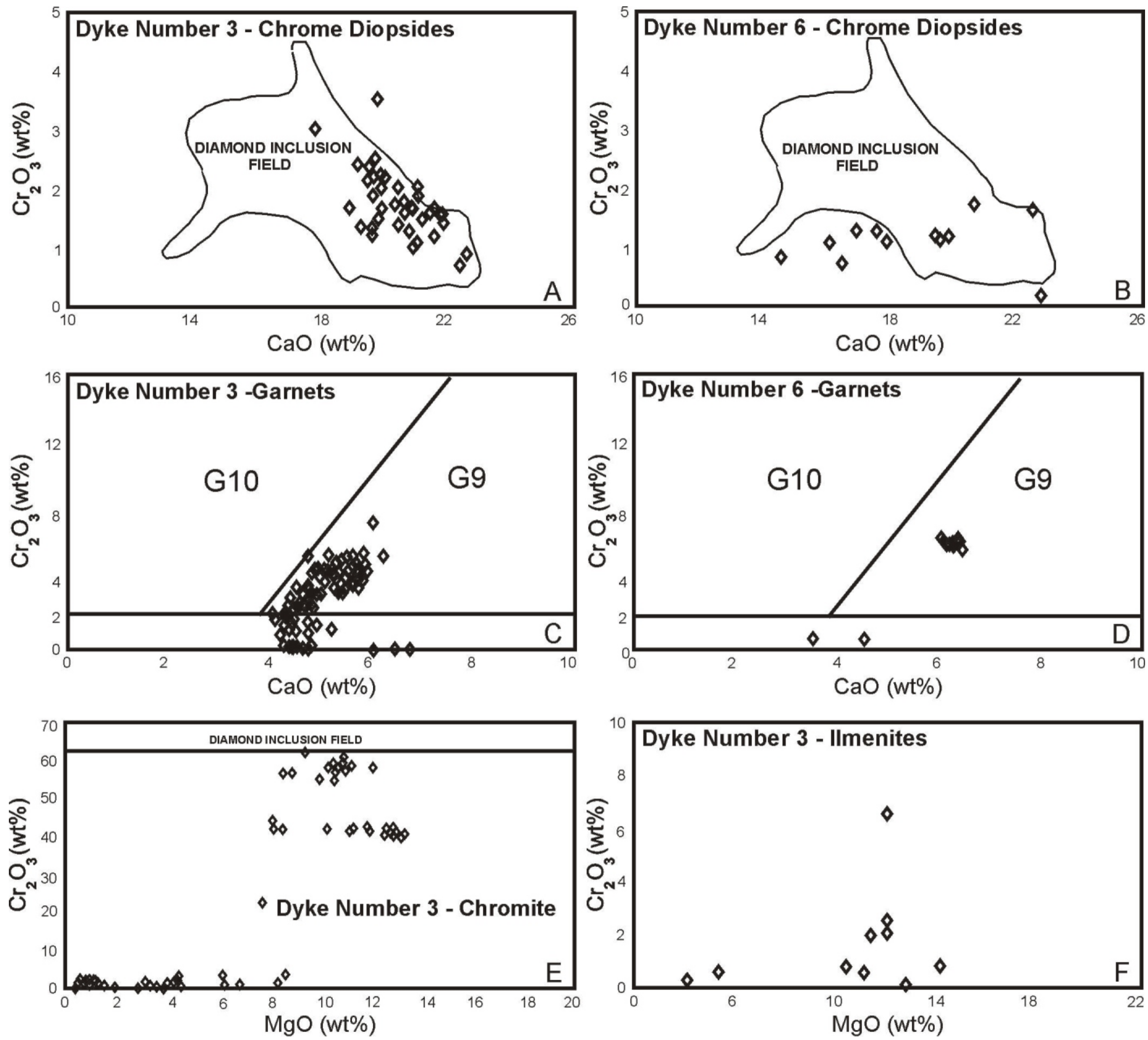

Figure 4. *Geochemical variation diagrams for mineral separates from kimberlitic dykes 3 and 6 (after Kivi, 1999a).*

Figure 4 (from Kivi, 1999a) shows geochemical data for diamond indicator minerals separated from Dyke Numbers 3 and 6 plotted on standard diamondiferous discrimination diagrams (*cf.*, Fipke *et al.*, 1995); possibly due to the small sample size, only sufficient garnet and chrome diopside were derived from the Dyke No. 6 sample. Both dyke samples have chrome diopsides that plot in the diamond inclusion field (Figures 4a and b); two chrome diopside grains from Dyke 5 also plot in the diamond inclusion field. Garnets from Dyke 6 are G9 (or lherzolitic; Fipke *et al.*, 1995), whereas one from Dyke 3 spreads into the G10 (or harzburgitic; *op. cit.* Figures 4c and d). Fipke *et al.* (1995) suggested that subcalcic G10 garnets are associated with diamonds (or at least 85 percent of diamond inclusion garnets have G10 compositions). Fipke *et al.* (*op. cit.*) also suggested that garnets with < 2% Cr_2O_3 are ecologitic or megacrystic. Numerous garnets from Dyke 3 and two from Dyke 6 plot below 2% Cr_2O_3, which may be interpreted to indicate that the kimberlites sampled different garnet sources.

Some chromite in Dyke 3 plot within or close to the diamond inclusion field on Figure 4e. There are also large populations with medium and low Cr_2O_3 contents, once again suggesting that the kimberlite has sampled material from different sources/regions. There also appears to be at least two populations in ilmenite from Dyke 3 (Figure 4f).

Kivi (1999b) reported on the analyses of 22 stream-sediment samples and one soil sample. The samples were processed for indicator minerals, which were subsequently identified by microscope analyses. He found (*op. cit.,* p. 3) only "a sparse population of indicator minerals, aside from VR11386A, located on top of DYKE 6". He incorrectly identified the location of this sample as it was actually the soil sample from on top of Dyke 3. Indicator minerals collected from the samples included olivine, clinopyroxene, pyrope (peridotitic) garnet, and zoned chrome spinel. Electron microprobe analyses weren't completed on these samples. Subsequent caustic fusion analyses of a 6 kg sample from Dyke 3 (Kivi, 1999c) failed to yield any diamonds.

Orthopyroxene (opx) and clinopyroxene (cpx) geothermobarometers (Doyle, 1999) indicate a possible 43-46 mW/m^2 geotherm for Dykes 3 and 6. Using the opx geothermobarometer, more samples plotted in the diamond field than with the cpx one. Some of the opx had harzburgite chemistry. Combining both geothermobarometers suggests a geotherm for the intrusive history of the dykes that is permissive of diamond stability.

CONCLUSIONS

Four sets of kimberlite to ultramafic lamprophyre intrusions have been mapped in the Nain Province of northern Labrador. The two suites in the northernmost Saglek Block in the Torngat Mountain and the Saglek areas have been identified petrographically as true kimberlites; geochemical data from the Saglek suite are unpublished. The capes Aillik–Makkovik set are likewise, at least in part, kimberlite, but the lithological nomenclature is confused, and the geochemical database is poorly developed (i.e., modern mineral chemistry comparisons with published data on kimberlites are lacking). The Ford's Bight diatreme has had no geochemical nor petrological examination. Diamonds have not been identified in any of the suites, but parts of at least one Torngat Mountain dyke contain the diamond indicator minerals G10 garnet and chrome diopside. Much more detailed sampling and mineral analyses must be carried out on these suites to fully ascertain their diamond potential. The main conclusion to be drawn from this review, however, is that the Nain Province of Labrador remains a significant target for diamond exploration.

ACKNOWLEDGMENTS

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Bridgwater *et al*. (1990, p. 253) report a kimberlitic or lamproitic dyke 1 km south of Hebron that contains “olivine-rich nodules” and “garnet-bearing inclusions”. They also noted blocks of lamproitic or kimberlite in the Saglek-Hebron area.

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