CHAPTER 11

LATE LABRADORIAN MAFIC AND ANORTHOSITIC INTRUSIVE BODIES (AND CLOSELY ASSOCIATED GRANITOID ROCKS) (P_{3C} 1660–1600 Ma)

11.1 INTRODUCTION

Gower and Krogh (2003) introduced the concept of trimodal mafic–anorthositic–monzogranitic magmatism as an alternative to the established acronym AMCG (anorthosite–monzonite/mangerite–charnockite–granite), arguing that AMCG has the following shortcomings:

i) it does not adequately recognize associated, volumetrically important, mafic rocks,
ii) it overemphasizes the role of charnockite and granite, and
iii) it carries with it anorogenic tectonic-setting conceptual overtones that do not seem to be appropriate in the Labradorian context. Either term, however, is tolerated for the rocks addressed in this section.

The mafic component of the trimodal magmatism is mostly represented by hydrous, commonly layered, mafic intrusions. Rock types represented include lherzolite, troctolite, olivine gabbronorite, pyroxenite, norite, and gabbro, and are associated with leuconorite, leucogabbro, monzonorite, pyroxene–hornblende monzonite, locally grading into syenite or granite (and their metamorphic derivatives). In eastern Labrador, the best-known bodies include the Adlavik Intrusive Suite in the Makkovik Province, the Grady Island layered intrusion in the Groswater Bay terrane and the White Bear Arm complex. Intrusive ages for mafic rocks in the Mealy Mountains intrusive suite have yet to be obtained, but amphibolites derived from mafic dykes have yielded 1640–1630 Ma metamorphic dates (Gower *et al.*, 2008b).

The anorthositic component of the trimodal magmatism is well represented in the Mealy Mountains intrusive suite and in parts of the White Bear Arm complex. Anorthositic rocks in the MMIS include leucotroctolite, leuconorite and anorthosite (Emslie, 1976). Leucotroctolite is mostly in the southwest part of the complex (Kenemich massif), whereas anorthosite and leuconorite are dominant in the northeast (Etagualet massif). Pegmatitic pods cogenetic with leuconorite crystallization in the Etagualet massif have yielded ages between 1655 and 1630 Ma (Bybee *et al.*, 2015). Farther south in the MMIS, the Crooks Lake anorthosite has an age of 1632 Ma. Another potentially relevant unit is the Alexis River anorthositic intrusion (ARAI), which has already been addressed in Section 9.1, where the assumption was made that it is early Labradorian. The reality check introduced here is that such is not established, and it could be coeval with the rocks addressed in this chapter.

Trimodal monzogranitic magmatism covers the compositional range from monzodiorite to granite, although monzonite is volumetrically dominant. Some rocks have been termed syenite. Association between monzogranitic and mafic rocks ranges from intimate–complex to mutually independent. Monzogranitic rocks normally form bodies separate from anorthositic units, although it is not uncommon to find enclaves of anorthosite in monzonite (but rarely the reverse). Monzogranitic rocks in the eastern MMIS have ages between 1645 and 1635 Ma (Emslie and Hunt, 1990). There are also some granitic bodies in eastern Labrador emplaced at about the same time that do not have apparent spatial links to mafic or anorthositic rocks. Three dated examples are i) the Cartwright alkali-feldspar granite at the Hawke River–Groswater Bay terrane boundary, ii) the Double Mer granite in the western Groswater Bay terrane, and iii) the Middle Eagle River granite in the Mealy Mountains terrane. These are addressed in Chapter 12.

The division between the three trimodal groups is not always clear, as some mafic and anorthositic bodies have intimately associated granitoid rocks and, equally, some granitoid bodies have anorthositic and mafic rocks. The organizational policy adopted is to assign a particular intrusion to one or other category based on the dominant rock types, but to then deal with all the component rock types in the body, regardless of composition. Within each category, the intrusions are considered on a terrane-by-terrane basis, from north to south, but first addressing intrusions in the Cape Harrison domain of the Makkovik Province.

Representative stained slabs of units addressed in this chapter are presented in Appendix 2, Slab images 11.1 (Cape Harrison domain), 11.2 (Groswater Bay terrane), 11.3 (Hawke River terrane), 11.4 (Lake Melville terrane), and 11.5 and 11.6 (both for the Mealy Mountains terrane).

11.2 CAPE HARRISON DOMAIN, MAKKOVIK PROVINCE

In the text following, the Adlavik Intrusive Suite is reviewed as a 'type' intrusion, then four other units are addressed for which a coeval age has been inferred as probable (these are the Kokkorvik dykes, the Pamiulik Point mafic intrusion, the False Cape mafic-monzonitic intrusion, and the West of Brig Island mafic intrusion), and, finally, a summary is given for other mafic rocks in the Makkovik Province that are possibly coeval, but for which age constraints are mostly lacking.

11.2.1 ADLAVIK INTRUSIVE SUITE

The Adlavik Intrusive Suite comprises layered gabbroic and dioritic rocks underlying about 200 km^2 in the Adlavik Bay area in the Makkovik Province. The suite is situated at the fringe of the region addressed in this report and is partly outside it (Figure 11.1). The author has not carried out any mapping of the rocks in the intrusion and has only examined it briefly at a few coastal localities, thus this summary is based mostly on the studies of others. It is felt here that it is important to address this work in some detail because the body has been regarded as the 'type' representative of extensive comparable and coeval mafic magmatic rocks that are found throughout the northern half of eastern Labrador and have been long referred to as 'Adlavik-type correlatives'.

Among the earliest reports of gabbroic rocks in the Adlavik Bay area were those of Gandhi *et al.* (1969) and Stevenson (1970), who refer to the body as the Adlavik gabbro and Adlavik Bay gabbro, respectively. Both recognized that the mafic intrusive rocks were younger than the mid-Paleoproterozoic Aillik Group, and that linkage existed between layered gabbroic rocks and associated diorites.

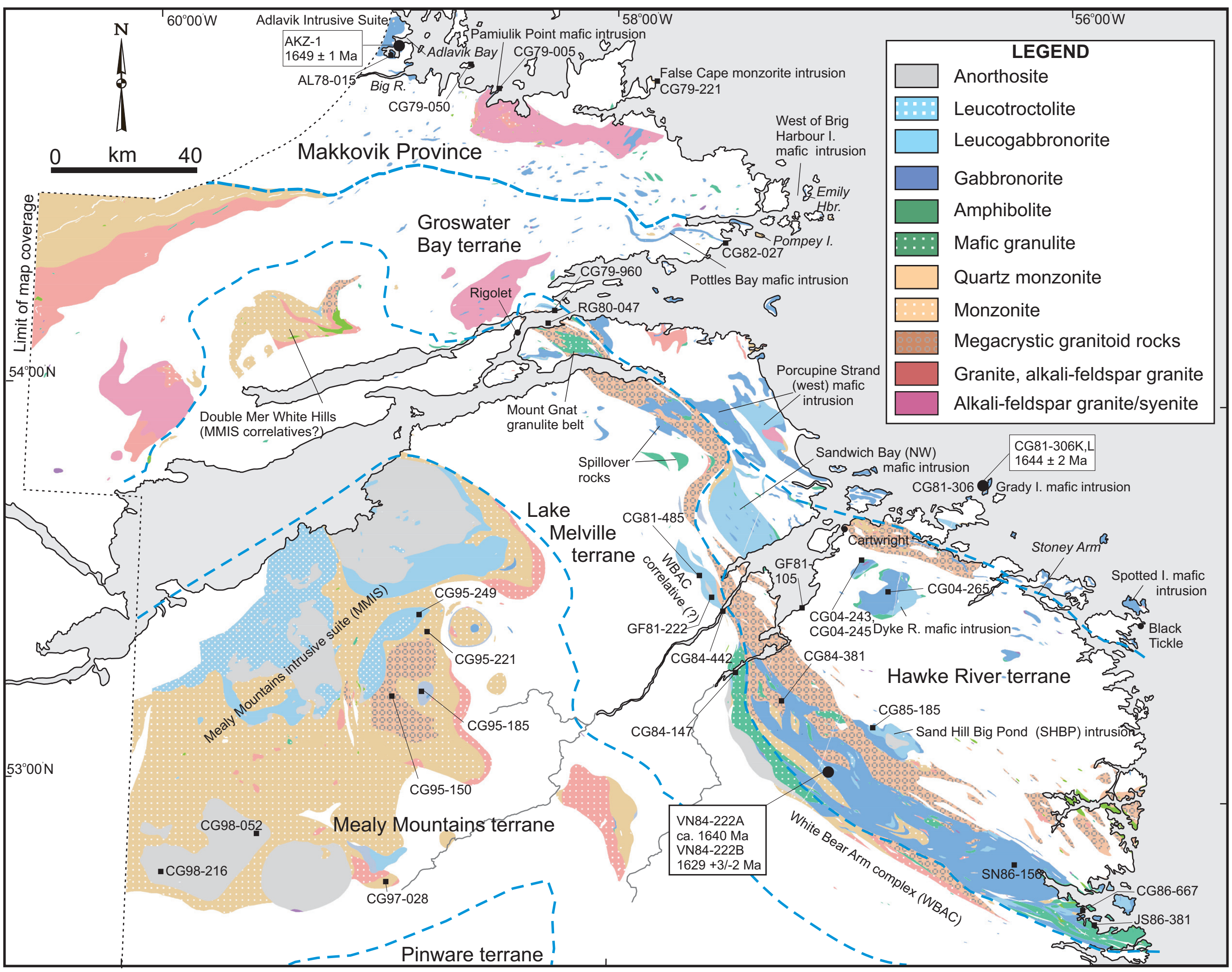


Figure 11.1. *Late Labradorian intrusive rocks focusing on mafic and anorthositic rocks and closely associated granitoid rocks.* See *next chapter for other late Labradorian granitoid rocks (left unlabelled in this figure).*

Gandhi *et al.* (1969) suggested that the body had a lopolithic structure, an interpretation adopted by Clark (1973, 1979). Clark (1979) applied the name Adlavik igneous complex and subdivided the intrusion into five 'facies'. These are briefly reviewed below, as revised and augmented by Kerr (1989a, 1994). After Clark, further description of the rocks was given by Gower (1981) and Gower *et al.* (1982a), mostly based on field notes and samples collected by A. Lalonde during 1:100 000-scale mapping by the Geological Survey of Newfoundland and Labrador in 1978 (Bailey *et al.*, 1979). Gower (1981) modified the name to Adlavik Intrusive Suite to conform to current nomenclature practices, and that name is still current.

The age of the Adlavik Intrusive Suite is known from a U–Pb concordant zircon age of 1649 ± 1 Ma dating a monzonite, interpreted to be part of the suite (Kerr and Krogh, 1990; Kerr *et al.*, 1992; sample AKZ-1; *a.k.a.* potassic monzodiorite; Kerr, 1994). The age of the associated mafic rocks is only geochronologically constrained by a K–Ar hornblende (recalculated) age from a grey-green gabbro of 1550 ± 56 Ma (Wanless *et al.*, 1973; sample GSC72-139). A minimum age for the gabbroic rocks is indirectly provided by dykes of granite that intrude the Adlavik Intrusive Suite and are comparable to the Monkey Hill granite, for which Kerr *et al.* (1992) reported a U–Pb zircon age of *ca.* 1640 Ma. Sm–Nd isotopic data yielded values of T_{DM} = 2038 Ma and 2060 Ma, and εNd (1.65 Ga) = +0.20 and –1.18 (samples 1173 and AKZ-1, respectively).

As Kerr (1994) has commented, the Adlavik Intrusive Suite is a multi-component intrusion and assessment at regional scale can hardly do justice to its many complexities. Nevertheless, some agreement exists at least that it can be broadly subdivided into gabbroic and dioritic rocks. With respect to its three-dimensional form, Kerr (1994,; his Figure 9) offers an imaginative and plausibly valid cross-sectional sketch of the overall geometry of the body and internal relationships between various subunits. He notes that, although primary layering is common, attitudes are inconsistent over short distances and little assurance offered that layering reflects overall orientations of lithological units.

11.2.1.1 Gabbroic Rocks (P_{3C}rg, P_{3C}ln, P_{3C}mn)

Gabbroic rocks in the Adlavik Intrusive Suite correspond to Unit 13 of Gower (1981), Unit 22a of Gower *et al.* (1982a), Unit 24 of Kerr (1994), and units P_{3C}um, P_{3C}rg, P_{3C}ln and P_{3C}d of Gower (2010 – Big River and Benedict Mountains map regions). Kerr (1994) classified the rocks into six subunits, which are partly equivalent to four of the five facies of Clark (1973) – the fifth facies is diorite (*see* next section). The information presented below is summarized from Kerr (1994).

Marginal gabbro and diabase. This subunit is best exposed in the Big Bight area and is also found around the western edge of the body, where it forms a thin (normally <5 m) discontinuous margin against the Aillik Group. It equates with Clark's basal chilled margin facies. It is grey-weathering, fine to medium grained, and has an equigranular, diabasic texture. It also occurs as rounded xenoliths in coarse gabbro, a feature suggested by Kerr (1994) to record disruption of the chilled margin by a slightly later magma (*cf.* Pamiulik Point intrusion, Section 11.2.3, for a similar texture).

Mafic cumulate facies. This corresponds partly to the rhythmic layered facies of Clark (1973). It is well exposed at Big Bight, where it forms the base or side of the intrusion. It is also present locally in the leucogabbro facies and the diorite unit. Rhythmic layering, igneous-graded bedding, and igneous crossbedding are well developed. Kerr (1994) recognized two irregular cyclic units commencing with coarse-grained ultramafic rocks (dominated by hornblende and biotite, after pyroxene). These are interlayered and overlain by layered gabbro and gabbronorite, and, at the top, gabbroic pegmatite.

Melagabbro facies. This subunit includes two of Clark's (1973) facies, namely his massive gabbro facies and his massive diabase facies. The rocks are dark-grey to black, coarse grained and grade upward into leucogabbro. Included is some gabbronorite.

Leucogabbro facies. Neither this facies nor the two following are represented in Clark's scheme. The rocks are grey to white or purple-brown, coarse- to very coarse-grained leucogabbro or leucogabbronorite. Plagioclase comprises up to 70% and may show magmatic alignment. It is essentially a plagioclase cumulate, with which thin mafic mineral accumulations and thin zones of rhythmic layering are interleaved. The rocks are homogeneous, except for crosscutting composite diabase and pegmatite.

Gabbroic pegmatite facies. Kerr (1994) describes the rocks as coarse-grained gabbroic and dioritic pegmatite containing acicular, locally hollow hornblende crystals. The subunit is associated with the mafic cumulate facies as sporadic masses (usually <400 m^2) and was interpreted by him as a local volatile-rich residual magma.

Composite diabase facies. The composite diabase facies occurs as fine- to medium-grained dykes, veins and irregular masses intruding all other units, including the dioritic rocks. The dykes commonly have a chaotic internal structure due to disruption of the diabase by intermediate material that Kerr (*op. cit.*) suggests to have originated in the local host rocks. The disrupted diabase may form 'pillow' structures having chilled margins. He interprets the rocks to be the product of mafic magmas interacting with residual liquids from the partly consolidated mafic cumulate rocks into which they were being emplaced.

Petrographic features. The author's collection of thin sections from the Adlavik Intrusive Suite gabbroic rocks is small but covers the range of rock types found within it, namely, pyroxenite (AL78-104), gabbro/leucogabbro (AL78-100), leucogabbro (AL78-110), granophyric leucogabbro (AL78-050) and gabbro/diorite (AL78-013A). A better source of petrographic information is provided by Kerr (1994), who summarizes typical examples of the melagabbro and leucogabbro facies as consisting of plagioclase ($An_{40–80}$; 30–75%), clinopyroxene (augite, 10–50%), orthopyroxene (5–20%; geographically restricted), hornblende ± actinolite (5–20%; commonly after pyroxene), biotite (red, 5–20%), olivine (minor, but 5–20% in gabbronorite), quartz and K-feldspar (up to 7%, interstitial), and minor iron oxide, titanite and apatite. The rocks range from fresh, dominated by plagioclase, clinopyroxene and biotite, to altered, dominated by hornblende, saussuritized plagioclase and actinolite. Hornblende commonly mantles clinopyroxene, and the latter may only be present as relict cores in amphibole masses. The mineralogical continuum is interpreted to reflect variation in the water content of the magma during crystallization (Kerr, 1994, also citing Clark, 1973). Gabbronorite variants contain pleochroic hypersthene, and fresh to relict olivine commonly mantled by orthopyroxene aggregates. Ultramafic rocks, and associated mafic cumulates, may contain large (up to 10 cm) megacrysts, or crystal aggregates, of amphibole with cores of clinopyroxene. Pale (Mg-rich?) biotite is also present.

11.2.1.2 Dioritic Rocks (P_{3C}dr)

These rocks correspond to Unit 14 of Gower (1981), Unit 22a of Gower *et al.* (1982b), Unit 25 of Kerr (1994), Unit P_{3C}dr of Gower (2010a; Big River and Benedict Mountains map regions), and the diorite facies of Clark (1973). The range of rock types was initially variously described as diorite to syenite by Gandhi *et al.* (1969) and syenodiorite to syenite by Bailey *et al.* (1979), but Gower (1981) and Gower *et al.* (1982a) commented that stained slabs show that the pink colour is misleading and that the rocks are rarely more potassic than monzodiorite. Kerr (1994) termed the rocks diorite, quartz diorite or monzodiorite, describing them as pale-brown, pink- or yellow-weathering, coarse grained and equigranular to plagioclase porphyritic. Discontinuous mafic mineral layers, primary foliations defined by plagioclase, and thin (<10 m) mafic-cumulate zones occur locally. The unit is cut by the composite diabase facies and bodies of coarse amphibole pegmatite. The amphibole pegmatites were earlier reported by Clark (1979), who termed them appinite, noting acicular hornblende up to 4 cm long.

At Adlavik Bay, diorite is noted by Kerr (1994) as apparently gradational from plagioclase cumulate rocks of the gabbroic unit, but that it also includes angular xenoliths of homogeneous gabbro and mafic cumulate material, thus implying the diorite to be younger. On the other hand, gabbro exposed at the inner, southwest part of Adlavik Bay includes stoped blocks of dioritic rock (Plate 11.1A), indicating the reverse. As will become evident following review of comparable and coeval intrusions elsewhere in eastern Labrador, such conflicting field relationships are commonplace, and point to multiple mafic to intermediate near-coeval magmas.

Kerr (1994) records the typical mineral assemblage in the dioritic rocks as consisting of plagioclase ($An_{40–50}$; 40–65%), quartz (up to 8%; intergrown with K-feldspar), K-feldspar (5–25%; as interstitial granophyre), clinopyroxene, hornblende and biotite (10–20% in total), orthopyroxene (up to 10%), and accessory apatite, iron oxide and zircon. He notes that, as in the mafic rocks, there is a continuum from near-anhydrous variants to rocks that lack pyroxene, instead being dominated by amphibole. Biotite is interpreted to be primary, as is some hornblende. One clinopyroxene-bearing monzodiorite in the author's collection (AL78-018A) is consistent with this description.

11.2.2 KOKKORVIK DYKES CORRELATIVES (P_{3C}d)

The Kokkorvik dykes (Ermanovics, 1993) have been foremostly identified in the Kaipokok and Aillik domains of the Makkovik Province, but some probably correlative rocks are present in the Cape Harrison domain, which is within the scope of this report.

According to Ermanovics (1993), the Kokkorvik dykes include dioritic rocks and, less certainly, rare, fine-grained diabase. As he points out, the rocks are probably equivalent to subalkaline lamprophyres described by Kranck (1953), who recorded them across the full width of the Makkovik Province. The dykes are generally fine grained, and form subhorizontal to shallow-dipping sheets typically 2 to 3 m thick, but may be up to 6 m. They are referred to as sills by Culshaw *et al.* (2002) because of their subhorizontal attitude, although most definitions would regard this usage of the word 'sill' to be unconventional inasmuch as they discordantly intrude their host rocks. Rb–Sr whole-rock isochron ages of 1635 ± 47 Ma and 1633 ± 59 Ma were obtained by Voner (1985) and B. Fryer (personal communication to I. Ermanovics, 1983, cited by Ermanovics, 1993), respectively. Culshaw *et al.* (2002), from Ar–Ar hornblende ages, concluded that data from one sample at least suggested emplacement earlier than 1685 Ma, but that spectra from other samples indicated 1650 to 1620 Ma. The dykes intrude the 1719 Ma Cape Strawberry granite and the 1715 Ma Blacklers Bight granite, thus providing a maximum age constraint on their emplacement. A flat-lying to gently southwest-dipping unfoliated diorite dyke containing euhedral hornblende phenocrysts that intrudes the Kitts U deposit may be a correlative intrusion. It has yielded a concordant U–Pb titanite age of 1662 ± 4 Ma (Sparkes *et al.*, 2010).

In the Cape Harrison domain, dykes that are probably correlative intrude the Dog Islands granite (Figure 6.5),

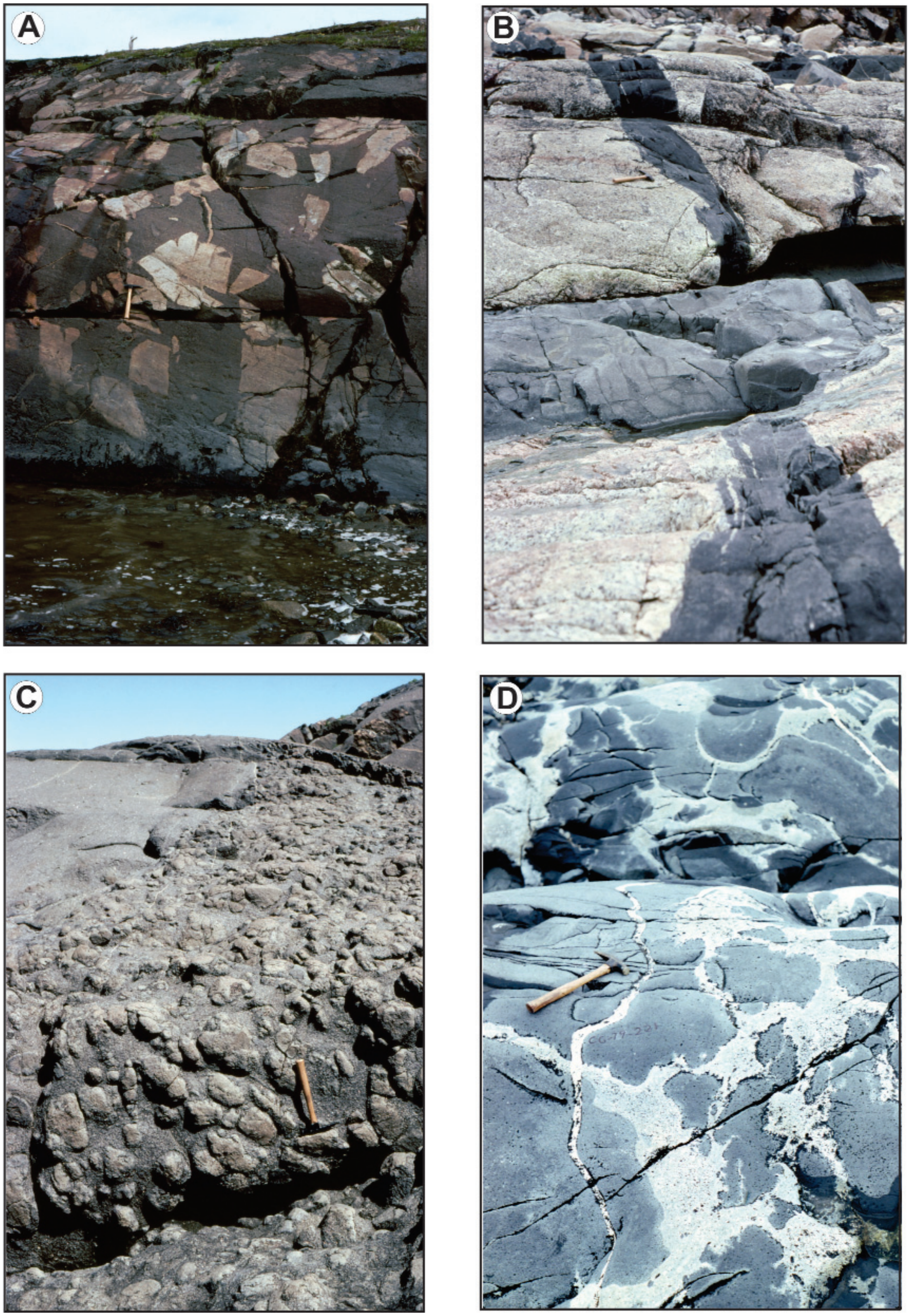


Plate 11.1. *Examples of mid- to late-Labradorian mafic intrusions in the Cape Harrison domain, Makkovik Province. A. Adlavik Intrusive Suite gabbro hosting angular granitoid enclaves (AL78-015), B. Early deformed mafic dyke crosscut by flat-lying later mafic dyke (CG79-050), C. Rounded enclaves of microgabbro in coarse-grained gabbro, Pamiulik Point (CG79-005), D. Net-veined mafic dyke, False Cape area (CG79-221).*

which, although undated, is correlated with the 1719 Ma Cape Strawberry granite. It was noted earlier that the Dog Islands granite is intruded by composite mafic–felsic, net-veined mafic dykes that are, in turn, crosscut by minor granitoid intrusions, and then non-net-veined, flat-lying mafic dykes (Plate 11.1B).

Thin sections are available from samples of the older and younger dykes depicted in Plate 11.1B. The older dyke (CG79-050B) is an inequigranular amphibolite, consisting mostly of hornblende and plagioclase, with trivial amounts of K-feldspar, biotite, opaque oxide, apatite, titanite, epidote and chlorite. It is thoroughly recrystallized with little vestige of its igneous protolith. The younger dyke (CG79-050C) is also extensively recrystallized, but it retains an igneous texture, having a groundmass of highly acicular amphibole with equant plagioclase (and minor quartz, biotite, opaque oxide, apatite, titanite, epidote and chlorite), plus a few euhedral, strongly zoned, amphibole phenocrysts. It was suggested earlier that the net-veined dykes might be the product of magma-mingling processes active during the waning stages of Dog Islands granite emplacement (Strawberry Intrusive Suite event) and that the flat-lying mafic dykes might correlate with the Kokkorvik dykes (Adlavik Intrusive Suite event). Alternatively: i) all might be linked to the Strawberry Intrusive Suite event, ii) all might be related to the Adlavik intrusive event, or iii) there was a continuum of sporadic igneous activity between the two.

11.2.3 PAMIULIK POINT MAFIC INTRUSION (P_{3C}rg, P_{3C}mn)

The rocks, grouped here as Pamiulik Point mafic intrusion, were originally partly distinguished by Stevenson (1970), although few of the rocks are as K-rich as his unit implies (*viz.* syenodiorite, monzonite, and syenite). Their distribution was refined by Gower (1981), who grouped the rocks as possible correlatives of the Adlavik Intrusive Suite, as did Kerr (1989a, 1994). Gower (1981) subdivided the rocks into pyroxenite, minor olivine gabbro and granophyric leucogabbro (his Unit 13), and diorite, leucodiorite, grading into monzodiorite and rare quartz monzonite (his Unit 14). These two units were designated by Gower (2010a; Benedict Mountains map region) as units P_{3C}rg and P_{3C}mn. Their extent, as shown by Gower (2010a), also embodies data from Davidson and Kowalczyk (1979). The name Pamiulik Point mafic intrusion is newly introduced here.

No geochronological data are available for the Pamiulik Point mafic intrusion. No obvious break exists between this body and the Mount Benedict Intrusive Suite, which is taken as tenuous evidence for coeval linkage. It makes no chronological difference whether the Pamiulik Point mafic intrusion is regarded as part of the Mount Benedict Intrusive Suite or as correlative with the Adlavik Intrusive Suite, given that both groups of rocks have geochronologically identical ages of 1650 Ma. The only isotopic data for the Pamiulik Point body is a Sm–Nd result reported by Kerr and Fryer (1994) from an olivine–orthopyroxene–clinopyroxene gabbro having values of T_{DM} = 2040 Ma and εNd (1.65 Ga) = +0.1. Separate identity for the Pamiulik Point mafic intrusion has been retained here in the light of Kerr and Fryer's (1994) comment that, if the syenitic to granitic rocks of the Mount Benedict intrusive suite are linked to the mafic rocks by fractionation of a basaltic parent magma, as justifiably argued by Kerr (1989a, 1994), then the mafic and felsic rocks should have similar εNd values – which they do not (the Mount Benedict Intrusive Suite has values for εNd (1.65 Ga) = –1.4 to –3.9).

Both units are grey- or brown-weathering, massive and coarse grained to very coarse grained. Layering and flowage features are present in some outcrops. An exotic-looking rock type associated with the body consists of abundant elliptical enclaves of microgabbro, all of roughly similar size, in a coarse-grained gabbro matrix (Plate 11.1C). It was interpreted by Gower (1981) to be due to intrusion of the coarser grained gabbro into the microgabbro prior to complete crystallization of the latter. A similar texture was described by Kerr (1994) from the Adlavik Intrusive Suite and attributed to disruption of a chilled margin by slightly later magma. Other features of the body are enclaves of ultramafic rocks (pyroxenite) and common microgranite dykes, one of which is a composite mafic–felsic intrusion. Some of the felsic dykes contain corroded plagioclase phenocrysts, akin to those in the Mount Benedict Intrusive Suite.

Five thin sections are available. Two are olivine gabbro to leucogabbro (CG79-002, CG79-005C), two are monzodiorite (CG79-016A, CG79-017) and one is a syenite (CG79-012). The olivine gabbro/leucogabbro contains well-twinned, strongly zoned plagioclase, granophyric intergrowths of quartz and alkali feldspar, olivine, brown clinopyroxene, red-brown biotite, an opaque oxide, apatite, and minor secondary actinolite, chlorite and white mica. The monzodiorite has well-twinned, moderately zoned plagioclase, perthitic K-feldspar, quartz, pale-brown clinopyroxene, primary igneous hornblende, orange-brown biotite, an opaque oxide, apatite and zircon, with secondary titanite, chlorite and white mica (not all minerals in both thin sections). The syenite has the same felsic minerals, but lacks primary mafic silicates, instead having secondary titanite, chlorite and a serpentine pseudomorph. It also contains an opaque oxide and apatite.

11.2.4 FALSE CAPE MAFIC–MONZONITIC INTRUSION (P_{3C}mn, P_{3C}mq)

The False Cape mafic–monzonitic intrusion (name newly introduced here) was identified by Gower (1981) as distinct from the Cape Harrison Metamorphic Suite, which borders it to the west. The body was assumed by Gower (1981) to be temporally equivalent to the Adlavik Intrusive Suite and that is the correlation adopted here. An alternative viable correlation is with some of the *ca.* 1800 Ma rocks, such as the Numok Intrusive Suite. No geochronological data are available.

The rocks range from monzodiorite to quartz monzonite. They are coarse grained and massive, and the more felsic rocks have a seriate to K-feldspar megacrystic texture. Typical textural types are shown in Appendix 2, Slab images 11.1. The rocks contain numerous gneissic enclaves (*e.g.*, CG79-221) and also have amphibolitic material. The rocks are intruded by numerous net-veined mafic dykes that are, in turn, intruded by minor granitoid veinlets (Plate 11.1D). Note that near-horizontal, net-veined mafic dykes are also common in the adjacent Cape Harrison Metamorphic Suite (*e.g.*, CG79-190; and farther south at CG79-174, CG79-176) and could imply more extensive related magmatism.

Two thin sections are available (CG79-219, CG79-222). The rocks are characterized by strongly zoned plagioclase fringed with albitic borders and partly enveloped in K-feldspar (perthite and microcline). Quartz is interstitial. Mafic minerals are olive-green biotite and blue-green amphibole. Both show symplectic relationships with quartz. They look like pseudomorphs after clinopyroxene, although no relicts are present to provide confirmation. Accessory minerals are opaque minerals (oxide and sulphide), apatite, titanite (mantles opaque minerals and forms unusually large separate grains), zircon, minor allanite and secondary chlorite and epidote.

11.2.5 WEST OF BRIG HARBOUR ISLAND MAFIC INTRUSION (P_{3C}rg, P_{3C}ln, P_{3C}mn, P_{3C}um)

The mafic intrusion west of Brig Harbour Island is situated in the easternmost Makkovik Province and is exposed on numerous islands west of Brig Harbour Island that are too small to show on Figure 11.1. It was mapped at reconnaissance level by Gower (1981), and referred by him as a layered ultramafic to mafelsic intrusion west of Brig Island, but not named. It was mapped in more detail by Owen (1985) as part of his Ph.D. thesis. The area was not covered by Kerr's (1989a, 1994) investigation.

Owen (1985) reported Rb–Sr isotopic data for the body (his Unit 7) that indicated a quasi-linear array suggesting a date of 1747 ± 310 Ma (I_{Sr} = 0.7025) based on 7 whole-rock analyses. The West of Brig Harbour Island layered mafic intrusion is closely identified with a ferrodiorite to ferrosyenite unit to the northwest (his Unit 9), referred to in this report as the Holton Harbour syenite (Figure 6.5). From this unit, Owen (1985) and Owen *et al.* (1988) reported a 7-point whole-rock errorchron of 1676 ± 77 Ma. On the basis of these results and assuming correlation with other similar layered mafic intrusions in eastern Labrador, an emplacement age of 1650 Ma has been adopted. Using this, Sr initial ratios have been recalculated for individual sample sites (having a range from 0.7023 to 0.7032), and are included on the 1:100 000-scale map (Gower, 2010a; Byron Bay map region). One Sm–Nd whole-rock analysis has also been obtained, giving a result of T_{DM} = 1928 Ma and εNd (1.65 Ga) = +0.93.

Gower (1981) described the body as a fractionated intrusion varying from ultramafic on its eastern side to quartz monzodiorite at its western margin. The ultramafic rocks, a few tens of metres thick and well exposed in the Emily Harbour area, consist of black-weathering, coarse-grained, massive, olivine- and orthopyroxene-bearing clinopyroxenite having a poikilitic texture defined by clinopyroxene crystals exceeding 4 cm in diameter. These grade westward into granophyric gabbro and leucogabbro, then into granophyric diorite and leucodiorite, and, finally, to quartz monzodiorite at its western margin. The sequence is not simple in detail as the rocks are rather variable in composition, texture and grain size. Other variations are introduced by cumulate fabric, poikilitic hornblende, and vague to well-defined igneous layering (generally north-northeast striking and dipping to the west).

Gower (1981) reported that the mafic intrusion is intruded agmatitically at its borders by the flanking granitoid rocks, from one of which a U–Pb concordant 1726 ± 34 Ma titanite age was obtained by Krogh *et al.* (2002) and interpreted to be of metamorphic origin. This should imply that the mafic intrusion is pre-1726 Ma, and thus contradicting the assumption of a 1650 Ma time of emplacement. Such is not necessarily the case, as magma-mingling phenomena are characteristic of the 1650 Ma mafic intrusions, thus producing inconsistent intrusive relationships (*see* Adlavik Intrusive Suite earlier). In the West of Brig Harbour Island mafic intrusion, other evidence for such phenomena is provided by net-veined mafic dykes (*e.g.*, CG79-297, CG79-327).

Petrographically, the rocks show an orderly fractionation sequence. An ultramafic rock (CG79-329) from near the eastern border of the intrusion contains olivine, orthopyroxene and clinopyroxene. The next closest to the eastern border (CG79-306) lacks olivine and has minor plagioclase. It is the most modified by metamorphism and it is somewhat equivocal whether it was originally ultramafic or melagabbro. No orthopyroxene was seen, but chlorite pseudomorphs suggest that it might once have been present. Three gabbroic rocks that follow (SG79-185, CG79-328B, CG79-298) all have clinopyroxene, which is lacking in two more fractionated samples (quartz monzonite CG79-328A, and leucodiorite CG79-334). It is clarified that quartz monzonite (CG79-328A) is not from the western side of the body as might be expected, but, instead, discordantly intrudes gabbro (CG79-328A) in a central part of the intrusion. All, except the olivine-bearing ultramafic rock, have plagioclase and some interstitial K-feldspar, partly present as interstitial granophyre, and all have red-brown biotite (except CG79-306, in which it has been chloritized). Amphibole (hornblende and/or actinolite) is present in all, except SG68-185. Other minerals are quartz, an opaque oxide, sulphide, apatite, titanite (mantling an opaque oxide in the two most fractionated rocks), and zircon (in the most fractionated sample – CG79-328A). Secondary minerals are white mica, epidote and chlorite.

11.2.6 UNNAMED OTHER ADLAVIK INTRUSIVE SUITE POSSIBLE CORRELATIVES (P_{3C}rg, P_{3C}ln, P_{3C}am, P_{3C}mn, P_{3C}um)

As is evident from Figure 11.1, numerous outcrops of mafic rocks deemed to be comparable and possibly coeval with the Adlavik Intrusive Suite have been mapped throughout the Makkovik Province, especially in its southern part. South of the Benedict fault (which is indicated on Figure 6.4) in particular, the distribution correlates with small hills that rise above the surrounding, largely unexposed, wetlands. Based on sparse outcrops in rivers and a few other places, the wetlands are inferred to be underlain by granitoid rocks. The inland area was almost entirely mapped at reconnaissance level by helicopter (Stevenson, 1970; Gower, 1981, 1986). Little time was spent searching for field relationships between units (which are scarce), so age constraints are weak and some of the rocks could be unrelated, and hence either older or younger. At the time of mapping, it was not recognized that two major, but similar, suites of mafic rock dominate, namely the 1650 Ma Adlavik Intrusive Suite correlatives and the 1426 Ma Michael gabbro. Many outcrops described in field notebooks are incorrectly termed Michael gabbro. Since mapping, much progress has been made in discrimination between the two suites, utilizing whole-rock geochemical and isotopic criteria based on samples collected during mapping. Some designation uncertainties still exist, especially where no samples are available. Note that the mafic rock occurrences addressed here were not covered by Kerr (1989a, 1994), although he did refer to some other correlative rocks farther west (outside the scope of this report) at Big River and East Micmac Lake.

Rock types present include ultramafite, mela- to leucogabbro and gabbronorite, diorite, monzogabbro/monzonorite, monzonite, and mafic dykes. Although commonly retaining igneous character, the rocks are variably metamorphosed and are commonly referred to in field notes with a 'meta' prefix (*e.g.*, metagabbro, implying an igneous texture but partly to entirely metamorphic mineral assemblage), or as amphibolite, where both the texture and minerals are almost entirely metamorphic. The rocks are black-, brown-, bronzy- or light- to dark-grey-weathering; fine to coarse grained, most commonly massive but may be foliated or sheared, and sparsely intruded by mafic dykes or microgranite/pegmatite veins. Layering was recorded at AD79-258 and SG68-082, and appinite at CG79-863. Plagioclase-phyric texture was noted at AD79-240 and CG79-532B, hornblende phenocrysts at CG79-750, and poikilitic biotite at CG79-560. The author guesses that such features would have been found to be widespread had the rocks been more thoroughly examined.

A wide range of rock types was examined in thin section. Two ultramafic rocks (CG79-524, CG82-034A) are available. Both have been classified as clinopyroxenite. One (CG82-034A) contains fresh olivine mantled by very narrow double orthopyroxene–amphibole coronas. It is intruded by a fine-grained diabase dyke (CG82-034B). There is no doubt that the diabase dyke belongs to the Michael gabbro. Its host might too – but, if so, its chemical composition is atypical. Four samples having orthopyroxene as part of the primary igneous assemblage (*i.e.*, non-coronal orthopyroxene) define a curved line about 18 km long parallel to strike within the Big River granitoid unit (CG82-022, CG82-033, CG83-425, SG68-134). They have somewhat disparate compositions (recrystallized gabbronorite, gabbronorite, hypabyssal gabbronorite and leucogabbronorite/diorite, respectively), so there is no compelling reason to believe them to be closely related, and thus the empirical linear configuration may have no significance.

Six thin sections were termed gabbro (CG79-474, CG79-532A, CG79-526, CG79-740, CG82-021, N68-067). All have primary igneous plagioclase, clinopyroxene, amphibole, biotite, an opaque oxide, and apatite. Olivine is present in CG79-526 and interstitial granophyre is present in CG79-474 and N68-067. Most contain metamorphic amphibole and biotite, and secondary white mica, chlorite and epidote. Of the three samples termed amphibolite (CG79-551, N68-071, SGJ68-081) all show vestiges of former igneous plagioclase and clinopyroxene, even though two of the rocks are strongly deformed. Other minerals sporadically present are quartz, biotite, opaque oxide and sulphide and apatite. All three samples are from the eastern part of the Makkovik Province. The sole mafic dyke that was thin sectioned from this group of rocks (CG79-532B) is one of two seen at the outcrop, both having similar trends and dips (035/076° and 040/080°) intruding a metagabbro. The sample contains oscillatory zoned, euhedral primary plagioclase microphenocrysts (up to 0.5 cm long) in a largely recrystallized matrix of amphibole, biotite, an opaque oxide and apatite.

Most of the samples of granitoid rocks associated with the Adlavik Intrusive Suite correlatives in the Makkovik Province come from a small area in the Pompey Island area (CG79-389, CG79-394C, CG79-395, SGJ68-107). This area has been mapped in detail by Owen (1985), who referred to the rocks as monzonite to syenite and conceptually grouped them as Adlavik Intrusive Suite related.

The rocks all have relict igneous or metamorphic plagioclase, K-feldspar (microcline or as interstitial granophyre), quartz, biotite, an opaque oxide, apatite and titanite. Amphibole and clinopyroxene are present in CG79-389 and CG79-395, and secondary white mica, chlorite and epidote are sporadically present. Other thin sections examined are SGJ68-107, which is monzodioritic gneiss that is situated 13 km to the northwest and more-or-less on strike with the rocks at Pompey Island, and AL78-136A, which is amphibole-bearing granite near the mouth of Big River. Both have similar mineral assemblages, most notably lacking clinopyroxene and containing titanite and zircon.

11.3 GROSWATER BAY TERRANE

The same organizational strategy as for the Adlavik Intrusive Suite and correlatives in the Makkovik Province has been adopted for the Groswater Bay terrane. Better known or more coherent bodies are described first, followed by a summary of other occurrences not otherwise included.

11.3.1 POTTLES BAY MAFIC INTRUSION (P_{3C}rg)

Parts of the Pottles Bay mafic intrusion are shown on the maps of Christie *et al.* (1953) and Kranck (1953), and all of it on the map of Stevenson (1970). Stevenson (1970) records that the intrusion forms a conspicuous, sinuous ridge southwest of Pottles Bay and is made up of almost black, massive, coarse-grained gabbro. It dips steeply to the north and he interpreted it as a sill (although mentioning that it is locally known as the Pottles Bay dyke). From his field notes, it can be added that the margins of the intrusion typically are sheared and show mylonitic and/or slickenside structures. During Stevenson's mapping, the intrusion was also sampled at two sites for paleomagnetic studies by Fahrig (*cf.* Fahrig and Larochelle, 1972). These sites have been plotted on Gower's (2010a) Groswater Bay map according to data supplied by the Geological Survey of Canada (K. Buchan, personal communication, 2008), but the location of one of them (WWF-04) may be slightly erroneous as Stevenson's field notes establish that a paleomagnetic sample was collected at SG68-188, which would place it 700 m north-northwest of its currently shown position.

The author has examined the intrusion at several sites along its length. It is mafic to ultramafic, dark-weathering, massive, and medium to coarse grained. The best information comes from the coastal exposure of the intrusion (CG82-027), where it is clear that there are very complex inter-relationships between the original igneous character of the body as a layered intrusion, and its subsequent metamorphism, deformation and injection by migmatitic material. A description of the locality, taken more-or-less directly from field notes, is given in Figure 11.2.

The Pottles Bay mafic intrusion has not been dated, but Sm–Nd isotopic data yielded values of T_{DM} = 2192 and 2300 Ma and εNd (1.65 Ga) = –0.25 and –0.98 (samples CG79-634, CG82-027D, respectively). These T_{DM} ages are anomalously old compared to most Adlavik Intrusive Suite correlatives. Note that sample site CG82-027D is from the location described in detail in Figure 11.2.

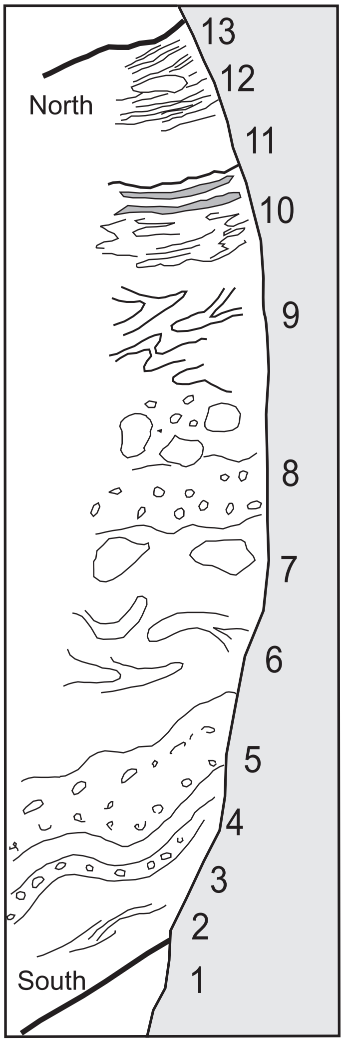
Four thin sections of the Pottles Bay mafic intrusion are coronitic gabbroic rocks. Two (CG82-027B, C) are olivine-bearing and display orthopyroxene–amphibole/garnet double coronas, with primary plagioclase, mauve clinopyroxene, red-brown biotite, an opaque oxide and apatite. Two (CG82-027D, E) have hydrated metamorphic assemblages, comprising abundant hornblende and garnet in lieu of olivine or pyroxene, plus minor orange-brown biotite, apatite, quartz and secondary epidote. A fifth thin section was prepared from the southern fine-grained margin of the intrusion (CG82-027A). The rock is a strongly foliated biotite-rich amphibolite, completely transformed to a metamorphic assemblage of plagioclase, amphibole (sodic hornblende?), orange-brown biotite, an opaque phase and apatite.

11.3.2 PORCUPINE STRAND (WEST) MAFIC INTRUSIONS (P_{3C}rg, P_{3C}ln, P_{3C}am)

Topographically, the area west of Porcupine Strand is characterized by fairly prominent forest-clad isolated hills separated by extensive low-lying wetlands. The hills are mostly underlain by mafic intrusive rocks, with which, locally, are closely associated granitoid rocks that are interpreted to be part of the same lithological package. The low-lying wetlands mostly lack exposure so it remains uncertain whether these areas are underlain by some intervening, other rock type (*viz.* quartzofeldspathic gneiss, as implied on the map of Stevenson, 1970), or whether the mafic intrusive rocks continue through them (as indicated by Eade, 1962). The present distribution of the mafic and associated granitoid rocks relies on mapping by Gower *et al.* (1980, 1981), coupled with re-evaluation, based on aeromagnetic data and regional geological synthesis, and results in a depiction between Stevenson's and Eade's maps.

Neither the mafic nor the associated granitoid rocks have been reliably dated, but some isotopic data are available. Three Sm–Nd results from mafic rocks were obtained by Devereaux (2011). A metadiabase (CG80-640B), an olivine gabbronorite (CG80-715) and an orthopyroxene-bearing gabbro (CG80-809) have, respectively, T_{DM} = 1925, 1937 and 1845 Ma and εNd (1.65 Ga) = +0.85, +0.93 and +1.82. Two K–Ar results were obtained by the Geological Survey of Canada following Stevenson's (1970) mapping, but were never published. The results were provided to the author and permission given to include them on the map of Gower (2010a; Groswater Bay map region). The rock sampled (SG68-110) was termed a quartzitic paragneiss by Stevenson, but was re-interpreted as a monzonite by the author, who has visited the site (CG80-640) and examined Stevenson's thin section. A hornblende mineral separate yielded two dates of *ca.* 4754 and 4798 Ma (recalculated), and were reported as an averaged value of 4776 Ma by Gower (2010a). A biotite mineral separate yielded a date of 2091 ± 60 Ma. Stevenson declined to interpret these anomalously old results, as does the author. The mafic rocks of the Porcupine Strand (west) mafic intrusions have also been investigated paleomagnetically by Park and Gower (1996; Sites JKP-76 to JKP-81).

The Porcupine Strand (west) mafic rocks range from ultramafic (pyroxenite) to leucogabbro/leuconorite, are black-weathering (locally honey, brown or grey), and are mostly massive and coarse grained. Gabbroic to leucogabbroic rocks are most common. Weak to moderate foliations are present in places, but seem to be localized, and may well be related to major northwest-trending shear zones postulated to pass through the district. Average grain size common-



13. Northern contact is with strongly deformed granite to granodiorite gneiss, containing lenses of pink leucosome and skialiths of hornblende–biotite-rich rock (former mafic dykes).

12. Gradation into thinly layered gabbro and some broad zones of pegmatite.

11. Very sharp junction with underlying lenses of gabbro / recrystallized gabbro.

10. Very dark-weathering, hornblende-rich gabbro having migmatitic streaks of quartz-feldspar material. At the base is some spectacularly layered ultramafite / leucogabbro.

9. Spectacular examples of primary layering transposed into secondary banding with mere enclaves of original gabbro remaining.

8. Another broad zone of very coarse-grained gabbro with large poikiloblastic hornblende and common garnet. Cut by muscovite-rich pegmatite. The very coarse-grained material is the recrystallized equivalent of the medium-grained rock.

7. Boudins of massive, medium- to coarse-grained gabbro with dispersed garnet. Primary texture remains.

6. Variable broad zone of medium- to very coarse-grained gabbro with abundant garnet. This shows relict primary layering that has been tightly to isoclinally folded and intensely sheared in places. Much of layering could be metamorphic differentiation.

5. Very coarse-grained material, as seen at 4. The coarse-grained material has well-displayed garnet coronas associated with mainly hornblende and plagioclase. Some vestiges of primary layering, but mostly recrystallized; 40 m wide.

4. Gradational margin with coarse-grained zone containing more garnet; 3 m wide. Grades into medium-grained, brown-weathering material.

3. Grades into massive, coarse-grained, olivine gabbro with hornblende coronas and discontinuous garnet coronas.

2. Dyke margin is fine- to medium-grained over 2 m. Strongly foliated in places with some schistose layers, as well as leucocratic quartz-feldspar veins containing garnet and chlorite.

1. Well-banded tonalitic gneiss with amphibolite enclaves. Isoclinally folded. In sharp contact with margin of mafic body.

Figure 11.2. *Coastal cross-sectional exposure of the Pottles Bay mafic intrusion from field sketch and notes (CG82-027). Notes have been edited for readability. Total width of intrusion uncertain, but guestimated to be about 400 m. The intrusion was originally described from south to north and interpreted to be top-to-the-south. A key point of the figure is the interplay between igneous, metamorphic and deformational processes.*

ly exceeds 1 cm, but rocks having crystals over 4 cm long were recorded. Conversely, some fine- or medium-grained rocks are also present, some of which are demonstrably mafic dykes. The variation from ultramafic to leucogabbroic rock types can be related to igneous layering, which was directly observed in a few outcrops at 0.1 to 1 m scale. Cumulate textures, especially involving primary purplish plagioclase with intercumulus primary clinopyroxene, were commonly observed in outcrop. From a few observations of igneous fabrics, it is apparent that, overall, the mafic intrusions are flat-lying to moderately folded sheets. Heterogeneous textures, involving a finer grained phase irregularly injected by coarser grained material of similar composition, suggest multiple phases of magma intrusion. Although, for the most part, the textures and mineral assemblages are primary, the rocks grade into amphibolite in places, especially near the margins of the mapped masses. This change may be linked to the postulated major shear zones mentioned earlier. The rocks are intruded by minor micrograniteor pegmatite dykes and veins, or quartz stringers, but they are not abundant.

Eleven thin sections are available from the Porcupine Strand (west) mafic intrusions. Seven of them are gabbro or norite, two are diabase dykes and two are ‘dioritic’. The gabbro or norite (CG80-640A, CG80-644, CG80-715, CG80-788B, CG80-809, CG81-246, RG80-527) typically contains plagioclase, pale-green clinopyroxene, amphibole, red-brown biotite, an oxide opaque mineral and apatite, all of which are mostly primary igneous minerals. Olivine is present in CG80-644, CG80-715 and RG80-527, and these rocks also have well-defined double coronas mantling olivine (inner – orthopyroxene; outer – pargasitic amphibole + spinel). These would be characteristic of Zone 1b if the rocks were Michael gabbro, but εNd = +0.93 for CG80-715 denies that such is the case for that sample

(Michael gabbro has values of εNd = *ca.* –5). The status of the other two is less certain. Garnet is a coronal phase in CG81-246.

The two diabase dykes (CG80-640B, GF81-014) have relict igneous and metamorphic plagioclase, some of which is phenocrystic; relict igneous clinopyroxene (GF81-014); amphibole; orange-brown biotite; an opaque oxide, apatite and epidote. Garnet is present in GF81-014.

The two dioritic rocks (GF81-119, GF81-120) contain plagioclase, K-feldspar (GF81-119), quartz, orange-brown biotite, amphibole, an opaque oxide, apatite, zircon and allanite. In addition, GF81-119 also contains scapolite. Both samples are from the southern part of the area and, in contrast to most of the samples, fall within the Hawke River terrane rather than the Groswater Bay terrane. They could be alternatively assigned as mafic to dioritic rocks correlative with the Earl Island intrusive suite.

The associated granitoid rocks include monzonite, syenite and granite. The rocks are generally massive and coarse grained (with some exceptions, *e.g.*, NN80-637, which is strongly foliated). Contacts between mafic and felsic rocks were rarely observed, but the impression was gained at CG80-718 that the mafic rocks horizontally cap felsic rocks. At CG80-641, granitic and syenitic rocks are interlayered on a 3–4 m scale. They are also intruded by minor (<20-cm wide) leucogranite and mafic dykes. Stained slabs show corroded plagioclase crystals in a K-feldspar and mafic mineral matrix, in a 'speckled-egg' texture, reminiscent of that seen in the Mount Benedict Intrusive Suite (Section 12.1.1).

Six thin sections (CG80-639, CG80-643, CG80-718, NN80-636, NN80-637, SG68-110B) contain plagioclase, K-feldspar (mixed perthite and microcline), quartz, orange- or red- brown biotite, dark-green hornblende, clinopyroxene (CG80-639, CG80-718, NN80-637), garnet (NN80-637, SG68-110B), an opaque oxide, apatite titanite, zircon, allanite, and secondary white mica, chlorite, and epidote.

11.3.3 GRADY ISLAND MAFIC INTRUSION (P_{3C}rg, P_{3C}mz)

The Grady Island mafic intrusion and associated granitoid rocks are situated in the Groswater Bay terrane 40 km east-northeast of Cartwright. The intrusion takes its name from Grady Island, which is the largest of a group of islands in the area that are all composed of similar rocks (plus a nearby mainland headland), and which are regarded by the author as collectively representing a single mafic and felsic layered intrusion, measuring roughly 12 by 4 km, elongate in a northeast direction (Figure 11.1).

The rocks are partially represented on maps by Kranck (1939, 1953), Christie (1951), Taylor (1951) and Eade (1962). Present knowledge of the overall body is partly based on mapping by Gower *et al.* (1981), but augmented by follow-up isotopic and paleomagnetic investigations involving the author, and a detailed mapping, petrographic and whole-rock geochemical study by O'Flaherty (1986). O'Flaherty's investigation focussed on a smaller island west of Grady Island that she informally termed Little Grady Island (not shown on Figure 11.1). It is from this island that most of the geological information, and all the isotopic and paleomagnetic data, have been obtained (Figure 11.3). Although the name Little Grady Island mafic intrusion has been previously introduced (O'Flaherty, 1986; Murthy *et al.*, 1989b), the usage here is to include this segment within the broader Grady Island mafic intrusion.

The age of the intrusion is best constrained by a near-concordant $^{207}Pb/^{206}Pb$ zircon age of 1644 ± 2 Ma from two samples – a syenitic rock and a pegmatitic gabbro (samples CG81-306K, L). The age is interpreted as dating the time of emplacement of the intrusion (Kamo *et al.*, 1996). Three titanite analyses were also obtained from the same samples and, together with the zircon data, define a mixing line having upper and lower intercepts of 1647 ± 5 Ma and 973 ± 11 Ma, respectively. A suite of samples collected earlier from the same site (CG81-306C, D, E, G, H, J) yielded a 1610 ± 30 Ma Rb–Sr isochron age (I_{Sr} = 0.70264), excluding CG81-306J from the regression (Brooks, 1983). A Sm–Nd isotopic analysis of a garnet-bearing metagabbro, also from the same site (despite its differing station identifier – CG84-483), yielded values of T_{DM} = 1818 Ma and εNd (1.65 Ga) = +3.17.

The Grady Island intrusion comprises mostly gabbro or gabbronorite with intervening zones of monzonite grading into syenite. Apart from Little Grady Island, the intrusion has not been mapped in detail, so the proportions of mafic to felsic rocks remain uncertain. The felsic units tend to weather most, hence are found underlying topographic troughs parallel to the strike of the intrusion. It is possible that additional felsic layers exist within areas shown merely as mafic rocks on Gower's (2010a) Table Bay map region.

On Little Grady Island (O'Flaherty, 1986), two vertically dipping layered units are well exposed (Figure 11.3; Plate 11.2A). Intrusive relationships at the contact between the lower and upper units indicate that the upper unit existed before emplacement of the lower unit (Plate 11.2B). The lower unit also contains gabbroic xenoliths that can be matched with material in the upper unit. The rocks are medium to coarse grained and grade from black- to red-brown-weathering norite at the lowermost part of the lower layered unit (base not seen) through grey monzonite to pink syenite. The syenite occurs within the monzonite, rather than at the top of this layered unit, indicating some monzonite crystallized at the roof of the layered unit before the syenite (Plate 11.2A). The final residue of the magma was expelled from the central part of the syenite to form pegmatite that cut through the roofing monzonite and into the

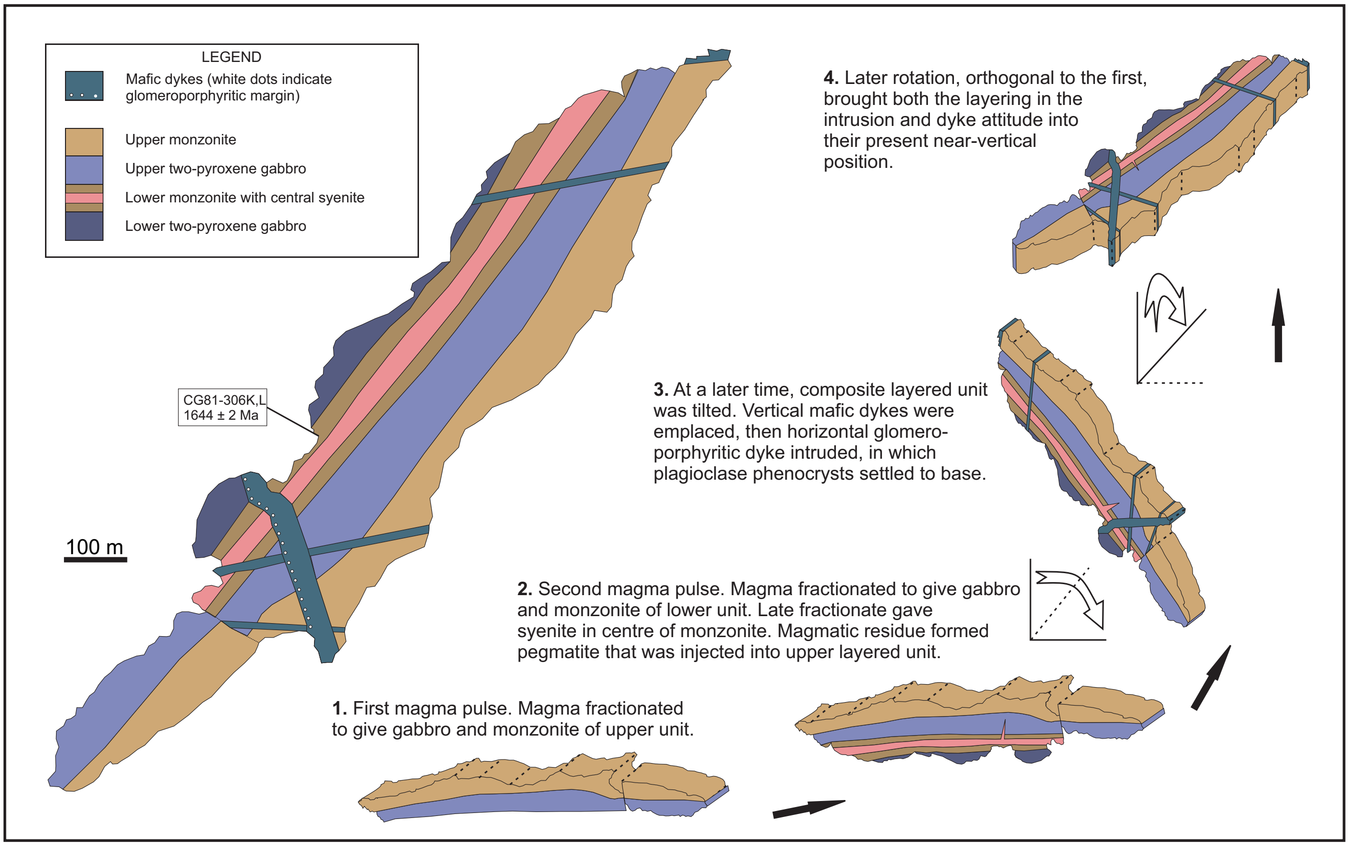


Figure 11.3. *Little Grady Island layered mafic–monzonitic intrusion, illustrating emplacement and deformational history (*cf. *O'Flaherty, 1986). If the plagioclase phenocrysts floated, then, of course, the sense of rotation would be reversed.*

upper layered unit. The base of the upper layered unit is ultramafic and shows superb layering on a centimetre scale (Plate 11.2C). It grades upward through gabbronorite and gabbro into monzonite (top of layered unit not seen). In the lower unit, the transition from norite to monzonite occurs over 1.5 m and from monzonite to syenite over 0.5 m. R. Emslie (personal communication, 1982) was doubtful that fractionation could explain the rock types present, pointing out that the ratio of monzonite to mafic rocks was rather high for that to be the case.

Throughout the whole of the Grady Island intrusion, both mafic dykes and minor granitoid intrusions (microgranite and pegmatite) are common. The mafic dykes have been interpreted to be feeder intrusions and an integral part of the mafic magmatic activity that generated the layered intrusion, but as they have also been interpreted to have been emplaced after the overall intrusion was steeply tilted, they may not be as closely related as previously supposed. It is likely that at least some minor granitic intrusions are related to the felsic component of the magmatism (as described above), but extrapolating this concept to all of them lacks justification. The mafic dykes on Little Grady Island are better known than most in the region as they have been the subject of a paleomagnetic study by Murthy *et al.* (1989b). They mostly trend east to northeast, are vertical, display clear chilled margins, and have widths between 4 and 11 m. One dyke is exceptional in that it trends north-northwest, is *ca.* 30 m wide (O'Flaherty gives 10 m, but, using Goggle Earth imagery, it is clear that this is an underestimate), and crosscuts the east-northeast-trending dykes. It also has rounded clumps of glomeroporphyritic plagioclase concentrated on its west side (Plate 11.2D), grading to a few clusters in the centre and none on its north side. O'Flaherty (1986) suggested that the (now-vertical) dyke was intruded horizontally and the glomeroporphyritic plagioclase is the result of crystal settling (or floatation). Figure 11.3 illustrates the deformational sequence to be inferred if gravity was the controlling mechanism for the location of the glomeroporphyritic plagioclase.

Thin sections from the Grady Island intrusion are divided into three groups, namely: i) gabbro/gabbronorite, ii) monzonite/syenite, and iii) mafic dykes. Eight samples of gabbro/gabbronorite are available (CG81-303A, CG81-306, CG81-306F, CG81-306G, CG81-306H, CG81-306J, CG81-306L, CG87-651). These are all from Little Grady Island, except CG81-303A, which is from another island 1 km south of Little Grady Island. Primary igneous minerals are plagioclase, K-feldspar (only in CG81-306F), clinopyroxene, orthopy-

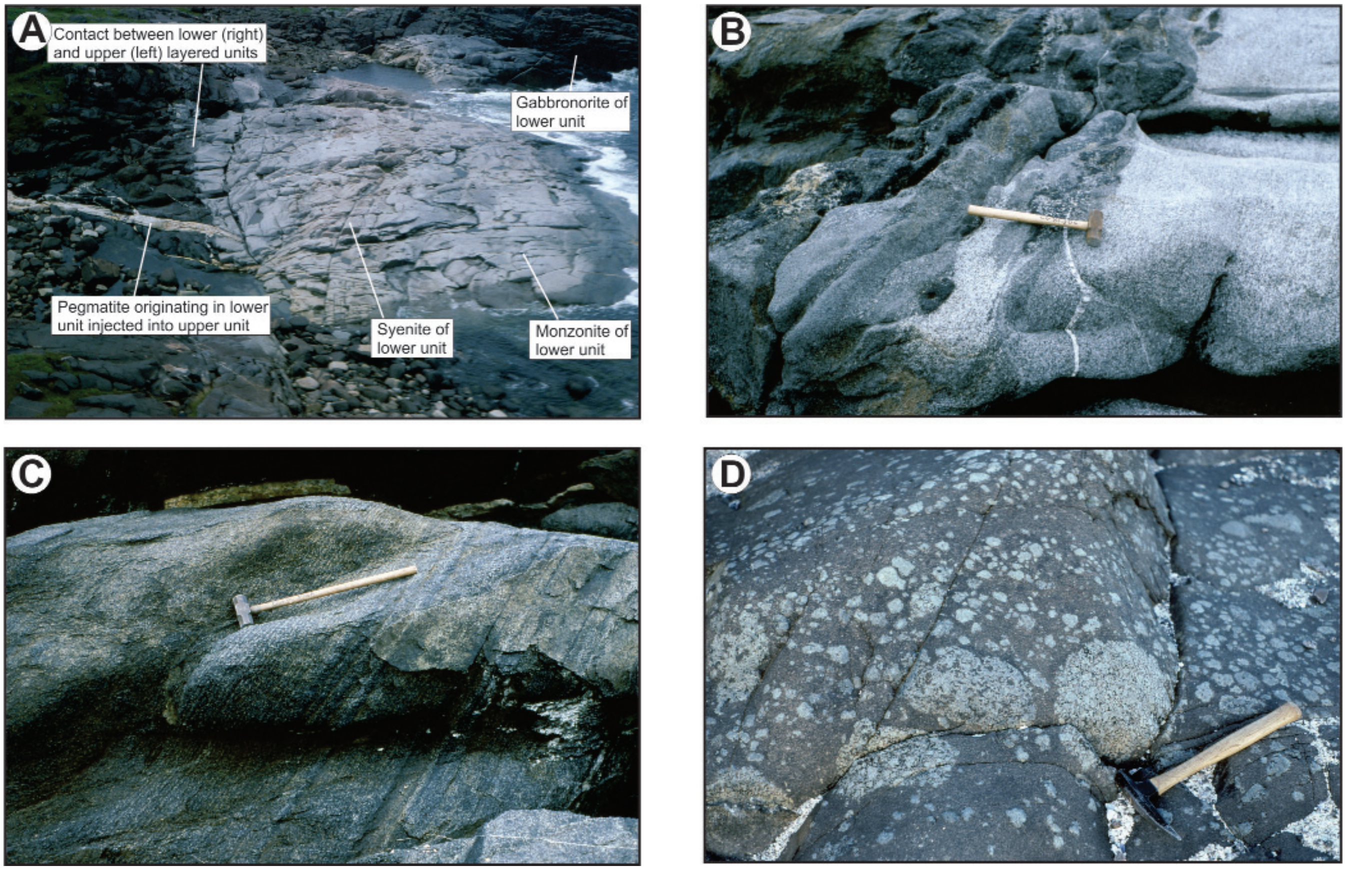


Plate 11.2. *Features of the Little Grady Island layered gabbronorite–monzonite unit. A. General view of lower layered unit and lower part of upper layered unit on Little Grady Island (CG81-306), B. Early deformed mafic dyke crosscut by flat-lying later mafic dyke (CG79-050), C. Contact between lower layered unit monzonite (right) and basal part of upper layered unit (CG81-306), D. Glomeroporphyritic southern side of mafic dyke, which discordantly intrudes layered units (CG81-306).*

roxene, biotite, an opaque mineral, and apatite. Relict primary plagioclase is moderately to strongly zoned, and heavily dusted with tiny opaque inclusions, except where recrystallized. Clinopyroxene is pale-green and is heavily charged with exsolved opaque mineral inclusions. Orthopyroxene (present in four thin sections) shows weak pleochroism, and also contains opaque mineral inclusions. Biotite is orange-brown or red-brown. In addition to recrystallized versions of the above-listed primary silicates, metamorphic minerals also include hornblende and garnet. Some reactions have been suggested by O'Flaherty (1986) as follows:

Pyroxene + Plagioclase + H_2O *= Hornblende + Quartz*
Hornblende + Plagioclase = Garnet + Clinopyroxene
Hornblende + Plagioclase = Garnet + Quartz + H_2O
Biotite(1) + Plagioclase = Biotite(2) +
Quartz + Magnetite + Garnet

These do not capture the full metamorphic history of these rocks, which has yet to be evaluated.

Thin sections of the monzonite/syenite available are CG81-300, CG81-305, CG81-306B, CG81-306C, CG81-306D, CG81-306E, CG81-306K, CG87-648, CG87-650, CG87-658 and CG87-659. The primary mineral assemblage consists of plagioclase, K-feldspar (perthite and some microcline), quartz, olive-green or orange-brown biotite, dark-green or blue-green amphibole, pale-green clinopyroxene with abundant opaque mineral inclusions, an opaque oxide (sulphide in four thin sections), apatite, titanite, zircon, and sporadic secondary allanite, white mica and epidote. The primary minerals are partially recrystallized to polygonal aggregates in all thin sections. Garnet is associated with aggregates of recrystallized clinopyroxene, biotite and opaque mineral(s) in CG87-658. Typically, clinopyroxene is relict or has been completely replaced by hornblende, quartz, titanite and opaque phases. Recrystallized orange-brown biotite mantling opaque minerals is also characteristic.

Mafic dykes for which thin sections are available are listed in Table 11.1. At one time, these dykes were thought by the author to be part of the 1426 Ma Michael gabbro suite (Gower, personal communication to C. O'Flaherty, 1986),

Table 11.1. Mafic dykes related to the Grady Island mafic intrusion

Sample	P'mag Site	Trend	Width(m)	Special Features
CG81-303B	No site	60	?	
CG84-483	PR84-116	175	30	Plagioclase-phyric
CG84-484	PR84-123	108	6	
CG84-485	PR84-138	75	11	
CG84-486	PR84-144	20	4	
CG87-648	PR84-110	96	6.5	Plagioclase-phyric
CG87-654	PR85-618	108	20	

but it was subsequently concluded, on the basis of whole-rock geochemical data, that they were more likely related to the 1650 Ma mafic rocks (Murthy *et al.*, 1989b). As an aside, Murthy *et al.* reference 'Brewer and Gower (*in preparation*)' for further information; that manuscript never progressed to publication submission.

Despite medium- to high-grade metamorphism, all samples display relict subophitic texture involving laths of well-twinned and, commonly, strongly zoned plagioclase and pale green heavily exsolved clinopyroxene. The plagioclase phenocrysts noted in Table 11.1 are up to 1 cm long.

Other characteristic mafic minerals are orthopyroxene (in four thin sections), green or blue-green amphibole, orange-brown biotite and garnet. These occur as polygonal, recrystallized aggregates that are either coronal to clinopyroxene or an originally primary opaque mineral. Garnet is much more common in the mafic dykes than the host gabbro/gabbronorite. Sporadic accessory minerals are apatite, hercynite and corundum(?), the latter as spindles in plagioclase.

11.3.4 SPOTTED ISLAND (AND SURROUNDINGS) MAFIC INTRUSION (P_{3C}rg, P_{3C}mz)

Spotted Island is underlain by mafic and granitoid intrusive rocks. Both Christie (1951) and Kranck (1953) identically show mafic rocks underlying the whole island, except for a strip of granitoid rocks along the southwestern side, plus mafic rocks at Black Tickle. Kranck carried out his project in 1949 and it seems likely that his mapping was incorporated into the map of Christie. The name of the intrusion is applied here for the first time, but this may well be subject to revision when more is known about its extent and nature. Information reported here is based on the mapping of Gower *et al.* (1986b).

In the field, the mutual intimate and complex relationships between the mafic and granitoid rocks are the most visually compelling feature. The mafic rocks consist of olivine gabbro, gabbronorite and gabbro, and their partially to completely amphibolitized equivalents. A few rocks were described as dioritic or monzodioritic. At nearby Black Tickle, the mafic rocks include olivine gabbro, transitional eastward into leucogabbro and then anorthosite, which may well reflect primary igneous differentiation. Typically, the mafic rocks are black-, grey- or brown-weathering, fine to coarse grained and massive to strongly deformed. The granitoid rocks are pink-weathering, fine to coarse grained and massive to strongly foliated monzonite, quartz monzonite and granite. Primary igneous contacts between the two groups of rocks display both knife-sharp boundaries and gradational transitions (SP85-142, VN85-418; the latter over a 2 m width), where not severely deformed due to shearing and/or folding. Several instances of mafic dykes showing chilled margins intrusive into monzonitic rocks were seen (SP85-134, SP85-135, SP85-136, VN85-417, VN85-420). As some dykes were identified as direct feeders to larger mafic intrusive bodies (*e.g.*, CG85-418), it is clear that they are closely related to the prevailing mafic magmatism. Xenoliths of monzonitic rocks in gabbroic dykes (VN85-415) also imply mafic magmatism postdating granitoid emplacement. On the other hand, monzonitic dykes intruding gabbro (GM85-406, SP85-137, SP85-146, VN85-418) and gabbroic enclaves within monzonite (SP85-148) imply that the mafic rocks were there first. In most cases, the mafic and monzonitic dykes are planar intrusions, but monzonite agmatitically invading gabbro was seen at GM85-406 and SP85-146. Field evidence forces the conclusion that the mafic and felsic rocks were more-or-less comagmatic.

Three K–Ar geochronological results are available from the area, all obtained by Grasty *et al.* (1969). The author has not examined any of the sites. A date of 944 ± 12 Ma (all dates recalculated using currently accepted decay constants) was obtained on biotite from microcline granite (L31D) from the northwest corner of Spotted Island. The other two were whole-rock results from mafic dykes sampled on nearby islands. From Wedge Island, about 3 km north of Spotted Island, a low-angle, 20-m-thick, very fresh, coarse-grained, olivine gabbro dyke yielded a result of 667 ± 19 Ma (L32A). From Round Hill Island, about 10 km southeast of Spotted Island, a steep, 60-cm-wide, metadiabase dyke showing subophitic texture yielded an age of 816 ± 19 Ma (L23A). The authors did not offer any specific interpretation of these results, but the 944 Ma and 816 Ma dates can be taken as reflecting Grenvillian metamorphism/uplift. The 667 Ma result, coupled with the fact that the rock was described as fresh olivine gabbro, might tempt linking it to the 615 Ma Long Range dykes. Such is unlikely, however, because no extensions of any such dyke have been mapped farther south and, everywhere else, the Long Range dykes are vertical intrusions. On balance, it seems probable that both dykes are related to the mafic rocks described here.

The gabbroic rocks, in thin section, fall into several groups. Two are olivine gabbro showing narrow orthopyroxene–amphibole + spinel double coronas (GM85-423, SP85-141A); three are gabbronorite showing pyroxenes fringed by metamorphic amphibole (CG85-421C, GM85-403, GM85-417); two are gabbronorite that is distinct in having garnet mantling opaque minerals (GM85-405, CG85-414); and three are amphibolite (GM85-408, SP85-142A, SP85-167A). The latter three rocks are extensively recrystallized, but GM85-408 contains hornblende–quartz clusters (probably after clinopyroxene) and SP85-167A was formerly olivine bearing and coronitic. The various types do not seem to show any obvious systematic spatial pattern, other than the olivine-bearing coronitic gabbro samples are both from the southeastern end of Spotted Island, whereas the garnet-bearing rocks are both from the northwestern end. Two amphibolite mafic dykes were also examined in thin section (CG85-421D, SP85-142A). They retain vestiges of skeletal plagioclase, plagioclase microphenocrysts, and evidence of former ophitic texture. All mafic rocks contain red-brown or orange-brown biotite and an opaque oxide. Most contain apatite, and a few have titanite, epidote, hercynite, or serpentine.

Of the granitoid rocks, although commonly termed monzonite in the field, almost all samples were determined to be granite based on thin section evidence (CG85-421A, CG85-421B, GM85-398, GM85-406, GM85-409, SP85-142B, SP85-147C (quartz monzodiorite), SP85-171B). All have extensively polygonized assemblages consisting of plagioclase, microcline (relict perthite in CG85-421A,. CG85-421B), quartz, olive-green biotite, and an opaque oxide. Other minerals seen in most thin sections are apatite, zircon, titanite and allanite, and a few have epidote or chlorite. Two have garnet (CG85-421B, GM85-408).

11.3.5 UNNAMED OTHER ADLAVIK INTRUSIVE SUITE POSSIBLE CORRELATIVES (P_{3C}rg, P_{3C}ln, P_{3C}am, P_{3C}mn, P_{3C}um)

11.3.5.1 General

The remarks made at the start of the previous section on 'Unnamed Other Possible Correlatives to the Adlavik Intrusive Suite' in the Makkovik Province, as regards to outcrop habit, mapping limitations and confusion with the Michael gabbro, apply equally to this subsection. Lacking proof that the Groswater Bay terrane mafic rocks are necessarily correlative with Makkovik Province interpreted equivalents, they are described separately here, albeit involving some repetition. The distribution of the rocks relies on the mapping of Stevenson (1970), Gower (1981), Gower *et al.* (1981, 1982a), Gower (1986) and Erdmer (1984; his units Hum, Hga, Ham).

A high proportion of the rocks assigned to this unit occur between eastern Groswater Bay and Spotted Island, which is partly a function of the area's good coastal outcrop. As a result, spatial patterns tend to suggest predominance of a particular feature (say, garnet distribution) in the east, which may simply reflect sampling bias. In consequence, the author has shunned serious evaluation of petrographic variations across the region in this subunit (but recognizing that, with safeguards, it could be done and some meaningful information probably extracted).

Geochronological data was reported by Schärer *et al.* (1986) for a garnet–biotite gabbro (CG80-350B; *a.k.a.* CG84-468) from near Cuff Island on the south side of the easternmost part of Groswater Bay. Two U–Pb rutile fractions gave *ca.* 931 Ma and *ca.* 923 Ma, from the margin and core of the *ca.* 50-m-diameter body, respectively. These dates do not establish emplacement age, but, rather, record the waning stage of Grenvillian orogenesis. Note that the body was classified as Michael gabbro by Schärer *et al.* (*op. cit.*) but geochemical data renders this doubtful.

Sm–Nd isotopic data gave the following values; T_{DM} = 1.87, 1.66, 1.92, 1.94, 1.85, 2.03, 1.82 Ga and εNd (1.65 Ga) = +2.55, +4.08, +0.85, +0.93, +1.82, +0.68, +3.17 (CG79-411B, CG80-560B, CG80-640B, CG80-715, CG80-809, CG84-350, CG84-483, respectively) (Devereaux, 2011).

The dominant rock type is medium- to coarse-grained gabbro, but included are minor ultramafic rocks, melagabbro, leucogabbro, norite, gabbronorite and dioritic to monzonitic rocks. Net-veined mafic intrusions are seen sporadically. These have metamorphic counterparts, generally in the guise of various types of amphibolite or mafic granulite. Some more felsic rocks, typically monzodiorite or monzonite, are also present, but are minor. A significant minority of the rocks are termed diabase in field notes and were either seen, or inferred, to be fine-, medium-, or even coarse-grained, mafic dykes, some of which are net veined. Mafic dykes are assigned to a separate section below.

A major contrast between these rocks and their interpreted equivalents in the Makkovik Province is their metamorphic state, generally displaying an irregular but overall increasing metamorphic grade progressing southward across the Groswater Bay terrane. This is most readily (but not necessarily) attributable to Grenvillian metamorphism (*cf.* Gower and Erdmer, 1988). Where least metamorphosed, the gabbroic rocks tend to be brown, honey-hued, grey or purplish, but, where transformed to metamorphic derivatives, they are mostly black or, if ultramafic, they may be greenish (both colour changes being mainly due to increasing amphibole content). Along with the mineralogical transformation, there is a crude correlative textural change from massive, ophitic-textured, commonly layered, primary igneous rocks, to foliated/banded, lineated or sheared metamorphic compositional equivalents. Contacts with host rocks may be sharp, discordant and intrusive; or gradational, concordant and transposed. A concomitant change (along with metamorphic modification) is increasing abundance of pegmatitic or microgranite minor intrusions. These are partly responsible for the hydration, as evinced by black, hornblende-rich fringes commonly flanking felsic veins. Other textural variations include coronitic textures mantling olivine, pyroxene or opaque minerals, and poikiloblastic pyroxene, amphibole or biotite.

11.3.5.2 Petrography

Note that several of the locations for which petrographic data are available were also used in paleomagnetic investigations by Murthy *et al.* (1989b) and Park and Gower (1996).

Ultramafic rocks. Examples examined in thin section (CG83-281, CG83-410*, CG83-444, CG83-593, MW82-044, PE82-090*) are somewhat diverse. The asterisk here and subsequently indicates samples for which microprobe mineral analyses have been reported by Gower (1986: sample CG83-410; forsterite, enstatite and magnetite) or Erdmer (1984: sample PE82-090; almandine, hypersthene, biotite and plagioclase (An37)). Three lack any felsic minerals

(CG83-410, CG83-444, MW82-044). Two of these contain olivine, which constitutes >80% of sample MW82-044 (anomalously high for any sample from eastern Labrador), but is very minor in CG83-410. Orthopyroxene is present in CG83-410, CG83-444, CG83-593, PE82-090, whereas clinopyroxene is seen in CG83-281, CG83-444 and MW82-044. Pale green amphibole (Mg-hornblende?) and an opaque oxide are found in all samples, buff-orange biotite in most, and garnet in PE82-090. The garnet in PE82-090 is sieved and enveloped in quartz and plagioclase (decompression texture?). Quartz and K-feldspar are present in some samples as minor metamorphic products.

Gabbronorite. Seven thin sections were labelled gabbronorite (CG79-664, CG80-560B, CG85-019A, CG85-662, GM85-654B, GM85-649A, CG87-652) or norite (CG79-601, CG79-662, CG87-655, CG87-657). There is not much that serves to define them as a group. In particular, CG79-664 is texturally anomalous and might be a misclassified Michael gabbro. Metamorphic, fibrous pale-green amphibole fringing clinopyroxene is fairly common, as is orange-brown biotite fringing an opaque phase. Garnet is present in two of the samples (CG80-560B, GM85-654).

Metagabbro. Twenty-one samples of metagabbro (CG79-636, CG80-048A, CG80-054, CG83-595, CG83-615, CG84-468D, CG84-468E, CG84-492A, CG84-492B, CG85-017, CG85-018, CG85-819, CG85-541, CG85-546A, CG87-353, GM85-652C, GM85-654A, GM85-668, MC77-071A, MC77-236B, VO81-655), two of metaleucogabbro (CG81-366, CG81-367) and three of metadiabase (CG85-547, GM85-652B, VO81-679) were examined in thin section. Plagioclase, clinopyroxene and an opaque oxide and/or sulphide are relict igneous and/or metamorphic phases. Where present, much of the orthopyroxene is a metamorphic coronal phase, as are some of the amphibole, biotite, and most of the garnet and hercynite. Apatite is a characteristic primary accessory mineral.

Amphibolite. Samples examined in thin section and termed amphibolite (CG79-647A, CG79-648, CG79-660, CG83-464; CG85-019B; CG85-547B, CG85-617, DB79-208, GM85-593A, MC77-238B, MW82-125, MW82-126, PE82-062, PE82-065, SG68-111B, SP85-115C, VO81-596B) lack ortho- or clinopyroxene (except clinopyroxene present in CG79-648, MW82-126), instead consisting mostly of metamorphic plagioclase, hornblende, orange-brown biotite, opaque oxide and sulphide, plus accessory quartz, K-feldspar, garnet, apatite, titanite, epidote, and chlorite. Some of the rocks (MW82-123B*, MW82-128) that lack orthopyroxene, but have clinopyroxene, garnet and scapolite are better termed (higher pressure) mafic granulite. Mineral analyses for garnet, clinopyroxene and plagioclase (An_{42}) from sample MW82-123B were reported by Erdmer (1984). To do justice to the variations in mineral assemblages in these rocks and their metamorphic implications would require much more detailed and rigorous investigations than has been attempted so far, but a preliminary evaluation was carried out by Gower and Erdmer (1988).

Associated granitoid rocks. Of the associated granitoid rocks included with this unit, three were named diorite (CG79-400, MW82-038, MW82-123A), two monzodiorite (CG79-871, PE82-247*), three monzonite (CG79-817, CG79-820, VO81-089) and one granodiorite/tonalite (MW82-129). They comprise plagioclase, K-feldspar, quartz (except PE82-247), biotite, hornblende, and opaque minerals (oxide and sulphide), plus clinopyroxene (in PE82-247, CG83-871), and garnet (in MW82-129, PE82-247). Mineral analyses for garnet, clinopyroxene, biotite and plagioclase (An_{13}) from sample PE82-247 were reported by Erdmer (1984). The relationship between these granitoid rocks and the mafic rocks with which they are associated is not made clear in either field notes, or the later region-based reports of Erdmer (1984) and Gower (1986). Especially in the higher grade rocks, it is quite likely that the spatial association between mafic and granitoid rocks is related to subsequent igneous or metamorphic processes, and that they have no genetic linkage.

11.3.5.3 Mafic Dykes (P_{3C}d)

Mafic dykes are an integral feature of the Groswater Bay terrane Adlavik-type mafic magmatism, and a more detailed, but still preliminary, investigation was carried out on some dykes exposed in coastal outcrops along the south side of Groswater Bay. As developed below, it cannot be taken for granted that these dykes are, necessarily, affiliated with Adlavik-type mafic magmatism. Table 11.2 lists dykes that were examined petrographically.

The dykes are all metamorphosed and strongly deformed, and commonly highly contorted into complex fold structures. There would have been little point in recording dyke trends. The dykes discordantly intrude gneissic fabrics in Labradorian (or older) host rocks. Commonly, two or more generations of mafic dyke are seen, showing the younger dyke(s) unequivocally discordantly intrude earlier dyke (s).

Rb–Sr isotopic data (Brooks, 1982b), which includes seven of the samples listed in Table 11.2, do not deliver definitive geochronological ages, but do provide three pieces of useful information. First, the three italicized samples in Table 11.2 indicate an isochron age of 1383 ± 56 Ma (I_{Sr} = 0.70165), which is, within error, comparable with the U–Pb zircon age of 1426 ± 6 Ma age for the Michael gabbro (Schärer *et al.*, 1986). This suggests some of the dykes, in fact, are not related to Adlavik-type mafic magmatism. Second, two of the earlier dykes (CG80-304B, CG80-337B) have close isotopic similarity. Third, two of the later dykes (CG80-304C, CG80-337C) also have isotopic similarity, but different from the earlier dykes. The two localities that sample earlier and later dykes (CG80-304, CG80-337) are 11 km apart, which implies that the matching of Rb–Sr isotopic character with relative age is potentially of regional significance (testing this thesis might be a rewarding study).

For the most part, the dykes have granoblastic fabrics, but relict ophitic texture remains discernable in some of them, although most of the plagioclase laths and(or) mafic minerals (especially clinopyroxene) that define primary texture are internally recrystallized to polygonal aggregates. It is in the rocks having relict ophitic texture that the coronal garnet is seen as necklaces of fairly coarse crystals mantling relict/recrystallized primary silicates. Non-coronal garnet forms an integral part of the high-grade granoblastic fabrics. Relict igneous or metamorphic granoblastic clinopyroxene is very common, but orthopyroxene is very rare, and no olivine remains. An opaque oxide (typically as recrystallized

Table 11.2. Metamorphosed mafic dykes from the Groswater Bay terrane

Sample	Relative Age	Rock Type	Special Features
CG80-304B*	Earliest dyke	Coronitic metadiabase	Relict ophitic texture; garnet coronas
CG80-304C*	Middle dyke	Amphibolite	Thin section no longer available
*CG80-304D**	Youngest dyke	Coronitic metagabbro	Relict ophitic texture; garnet coronas
CG80-321B		Coronitic metadiabase	Plagioclase-phyric; garnet coronas; granoblastic
CG80-333A	Earlier dyke	Leuco-amphibolite	Garnet (non-coronal), scapolite
CG80-333B	Later dyke	Amphibolite	Garnet (non-coronal), scapolite
CG80-337B*	Earlier dyke	Amphibolite	Foliated; granoblastic
CG80-337C*	Later dyke	Amphibolite	Foliated; granoblastic; scapolite
CG80-338A	Earlier dyke	Amphibolite	Gneissic; granoblastic
CG80-338B	Later dyke	Leuco-amphibolite/Diorite	Foliated; retrograded
*CG80-348**		Amphibolite	Garnet (non-coronal), scapolite; granoblastic
*CG80-350B**		Coronitic metagabbro	Relict ophitic texture; garnet coronas
CG80-388A		Coronitic metadiabase	Plagioclase-phyric; garnet coronas; granoblastic
CG80-694A	Earliest dyke	Amphibolite	Garnet (non-coronal); scapolite; granoblastic
CG80-694B	Middle dyke	Leuco-amphibolite/Diorite	Foliated; retrograded
CG80-694D	Youngest dyke	Amphibolite	Foliated; granoblastic

* Rb–Sr data available. *Italics* – samples that might be Michael gabbro (*see* text).

aggregates) and apatite are common accessory minerals. Secondary titanite, allanite, epidote, white mica, carbonate, serpentine and chlorite are sporadically present.

11.4 HAWKE RIVER TERRANE

11.4.1 DYKES RIVER MAFIC INTRUSIONS (P_{3C}um, P_{3C}rg, P_{3C}ln, P_{3C}ln)

Mafic intrusive rocks in the Dykes River area (Figure 11.1), southeast of Cartwright, are indicated on Eade's (1962) map. Eade's information was based on two short ground-traverse loops from lakes in the area and one lakeshore observation. The information presented here combines the field notes and sampling of Gower *et al.* (1982b) with information from mineral exploration northwest of Dykes River (Clarke and De Carle, 1996; Lucko, 1997; Gower, 2010c) and examination in 2004 by the author of (then) recently created roadcuts. The name 'Dykes River mafic intrusion' is newly introduced here. No geochronological data are available.

As mapped, there are two bodies separated by a few kilometres of dioritic rocks of the Earl Island intrusive suite, which also surrounds the intrusions on their other sides. The mafic bodies are assumed to be closely related. A key characteristic of the intrusions that distinguishes them from other presumed correlative mafic intrusions in eastern Labrador, is the more common presence of ultramafic rocks (Plate 11.3A), especially in the smaller, northwest body. Rock types present in the bodies are peridotite, gabbronorite, gabbro, diorite, and their melanocratic and leucocratic analogues, plus metamorphic derivatives (mostly various types of amphibolite). The rocks are black-, grey-, greenish-, brown- or rusty-weathering and medium to coarse grained. The brown/rusty appearance is due to significant sulphide in some rocks. Typically, the rocks are massive, homogeneous and poorly foliated, although zones of ultramylonite attest to very severe localized deformation. More detailed mapping would undoubtedly reveal a much more complex structure than currently depicted on 1:100 000-scale maps. Subophitic textures are commonly preserved in the gabbroic rocks. Double-corona textures fringing olivine were sporadically noted in CG04-245 (Plate 11.3B), CG04-265, CG04-267, CG04-271, CG04-272, VO81-481. Hornblende was recorded in some outcrops as megacrysts, or as poikilitically enclosing pyroxene. It is evident that amphibole is an essential primary igneous mineral in some of these rocks and that, where termed meladiorite or diorite in the field, such identification is likely to be valid (rather than necessarily being hydrated metamorphic derivatives, as is commonly the case in the Lake Melville terrane, for example). Primary igneous layering was seen in many outcrops (CG04-243, CG04-246, CG04-265, CG04-267, VO81-264, VO81-268, VO81-293, VO81-295). The layers range in thickness from about 1 cm to 10s of centimetres (generally, narrow mafic layers with much wider felsic layers in between), and, collectively, multiple-layered units may be 10s of metres thick. Some of the layers are clearly graded from ultramafic bases to anorthositic tops (Plate 11.3C).

Plate 11.3. *Features of Dykes River mafic intrusion, and net-veined mafic rock from southeast Sandwich Bay. A. Ultramafic rock, Dykes River mafic intrusion (CG04-243), B. Coronitic metagabbro, Dykes River mafic intrusion. Orange cores to mafic mineral grains are altered olivine (CG04-245), C. Ultramafic to anorthositic layering in Dykes River mafic intrusion (CG04-265), D. Net-veined mafic rock of uncertain affiliation; southeast shore of Sandwich Bay (GF81-105/MC77-075).*

Lenses of metallic oxide up to 30 cm wide and several m long, were recorded at CG04-248. Amphibolitic rocks tend to occur around the fringes of the Dykes River bodies. Although the amphibolite commonly also retains vestiges of primary fabrics, migmatization is locally evident. White-weathering pegmatitic pods, lenses and veinlets occur sporadically throughout the intrusions.

Petrographically, the rocks are divided here into four groups, namely: i) ultramafite, ii) gabbronorite/gabbro, iii) diorite, and iv) amphibolite. The ultramafic rocks (CG04-243A, CG04-243B, CG04-243C, CG04, 247, CG04-248A) are olivine cumulates with intercumulus poikilitic clinopyroxene and, less commonly, orthopyroxene. Typically, the olivine is enveloped in a narrow corona of fibrous, radial orthopyroxene and a very broad corona of symplectic pale-green to colourless amphibole plus spinel. As addressed elsewhere, such a texture is characteristic of reaction between olivine and plagioclase, but no plagioclase is present in these samples. As the coronal minerals occupy all the space between olivine crystals (where intercumulus pyroxene is lacking), it is inferred that some plagioclase was originally present but has all been consumed. Spinel, in addition to its occurrence as a symplectite mineral, forms small, dark yellowish-green subhedral to euhedral crystals. These appear to be primary magmatic, perhaps hosting much of the high Cr (*cf.* pictotite) indicated from whole-rock analyses (855–2084 ppm; Gower, 2010c). Apart from spinel, most of the oxide present is secondary from olivine serpentinization. Sulphide was recorded in CG04-248A.

Three gabbronorite/gabbro samples were examined in thin section; all are distinct, being olivine gabbro (VO81-481), gabbro (CG04-266) and gabbronorite (CG04-275). The olivine gabbro has a cumulate texture and exhibits orthopyroxene–amphibole + spinel double coronas, has poikilitic clinopyroxene, and late-crystallizing primary igneous opaque oxide mantled by primary yellow-brown amphibole (which, itself, has an amphibole–spinel symplectite against plagioclase). The other two rocks are also cumulate rocks, but involving cumulus pyroxenes and plagioclase, and both are characterized by the same style of intercumulus opaque oxide mantled by yellow-brown amphibole as seen in the olivine gabbro (only much more abundant).

Despite discriminating between diorite and amphibolite, some doubt exists in the author's mind regarding whether the rock-name distinction is really meaningful. The diorite (CG04-245C) is so-termed because the principal minerals, namely plagioclase and hornblende, look igneous and the rock has no fabric. Of the amphibolites, VO81-226 also lacks a fabric, but plagioclase and amphibole occur as polygonal recrystallized aggregates outlining a former ophitic texture. The other three amphibolite samples (VO81-243, VO81-236, CG04-248B) are, in the order listed, progressively more melanocratic and more deformed, so cover the spectrum from diorite to amphibolite. The last listed, CG04-248B, is texturally interesting in that it is severely mylonitized but retains numerous small porphyroclasts of plagioclase and hornblende in a polygonized matrix of the same minerals. It also has strands and clusters of small, euhedral garnet porphyroblasts, and is the only mafic rock from the Dykes River mafic intrusions known to be garnet bearing.

To be concluded from field and petrographic data is that the Dykes River intrusions were derived from hydrous mafic magmas that differentiated to produce ultramafic to dioritic rocks, and were later subjected to locally severe deformation, but only medium-grade metamorphism.

11.4.2 DYKES RIVER MAFIC INTRUSIONS POSSIBLE CORRELATIVES (P_{3C}um, P_{3C}rg)

Apart from the Dykes River mafic intrusions, there are many other smaller bodies of mafic rocks scattered throughout the Earl Island intrusive suite, ranging up to roughly 5 km long. Evidence does not demand that they belong to the same mafic intrusive event as that represented by the Dykes River bodies, but they do show many similarities, hence the author's preferred view that genetic linkage exists. Prior to 1:100 000-scale mapping, these occurrences were not shown on geological maps, except for one body about 5 km southwest of Stoney Arm designated as basic gneiss by Eade (1962). Key similarities of these rocks with the Dykes River mafic intrusions are: i) the relatively high proportion of ultramafic rocks, ii) gradation from gabbroic to dioritic rocks (and their metamorphic equivalents), iii) rarity of olivine-bearing rocks.

Ultramafic rocks. These are dark-green- to black-weathering, medium to coarse grained (crystals up to 2 cm across – VN85-075) and massive to sheared. Two occurrences were described as having 'sill-like' form, and one (CG81-047) is a dyke. Rarely, they are injected by quartz or pegmatitic veinlets. In the field, they were mostly termed pyroxenite, and only one was recorded as olivine bearing.

Thin sections were prepared from all nine known localities (CG81-047, CG85-348, GM85-308, GM85-338, GM85-540B, GM85-557A, GM85-576, MC77-025B, VN85-075). Despite field names, only one contains minor clinopyroxene (VN85-075) and no olivine is present in any of the samples examined in thin section. The prevailing mineral assemblage is metamorphic, overwhelmingly comprising pale-green amphibole and pale-orange-brown biotite, with minor plagioclase (but perhaps enough in some cases for the rock to be termed mela-amphibolite), an opaque oxide, sulphide (in GM85-308, GM85-338, GM85-540B, GM85-576), and traces of secondary titanite, rutile, chlorite, epidote and prehnite. The pale colours of amphibole and biotite suggest Mg-rich compositions. Field names reflect protolith contenders, as it is likely that the rocks were originally pyroxenite or melagabbro.

Mafic rocks. The mafic rocks were mostly termed gabbro, metagabbro, diorite or amphibolite in the field. Field notes very commonly hedge on whether the rock was metagabbro or diorite, encouraging the conclusion that no clear-cut distinction exists, which is supported petrographically. The rocks are grey- or black-weathering, medium to coarse grained, and, most commonly, massive or weakly foliated (but thin section GM85-644A is mylonitic). Relict subophitic texture was recorded at many outcrops and indistinct layering sporadically (CG85-341, CG85-659, GF81-093). Typically the rocks are not phenocrystic, although sample GM85-583B does have a few larger-than-groundmass plagioclase crystals. Sharp contacts against the enveloping granitoid rocks were noted in many places. In rare instances, the rocks are injected by granitic veinlets. A spectacular example of net veining of a mafic rock in a pelitic gneiss host rock is seen at GF81-105/MC77-075 (Plate 11.3D).

The mineral assemblage is transitional between igneous and metamorphic (thin sections CG81-080, CG85-338, CG85-341, CG85-352, CG85-357, CG85-508, EA61-056, GM85-002, GM85-100, GM85-264, GM85-306, GM85-326, GM85-339, GM85-535, GM85-552B, GM85-557D, GM85-583B, GM85-644A, GM85-680, LC85-017A, LC85-020, LC85-064B, LC85-067, MC77-232C, VN85-006, VN85-061, VN85-280, VN85-512). It consists of partially primary plagioclase and relict primary clinopyroxene in about 40% of the samples, relict primary orthopyroxene (20% of samples). All samples have relict igneous and/or metamorphic leaf-green to blue-green hornblende and, in most samples, orange-brown biotite, relict igneous and(or) metamorphic opaque oxide, sulphide and apatite in most samples, and sporadic secondary titanite, allanite, epidote, white mica, chlorite and prehnite. Quartz (common) and K-feldspar (rare) are present as interstitial minerals in some samples. Quartz also occurs as inclusions in amphibole where it has pseudomorphed clinopyroxene, a process also indicated by amphibole fringes around clinopyroxene. Garnet was seen in one thin section (CG85-341; near a thrust). That its scarcity is genuine is supported by it having only been recorded in the field at two other sites in mafic rocks associated with the Earl Island intrusive suite (GF81-026, GF81-093; both close to the west end of the Earl Island domain). One thin section (CG81-080), from a locality near the intersection of major pre-Grenvillian and post-Grenvillian faults has been retrograded to a greenschist-facies assemblage.

As for the Dykes River intrusions, it is concluded that the rocks were derived from hydrous mafic magmas that differentiated to produce ultramafic to dioritic rocks, and later subjected to locally severe deformation, but only moderate metamorphism.

11.4.3 METAMORPHOSED MAFIC DYKES IN THE EARL ISLAND INTRUSIVE SUITE (P_{3C}d)

11.4.3.1 Field Description

Deformed and metamorphosed mafic dykes (also referred to as amphibolite dykes or metadiabase dykes in the database) are common within the Earl Island intrusive suite. All are amphibolite, with one exception that is ultramafic (CG81-047). The dykes are typically 1–5 m wide (15 m at GM85-647) and commonly retain a roughly planar shape, despite being boudinaged, folded, or otherwise contorted by deformation. The dykes do not show any consistent orientation, which, given their structural history, is not surprising. The rocks are characteristically grey- or black-weathering, fine to medium grained, weakly foliated to mylonitic, equigranular and homogeneous. A few have plagioclase or hornblende phenocrysts. That they are dykes is not in doubt as their contacts truncate fabrics and minor intrusions within their host granitoid rocks and, despite metamorphism, some dykes retain chilled margins. The dykes are also intruded by later minor granitoid intrusions in places.

At two localities (CG84-436, CG85-492), two phases of mafic dykes are present (Plates 10.5 and 10.6). The earlier dykes are grey-black-weathering, strongly deformed and somewhat migmatitic. They have internal fabrics that are similar to those in their granitoid hosts, but their margins truncate minor granitoid intrusions within the host rock. The later dykes are black-weathering, weakly foliated and clearly discordantly intrude the earlier mafic dykes.

11.4.3.2 Age

The age of the mafic dykes has been constrained by U–Pb geochronology at four localities – the two mentioned above, plus two others where only a single phase of mafic dyking is seen (Table 10.1). Localities mentioned in this section are located on Figure 10.1.

At Red Island (locality CG84-436), the quartz diorite host rock to both phases of mafic dykes has a concordant zircon age of 1671 ± 4 Ma (Schärer *et al.*, 1986) and the younger mafic dyke is discordantly intruded by a K-feldspar megacrystic intermediate rock that has yielded a discordant zircon age of 1660 +8/–7 Ma (Gower *et al.*, 1992). This age bracketing implies that both mafic dyke phases were emplaced between *ca.* 1671 and 1660 Ma.

At Partridge Bay (locality CG85-492), a quartz diorite host rock, very similar to that at Red Island, has a concordant zircon age of 1668 +6/–4 Ma (Schärer and Gower, 1988). A pegmatite that discordantly intrudes the younger mafic dyke has an age of 1622 ± 3 Ma, based on a zircon–xenotime regression (Gower *et al.*, 1992). The time of emplacement of the mafic dykes is thus constrained to between *ca.* 1668 and 1622 Ma. As the host rock also yielded a concordant titanite age of 1642 ± 4 Ma (Schärer and Gower, 1988), however, it can be concluded that the mafic dyking was between *ca.* 1668 and 1642 Ma, because the younger mafic dyke is at amphibolite facies, an event that would have reset the titanite age in the host rock had it happened after 1642 Ma.

At the third locality (Shoal Bay, CG85-532; Plate 10.7B), a pink granite is intruded by a near-planar metamorphosed mafic dyke that looks like the younger of the two phases described above. The granite gave a moderately discordant zircon age of 1663 ± 3 Ma and a concordant titanite age of 1649 ± 4 Ma (Schärer and Gower, 1988). Employing the same reasoning as given for the previous sample regarding time of metamorphism *vs.* titanite closure, the time of emplacement of the dyke is constrained to between *ca.* 1663 and 1649 Ma.

At the fourth site (1.8 km farther west-northwest at Shoal Bay), tonalite–granodiorite gneiss (CG85-654A) is discordantly intruded by a pink granite (CG85-654B) like that seen at the previous site (Plate 10.7A). A metamorphosed mafic dyke intrudes the tonalite–granodiorite gneiss, but its relationship to the pink granite is not seen. The tonalite–granodiorite gneiss has a moderately discordant zircon age of 1671 +4/–3 Ma (Schärer and Gower, 1988) and a concordant titanite age of 1646 ± 2 Ma. The pink granite gave a moderately discordant age of 1662 ± 3 Ma (Kamo *et al.*, 1996). One analysis of titanite from the mafic dyke (CG85-654C) yielded a $^{207}Pb/^{206}Pb$ age of 1617 Ma (Kamo *et al.*, 1996). Most rigorously, the geochronological data indicate most mafic dyke emplacement was between *ca.* 1671 and 1617 Ma, but, utilizing titanite-closure reasoning, it was probably between 1671 and 1646 Ma.

Collectively, U–Pb geochronological data provide formidable evidence for emplacement of both phases of mafic dykes between *ca.* 1670 and 1645 Ma. The earlier mafic dykes were probably emplaced before or during the major Labradorian orogenic event, which regional geochronological data indicate to have occurred around 1665 Ma. The youngest mafic dykes were probably coeval with the major mafic intrusions in the region that were emplaced between 1650 and 1640 Ma. The dykes are thus an integral part of the Labradorian magmatic history, and cannot be linked to any earlier or later anorogenic event.

Some Ar–Ar isotopic data are also available (Table 11.3). Three of the mafic dyke samples are from sites at which U–Pb age constraints are available. The dates show a range from 1584 ± 7 to 1161 ± 3 Ma. These results do not

Table 11.3. Ar–Ar data for metamorphosed mafic dykes intruding the Earl Island intrusive suite

Sample No	RockType	U–Pb Age Constraints	Age (Ma)	Method	Source
CG84-436C	Unmigmatized mafic dyke	1671 Ma > dyke > 1660 Ma	1161 ± 3	Hornblende; Ar–Ar, total gas	Dallmeyer (unpub.)
CG85-492B	Migmatized mafic dyke	1668 Ma > dyke > 1622 Ma	1584 ± 7	Hornblende; Ar–Ar, total gas	Dallmeyer (unpub.)
CG85-492C	Unmigmatized mafic dyke	1668 Ma > dyke > 1622 Ma	1518 ± 4	Hornblende; Ar–Ar, total gas	Dallmeyer (unpub.)
VAN84-14B	Unmigmatized mafic dyke	Regional correlation	1382 ± 8	Hornblende; Ar–Ar, total gas	van Nostrand (1988)
VAN84-32A	Unmigmatized mafic dyke	Regional correlation	1246 ± 1	Hornblende; Ar–Ar, plateau	van Nostrand (1988)
VAN84-32A	Unmigmatized mafic dyke	Regional correlation	1241 ± 3	Hornblende; Ar–Ar, total gas	van Nostrand (1988)

provide emplacement ages but, instead, reflect variable Ar loss during relatively weak Grenvillian metamorphism (Gower, 2003).

11.4.3.3 Petrography

Table 11.4 is a list of 16 mafic dykes intruding the Earl Island intrusive suite that have been examined petrographically. Plagioclase is mostly metamorphic, but relict igneous plagioclase is preserved in a few thin sections. In CG85-004B, igneous plagioclase is distinct in that it shows strong zoning, is skeletal, and is heavily dusted with opaque inclusions. The rock is texturally distinct from the other samples and it is possible that this dyke is not related to the others, as it is also the only mafic dyke to retain relict igneous clinopyroxene. Plagioclase is somewhat recrystallized in MC77-009B and VN85-525, but, in MC77-009B, plagioclase shows remnants of primary skeletal form, and, in VN85-525, primary plagioclase phenocrysts up to 1 cm long displaying irregular recrystallized borders are seen. In all samples, amphibole is mostly leaf-green to blue-green hornblende, except in CG81-047 (ultramafic rock), in which some amphibole is tremolitic. Most samples contain biotite (green-buff to orange-brown), an opaque oxide and apatite. About one third of the samples contain sulphide. Titanite, allanite and epidote are each present in about half the samples, and, in some cases, are stable phases. Accessory quartz is seen in a few samples. Secondary minerals are mostly chlorite and white mica. Apart from the mention of clinopyroxene above, there are no primary mafic silicates, although quartz-sieved hornblende testifies to the former presence of clinopyroxene in MC77-009B. Garnet was recorded in the field in the earlier mafic dyke at Red Island (locality CG84-436). Its lack elsewhere and stability of epidote point to only moderate metamorphism, which must have been Labradorian as *ca.* 1650 Ma titanite dates deny a severe post-Labradorian metamorphic overprint.

Table 11.4. Metamorphosed mafic dykes (amphibolite) intruding the Earl Island intrusive suite

Sample	Trend	Special Features	Age Constraints
CG81-047	020/75	Ultramafic	
CG84-436B	Unknown	Earlier dyke	1671 Ma > dyke > 1660 Ma
CG84-436C	065/90	Later dyke	1671 Ma > dyke > 1660 Ma
CG84-478	020/90	Plagioclase phenocrysts	
CG85-004B	135/45	Later dyke; skeletal, clouded plagioclase	
CG85-492B	095/?	Earlier dyke	1668 Ma > dyke > 1622 Ma
CG85-492C	150/?	Later dyke	1668 Ma > dyke > 1622 Ma
CG85-508	020/90		
CG85-532B	015/90		1663 Ma > dyke >?1649 Ma
CG85-654C	Unknown	Abundant epidote	1671 Ma > dyke > 1617 Ma
GM85-574A	Unknown	Hornblende phenocrysts	
GM85-674B	060/90	Folded foliation	
GM85-681D	Unknown	Some epidote	
GM85-686B	172/85	Plagioclase phenocrysts	
MC77-009B	Unknown	Relict skeletal plagio-clase quartz inclusions in hornblende	
VN85-525	Unknown	Plagioclase phenocrysts	

11.4.4 WHITE BEAR ARM COMPLEX AND SAND HILL BIG POND INTRUSION

11.4.4.1 General Description

The White Bear Arm complex (WBAC) is a major mafic plutonic body extending from Sandwich Bay to the southeast Labrador coast, a distance of 150 km. The Sand Hill Big Pond intrusion (SHBP) is an elliptical body northeast of the WBAC, measuring roughly 20 by 8 km (Figure 11.4). The two units are addressed collectively, adopting Gower *et al.*'s (1986b) interpretation that they were a single entity prior to being spilt apart by emplacement of the Paradise Arm pluton (Figure 11.5).

One of the earliest references to the WBAC was made by Kranck (1939) who recorded basic (amphibolite) schists in the Cape St. Michael area and anorthositic rocks on Square Island. Christie (1951) also noted gabbro, anorthosite and amphibolite in the Square Island area. The inland extent of the body was delineated by Brinex geologists in the early 1950s and reported on by Piloski (1955). Piloski termed the intrusion the White Bear Arm gabbro and noted it as extending 75 miles northwest from White Bear Arm; having a width of 8 miles; and consisting of gabbro, diorite and anorthosite. The earliest published map to show the full extent of the body was by Eade (1962), who incorporated the unpublished mapping of Brinex. Eade lists gabbro, diorite, anorthosite and pyroxenite as component rock types. The southeast coastal part was mapped in

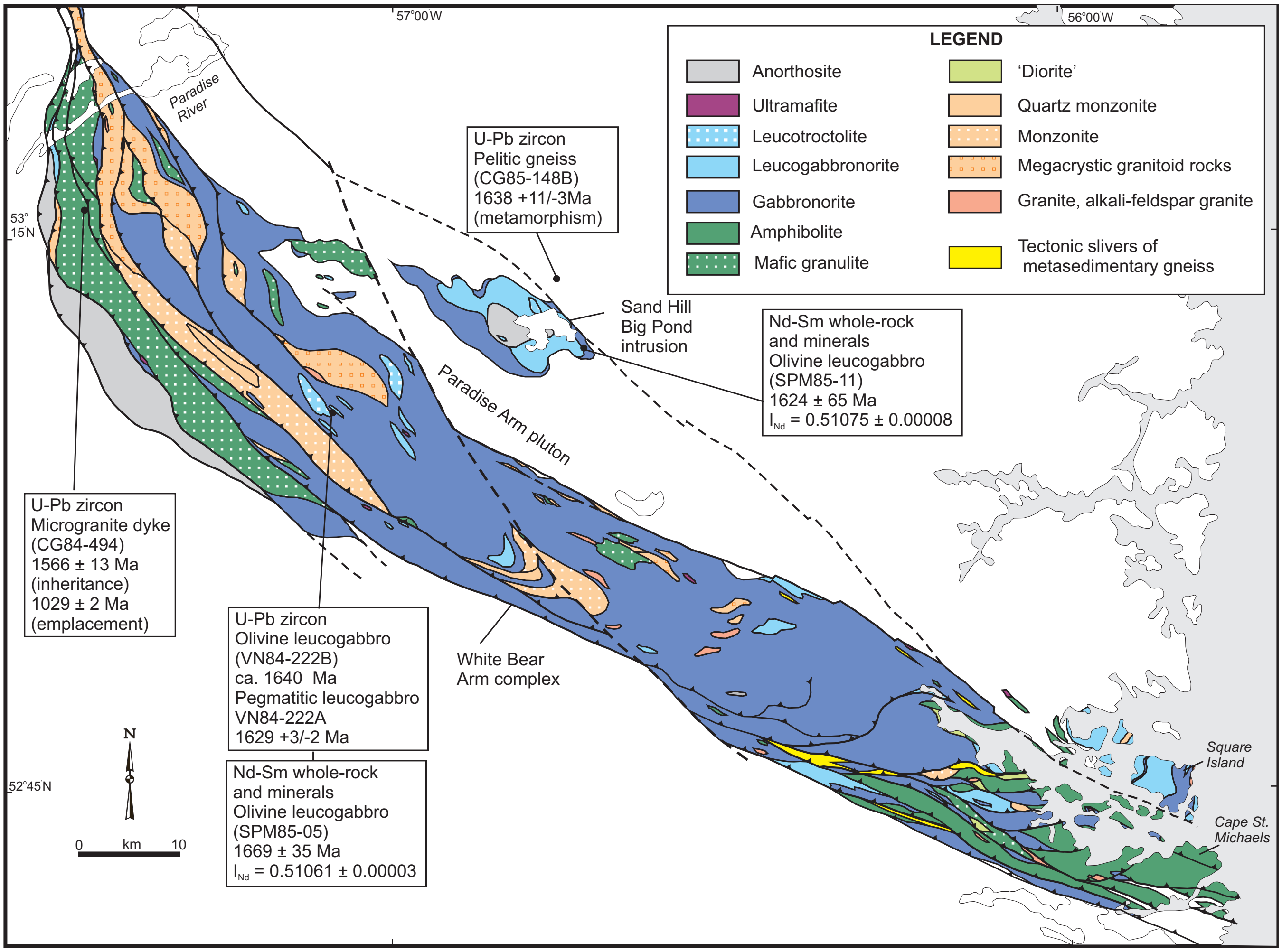


Figure 11.4. *Rock type distribution in the White Bear Arm complex and Sand Hill Big Pond intrusion.*

more detail by Wardle (1976, 1977) who referred to the intrusion as the White Bear Arm norite and recorded the rocks as norite, anorthositic norite, pyroxenite and amphibolitic metamorphic derivatives. The modification of the name to White Bear Arm complex was made by Gower *et al.* (1985), following 1:100 000-scale mapping of the northwest end of the body in the Paradise River area, in acknowledgement that the body comprises both igneous and metamorphic parts. This theme was developed by Gower *et al.* (1987), who subdivided rock types of the White Bear Arm complex into two broad groups, namely i) those having primary igneous mineral assemblages and textures, and ii) recrystallized and hydrated metamorphic derivatives. These groups can be equated in general terms with units 1 and 2, respectively, of Wardle (1977). The first group includes fine- to extremely coarse-grained gabbronorite (having leucocratic and melanocratic variants), olivine gabbronorite, monzogabbronorite, monzonite–syenite (including quartz bearing types) and granite. The second group includes mafic granulite, amphibolitic and dioritic gneiss associated with lesser tonalitic, monzonitic and granitic gneiss. This still seems a useful approach and the concept is retained behind the present classification.

The SHBP intrusion was mapped at 1:100 000 scale and named by Gower *et al.* (1986b), although its extent had been roughly delineated earlier by Brinex geologists (Piloski, 1955). Their mapping was compiled by Eade (1962). Brinex carried out further mapping in the 1960s (Donohoe, 1966). The rocks are recorded as anorthosite–gabbro. The boundary of the intrusion shown by Donohoe corresponds broadly with that determined during 1:100 000-scale mapping. Note that, in Donohoe's report, Sand Hill Big Pond is termed Don Lake.

11.4.4.2 Structure

The structural geometry of the WBAC is important in its understanding (Figure 11.5). The southern flank of the body has been deformed into numerous thrust-bound slices,

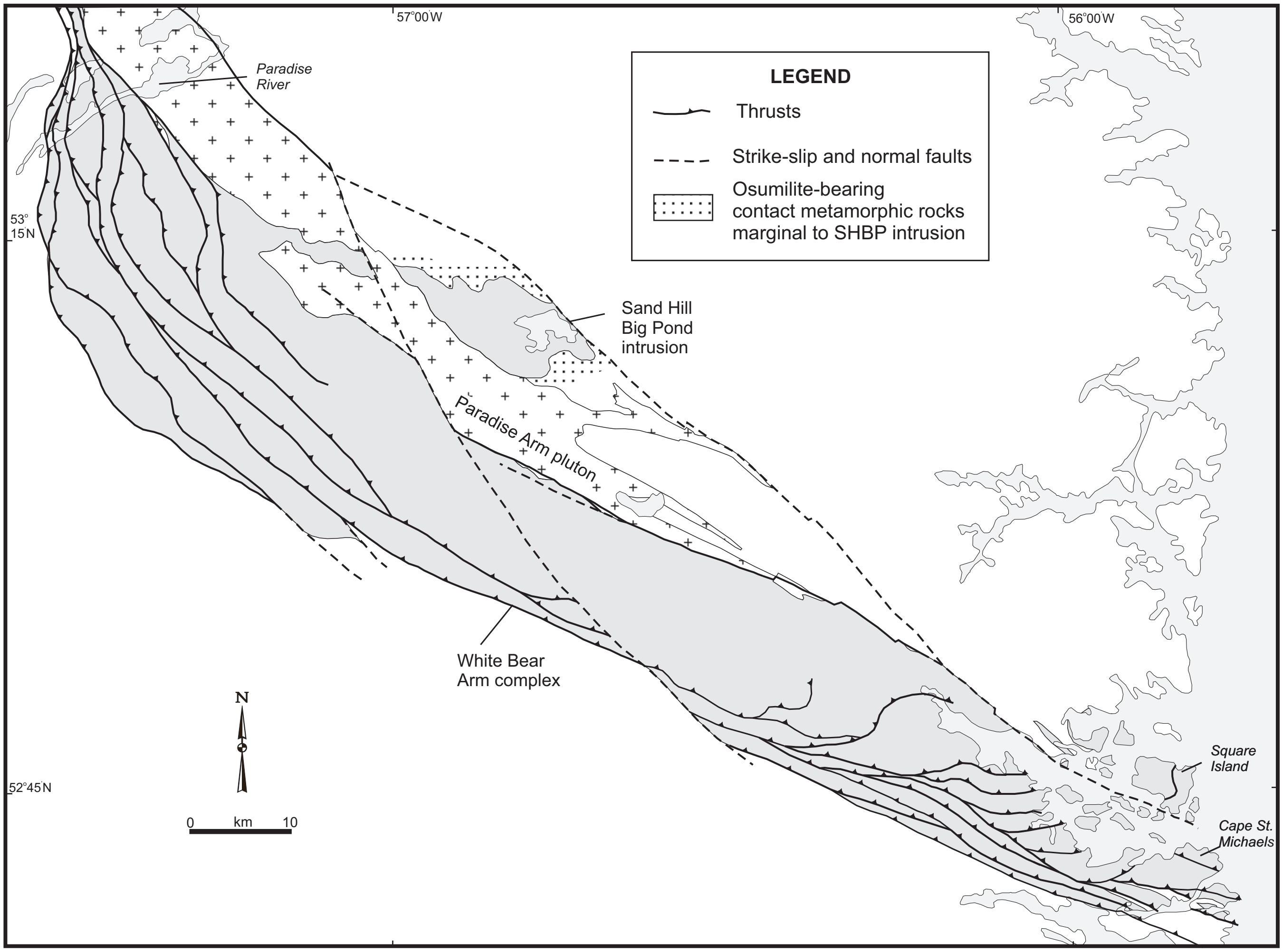


Figure 11.5. *Structural framework for the White Bear Arm complex and Sand Hill Big Pond intrusion.*

with which metasedimentary gneiss slivers are interleaved. The thrusts are most abundant at the ends of the intrusion, having west to southwest vergence at its northwestern end, and southeast to south vergence at its southeastern end. The thrusting is interpreted to be Labradorian (Gower *et al.*, 1997a; Gower, 2005), but, at its western end, structures were modified during Grenvillian metamorphism. Note that both ends of the WBAC wrap around, such that structures are north trending. The northern flank of the WBAC is also fault-bounded, being a zone of weakness that has been utilized by the 1639 Ma Paradise Arm pluton (next chapter). This has acted as a wedge separating the SHBP intrusion from the WBAC, implying that the initiation of the fault must be earlier Labradorian. The contact between the Paradise Arm pluton and SHBP intrusion is likely intrusive, but such has not been firmly established. The SHBP intrusion, along its northern and southeastern flanks, intrudes the Paradise metasedimentary gneiss belt resulting in high-grade, osumilite-bearing, contact metamorphic assemblages (Arima and Gower, 1991) (Section 7.3.3.5). These are not present along the SHBP intrusion's northeastern boundary, which is interpreted to be a fault. Finally, the WBAC was affected by later (probably Grenvillian), northwest-trending, dextral faults, that obliquely cross the WBAC. The most significant of these is shown in Figure 11.5 which offsets the western half of the WBAC and Paradise Arm pluton from their eastern parts by about 8 km.

Figure 11.6 shows some aspects of the interpreted emplacement and subsequent deformation of the WBAC. Given the evidence of primary igneous layering, the body is assumed to have formed in a laterally extensive horizontal magma chamber. It is then envisaged as having been tectonically emplaced as an inclined tongue (or, to be thought of, as a flat sheath-like structure, Figure 11.6A). The lack of a well-developed imbricate thrust package in the central part of the southern side is considered due to excising of the nose of the structure by later faulting. Two alternatives are offered in Figure 11.6, namely either south-side-up or dextral strike-slip faulting (Figure 11.6B–E are discussed in a

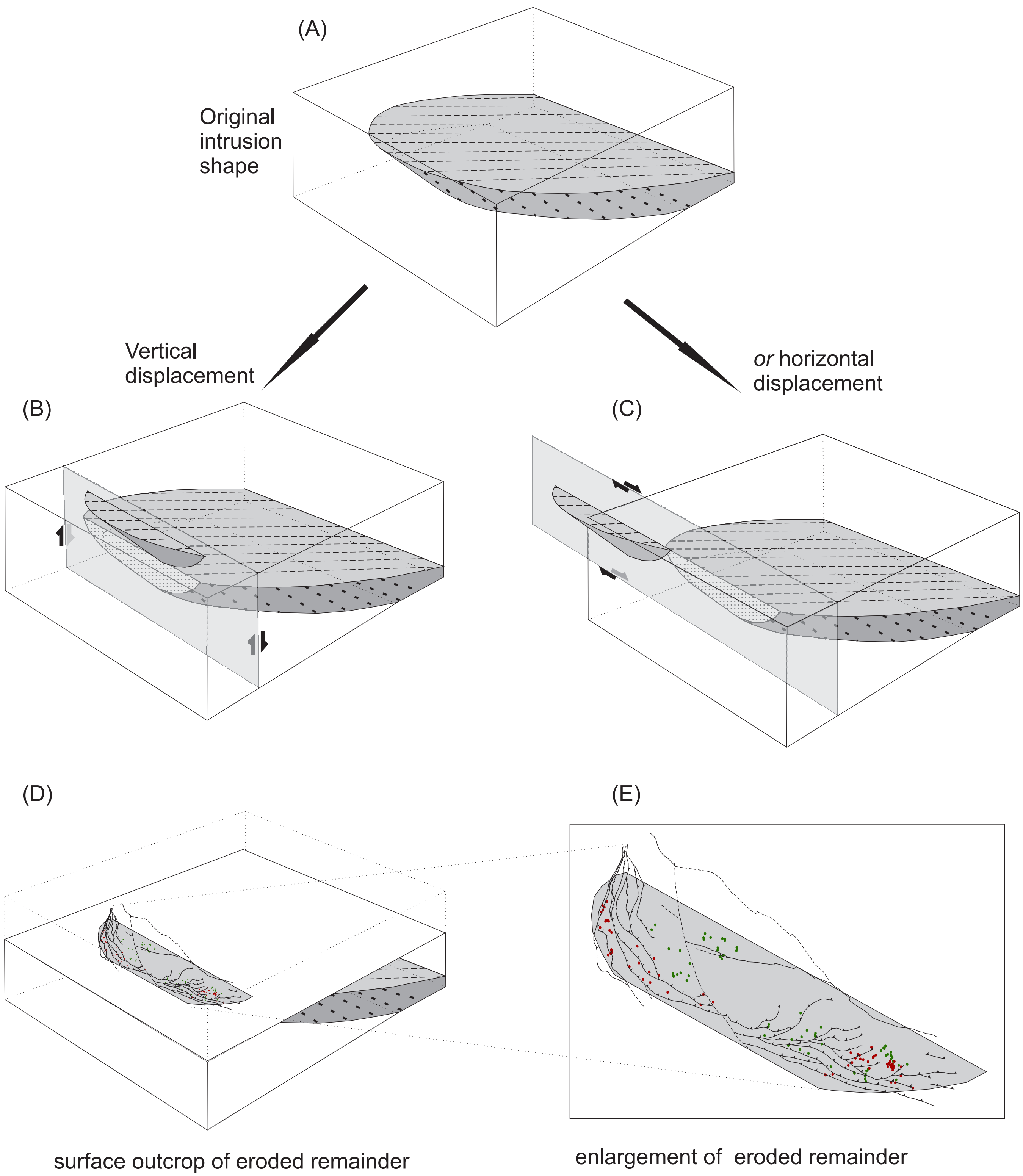


Figure 11.6. *Interpreted mode of emplacement and subsequent deformation of the White Bear Arm complex.*

subsequent section). Based on regional kinematic evidence, the author favours a dominantly dextral strike-slip regime, but also involving some uplift on the southern side. The age of this displacement is inferred to be Grenvillian. A possible candidate for the displaced 'nose' of the structure is the 'WBAC correlative?' described following documentation of the WBAC.

11.4.4.3 Age of WBAC and SHBP

U–Pb dating. The age of the White Bear Arm complex is known from a U–Pb investigation by Kamo *et al.* (1996). Two samples were analyzed, a coronitic olivine leucogabbro and a mafic pegmatitic phase of the leucogabbro (Figure 11.4). From the coronitic olivine leucogabbro (VN84-222B), zircon, baddeleyite and monazite were recovered. The analytical results point to a complex history. Results can be summarized as follows: i) three multigrain fractions of zircon define a regression line with poorly constrained upper and lower intercepts of 1639 +661/–7 Ma and 970 +970/–670 Ma, ii) two multigrain baddeleyite fractions define an imprecise line having upper and lower intercepts of 1630 +103/–8 Ma and 1070 +405/–360 Ma, iii) two additional single baddeleyite grains, but having zircon overgrowths, fall on a reference mixing line between 1640 and 1470 Ma (the upper intercept is 1650 +142/–14 Ma, if the lower intercept is anchored between 1500 and 1470 Ma), iv) five single monazite grains yield concordant and near-concordant $^{207}Pb/^{206}Pb$ ages between 1604 Ma and 1541 Ma, and v) the monazite results, when combined with those from zircon and baddeleyite, plot on or near a reference mixing line from 1640 to 1470 Ma.

From the pegmatitic leucogabbro (VN84-222A), zircon and titanite were recovered (Kamo *et al.*, 1996). Four near-concordant and concordant, multigrain zircon fractions define a precise upper intercept of 1629 +3/–2 Ma. A multigrain titanite fraction (not included in the zircon age calculation) is 18% discordant from this intercept, projecting to a lower intercept of *ca.* 320 Ma. Collectively, results from both samples point to emplacement of the WBAC at *ca.* 1640–1630 Ma, and subsequently affected, first, by Pb loss at *ca.* 1470 Ma (Pinwarian), second, by further Pb loss between *ca.* 1070 and 970 Ma (Grenvillian), and, third, by minor Pb loss at *ca.* 320 Ma (time of Sandwich Bay mafic dyke emplacement).

Two other relevant U–Pb geochronological results are: i) from a microgranite dyke near the northwest end of the WBAC that intrudes mylonitized gabbronoritic rocks (Schärer *et al.*, 1986), and ii) granitic-melt products associated with pelitic gneiss from the Paradise metasedimentary gneiss belt (PMGB) close to the Sand Hill Big Pond intrusion (Kamo *et al.*, 1996). The microgranite (CG84-494) was interpreted by to be Grenvillian, based on a concordant monazite fraction that yielded an age of 1029 ± 2 Ma. Using the 1029 Ma age as the lower-intercept anchor point for a regression that includes three multigrain zircon fractions, gives an upper intercept of 1566 ± 13 Ma, which Schärer *et al.* (1986) considered to reflect inheritance. If the inherited zircon is assumed to have come from the WBAC, then a minimum age of *ca.* 1550 Ma for the WBAC is implied. From the PMGB, the granitic-melt products (CG85-148B – microgranite vein; CG85-148C – granitic melt pod) collectively yielded an upper intercept of 1638 +11/–3 Ma based on five multigrain concordant zircon analyses and one near-concordant monazite fraction, which was interpreted to date time of metamorphism (Kamo *et al.*, 1996; *cf.* Gower *et al.*, 1992 for earlier results from the same locality). As the WBAC is known to intrude the PMGB (*e.g.*, Arima and Gower, 1991), this date indicates an age of *ca.* 1640 Ma for its emplacement.

Sm–Nd and Rb–Sr dating. Sm–Nd and Rb–Sr isotopic data were reported by Prevec *et al.* (1990), their results augmenting and superseding preliminary information obtained by Prevec (1987). For the Sm–Nd whole-rock investigation, 6 samples were analyzed from one locality in the WBAC (SPM85-01, -03, -04, -05, -07, -08; locality VN84-222 – the same site as used for U–Pb dating), plus one sample from a site in the SHBP (SPM85-11). The whole-rock data define an isochron age of 1810 ± 350 Ma (I_{Nd} = 0.5105 ± 0.0004). Mineral Sm–Nd isotopic data were obtained on one sample from the WBAC (SPM85-05) and one sample from the SHBP (SPM85-11). A four-point isochron (whole rock–plagioclase–orthopyroxene–clinopyroxene) from sample SPM85-05 gave an age of 1669 ± 35 Ma (I_{Nd} = 0.51061 ± 0.00003) and a six-point isochron (whole rock–plagioclase–orthopyroxene–clinopyroxene–olivine–amphibole) from sample SPM85-11 gave an age of 1624 ± 65 Ma (I_{Nd} = 0.51075 ± 0.00008).

For the Rb–Sr investigation, data were reported for the same samples, with the addition of whole-rock samples SPM85-06 from the WBAC and SPM85-12 from the SHBP. The whole-rock analyses scatter around a 1650 Ma reference line (reference I_{Sr} = 0.7025). Mineral Rb–Sr data for SPM85-05 yielded a four-point isochron of 1717 ± 180 Ma (I_{Sr} = 0.7031) and, for SPM85-11, yielded a six-point isochron of 1848 ± 260 Ma (I_{Sr} = 0.70243). As discussed by Prevec *et al.* (1990), the results do not generate very reliable geochronological information as both Sm–Nd and Rb–Sr systems are disturbed. Nevertheless, the data are compatible with a Labradorian emplacement age for the WBAC, and indicate absence of significant Grenvillian overprint. One useful observation is that, for sample SPM85-011, coronitic amphibole is on the same regression line as that for the primary igneous phases, suggesting coronite formation during, or shortly after, magmatic crystallization.

11.4.4.4 Ultramafic Rocks (P_{3C}um)

Ultramafic rocks are found scattered throughout the White Bear Arm complex (Figure 11.7), mostly occurring as minor pods and lenses. The occurrences appear to be more common at the southeastern end of the body, but this is probably an artifact of better rock exposure, which includes shoreline and roadcuts. The ultramafic rocks are green-, grey-, black- or rusty-weathering, medium to coarse grained and massive to highly sheared. According to field notes (but not entirely supported by petrographic studies), the typical rock type is pyroxenite or an approximate metamorphic equivalent such as 'hornblendite' or actinolite-chlorite rock. Pyroxene porphyroclasts up to 0.5 cm in diameter are mentioned at site RW75-285. Primary igneous layering was recorded at RW75-324 as 25–30-cm-wide layers, interbanded with gabbro.

Seven samples were examined in thin section. Five samples partially preserve igneous assemblages (CG84-143, CG84-351, CG84-396, JS86-387, MN86-101). The first three listed samples, from the western part of the WBAC, are all wehrlite (olivine–clinopyroxene primary igneous assemblage). Some primary orthopyroxene, minor plagioclase, metamorphic brown amphibole and orange-brown biotite, an opaque oxide, minor sulphide and hercynite are also present (but not all minerals in all thin sections). The other two are from the southeast coastal area. Sample JS86-387 (dunite/lherzolite) is particularly notable for its essentially igneous character and lack of evidence of deformation and metamorphism. It contains euhedral, cumulate, serpenitinized olivine (retaining kernels of primary material), with interstitial primary plagioclase infilling. The two are separated by narrow double coronas of orthopyroxene and amphibole plus spinel. Sample MN86-101 (harzburgite) is somewhat similar, but contains much more orthopyroxene, which is thoroughly polygonized and lacks plagioclase. Some unserpentinized olivine is preserved.

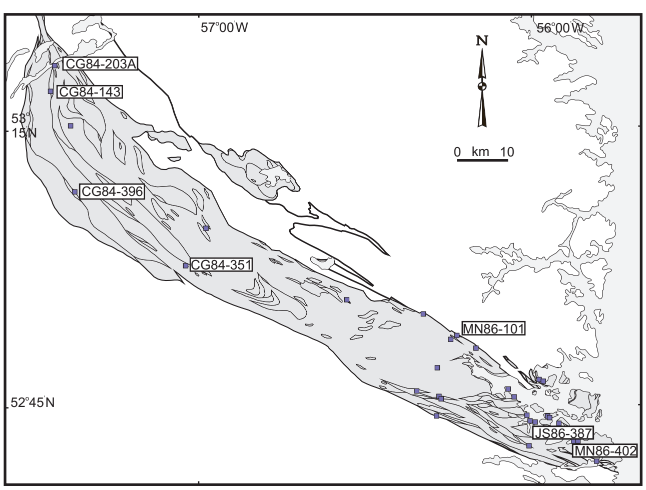


Figure 11.7. *Distribution of ultramafic rocks in White Bear Arm complex.*

The two other samples (CG04-203A, MN86-402) have entirely metamorphic assemblages, which can be partly correlated with localities being close to the southwest, thrust-defined margin of the WBAC. Sample CG04-203A has a tremolite/actinolite–chlorite–opaque mineral assemblage and MN86-402 comprises leaf-green amphibole, very minor anhedral plagioclase, an oxide opaque mineral, carbonate (in criss-crossing fractures) and trivial amounts of titanite, quartz and rutile.

No ultramafic rocks were recorded from the SHBP intrusion.

11.4.4.5 Anorthosite (P_{3C}an)

Anorthosite in the WBAC is mostly located at the northwest end of the body on its southwestern flank (Figure 11.4). Representation of both the rock type and its extent on the 1:100 000-scale maps (mostly in the Paradise River map region) remains provisional. In the field, the rocks were given a wide range of protolith names, which, apart from anorthosite, also included leucogabbro, leuconorite, diorite and quartz diorite. Supporting field description is generally meagre, merely providing the information that the rocks are grey-weathering, leucocratic, medium grained, strongly foliated and recrystallized.

Applying protolith terminology, five thin sections (NN84-479D, NN84-538, VN84-437, VN84-522, VN84-534) were named, respectively, leucogabbro, leuconorite, leucodiorite, and anorthosite (two samples). A sixth thin section, VN84-535, from within, but near the margin of the 'as-mapped' anorthosite, is a felsic granulite; it may well be a tectonic sliver derived from a monzonitic protolith. As the differing names imply, the mineral assemblages are variable, comprising plagioclase, hornblende, clinopyroxene, orthopyroxene, garnet, an opaque oxide, and hercynite (in varying amounts and combinations), plus small amounts of K-feldspar and quartz in leucogabbro and leucodiorite. Recrystallized clusters of mafic silicates attest to derivation from much coarser grained protoliths. Despite the use of protolith names, textures indicate that the mineral assemblages are high-grade metamorphic, which is consistent with regional interpretation that the rocks are entrained in a complex west-verging, granulite-facies thrust zone.

Notwithstanding being responsible for its representation on the 1:100 000-scale map for the area, the author has reservations regarding the legitimacy in calling these rocks anorthosite and considers a leucogabbronorite protolith a valid alternative; or that greater stress should be placed on their metamorphic state.

Anorthositic rocks are also found in the centre of the SHBP intrusion. The rocks are white- or grey-weathering, medium to very coarse grained, and massive.

The single thin section available (CG85-145) shows a much lower metamorphic grade than the WBAC anorthosite. It has a near-pristine primary igneous assemblage comprising plagioclase, minor strongly pleochroic orthopyroxene, pale-green clinopyroxene with exsolved opaque inclusions, an opaque oxide, and secondary pale-green amphibole, red-brown biotite (some primary) and serpentine (after orthopyroxene).

11.4.4.6 Leucogabbronorite and Leucotroctolite (P_{3C}ln, P_{3C}lt)

Leucogabbronorite and leucotroctolite in the WBAC are white-, pale grey-, creamy-grey- or grey-brown-weathering, mostly massive to weakly foliated, medium- to very coarse grained (plagioclase up to 10 cm long), and generally homogeneous (Plate 11.4A). Some schistose or even gneissic fabrics are developed in places, mostly away from the central part of the WBAC (Plate 11.4B). Some rocks, termed 'leucodioritic', can be taken to be metamorphic derivatives of leucogabbronoritic protoliths. Throughout the WBAC, leucogabbronorite/troctolite is a subsidiary rock type on 1:100 000-scale maps, but also forms a minor component of outcrops designated as gabbronorites. An exception where leucogabbronorite is a dominant rock type in the WBAC is at its southeast end, in the Square Island area. In this area, indistinct to obvious primary igneous layering is present, for example as 1-cm-thick mafic layers separated by 10–15-cm-thick layers of plagioclase (CG86-667 and RW75-436). The layering in the Square Island area indicates that the primary igneous fabric is overall north-trending and open-folded, which contrasts with the overall northwest trend of the WBAC. The leucogabbronoritic and leucotroctolitic rocks are intruded by metamorphosed mafic dykes, microgranite and pegmatite dykes and rare quartz veins.

As mapped at 1:100 000 scale, leuconorite is a major rock type in the SHBP intrusion and leucotroctolite is minor, but no clear-cut demarcation was seen between anorthosite, leuconorite and leucotroctolite. The rocks tend to be dark weathering, medium to very coarse grained (pyroxene crystals up to 40 cm long) and massive. Their mineral assemblages are dominated by black/grey plagioclase and rusty brown orthopyroxene.

Double coronas around olivine (inner corona of fibrous radial orthopyroxene and an outer corona of amphibole + spinel symplectite); amphibole coronas around orthopyroxene and/ or clinopyroxene; and amphibole and biotite coro-

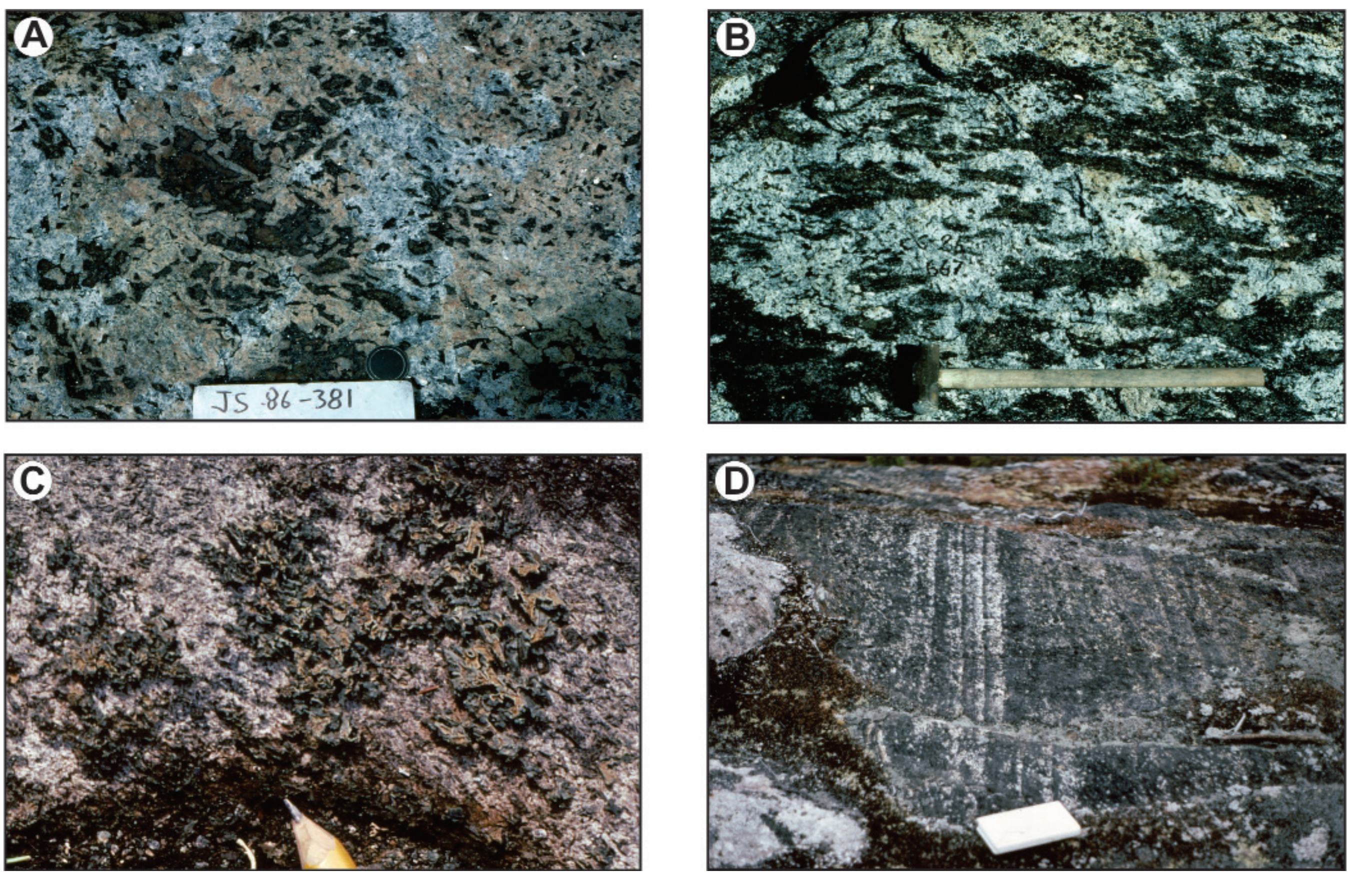


Plate 11.4. *Features of White Bear Arm complex (WBAC) and Sand Hill Big Pond (SHBP) mafic intrusion. A. Leucogabbronorite showing primary igneous texture and amphibole mantling orthopyroxene, WBAC (JS86-381), B. Metaleucogabbronorite consisting mainly of recrystallized amphibole and plagioclase, WBAC (CG86-667), C. Coronitic metagabbro; similar to Plate 11.3B, but white inner orthopyroxene coronas more obvious, SHBP (CG85-185), D. Relict primary igneous layering in metagabbro, WBAC (CG84-147).*

nas around an opaque oxide can be commonly seen in outcrop (Plate 11.4C). A summary of the geographical variation of types of coronitic texture within the WBAC and SHBP is given in Section 11.4.4.11 in a composite review of the petrographic features of troctolite, norite and gabbro, and their leucocratic equivalents.

11.4.4.7 Gabbronorite, Troctolite (P_{3C}rg)

Rocks to which the designator P_{3C}rg has been applied in the WBAC are mostly gabbronorite. Modal analyses carried out by Prevec (1987) show that the most common rock type in the WBAC is gabbronorite transitional to norite. Other rock types are olivine gabbronorite and lesser troctolite, and partly metamorphosed equivalents such as mafic granulite, amphibolite, diorite and their gneissic counterparts. Note that, even from the earliest mapping, the name diorite or dioritic gneiss has been commonly applied (Piloski, 1955; Eade, 1962). It should be taken to mean a hydrated metamorphic equivalent of a gabbronoritic protolith in which the pyroxene has been partially, or totally, replaced by amphibole (± quartz).

The rocks are mostly described as (light/dark) grey-weathering, but may also be black, purplish, brown, buff, rusty, dull greenish, or even white. A wide spectrum of fabrics (massive, weakly to strongly foliated, schistose, or gneissic) and grain sizes (fine to very coarse grained) exists. Typically, the igneous-looking rocks are homogeneous. Many have ophitic textures, and some are plagioclase-phyric (JS86-040, RW75-326 – phenocrysts up to 6 cm long, RW75-337, RW75-369, RW75-492). Locally, spectacular gabbroic pegmatites are associated. Coronitic textures are common. Rarer features are schillerization of plagioclase (RW75-340) or a bronzy shimmer to orthopyroxene (RW75-420). Igneous textures are obliterated in the more strongly deformed parts of the body.

Primary igneous layering commonly survives metamorphism and deformation (Plate 11.4D). It takes several forms, including graded cumulate units, rhythmic layering, and igneous crossbedding (there are many instances, however, where no information beyond being layered is provided in field notes). Commonly, layers are somewhat diffuse and ill defined. An example of a graded unit is found at RW75-275 where the graded units are 0.5–1.0 m wide, have a mafic-mineral-rich sharp base and gradational tops into normal gabbronorite. Another graded unit (MN86-358) was noted to vary from ultramafic to anorthositic over a 3 m interval. Rhythmic layering was recorded at RW75-312, RW75-422 and RW75-488 in units 5–20 cm thick, which, locally, are also graded. From weathering patterns on outcrop, cryptic layering was suggested to be present at RW75-416. Igneous crossbedding was noted at RW75-275. In places, an igneous mineral lamination, parallel to primary layering, was recorded (*e.g.*, RW75-438). More often than not, the orientation of layering was not measured, so, except in the Square Islands area, it remains unknown if any regional pattern exists.

The gabbronoritic rocks in the WBAC also host enclaves or (cognate?) xenoliths of other mafic material, such as pods of orthopyroxene (CG86-662, MN86-105, RW75-435), ultramafic pods of unspecified minerals (MN86-111, MN86-357, MN86-394, MN86-395), magnetite clusters (MN86-045), fine-grained gabbronorite (RW75-254), and troctolite (SN86-180).

Parts of the WBAC are invaded by now-metamorphosed mafic dykes or minor granitoid intrusions. Mafic dykes are common and addressed in a subsequent section. Minor granitic intrusions include a range of centimetre-scale felsic veinlets, metric-scale microgranite and pegmatite dykes, and decimetre-scale granite to granodiorite intrusions. Felsic veinlets, in particular, can be allied closely with metamorphism, in that they show fringes of amphibole- or garnet-rich material. Some of the pegmatites also carry garnet and a few are characterized by blue quartz. Pegmatite is crosscut by a metamorphosed mafic dyke at locality SN86-179. Local evidence, coupled with regional considerations, dictate a close genetic association of mafic dykes and some granitic intrusions with their WBAC host rocks.

In the SHBP intrusion, gabbronorite mostly occurs in the outer parts of the body, although does not seem to form a continuous zone. As mapped, a gradation exists from gabbronorite in the outer part, through leucogabbronorite/leucotroctolite to an anorthosite core. More detailed mapping is needed to verify if this is genuinely the case. Petrographic features of the SHBP intrusion are reviewed in Section 11.4.4.11.

11.4.4.8 Monzogabbronorite (P_{3C}mn)

Monzogabbronorite is given a separate designation on 1:100 000-scale maps of the WBAC, but it is volumetrically trivial. The designation was only applied to 23 data stations in the WBAC, and mostly as an alternate to another unit. The rocks are grey-brown-weathering, medium to coarse grained, and massive to foliated. Unlike in the Mealy Mountains intrusive suite, they do not form discrete bodies of significant size, but, rather, occur as variants associated with the prevailing rock type in the area (*e.g.*, an abnormally potassic leucogabbronorite, or an unusually mafic-mineral-rich monzonitic rock). An exception to this generalization applies to the interface between the SHBP intrusion and the Paradise Arm pluton, where three small, separate but aligned occurrences of monzogabbronorite were mapped, supporting genetic linkage between these two bodies, already implied by their similarity in age.

Four thin sections from the WBAC have been termed monzogabbronorite (MN86-387, NN84-479D, SN86-077, SN86-121). All have anhedral, well-twinned plagioclase, interstitial quartz, orange-brown biotite and leaf-green amphibole; most have minor K-feldspar (not SN86-121), clinopyroxene (not SN86-077, which has orthopyroxene instead) and an opaque mineral (not NN84-479D). Garnet is seen in SN86-121. Other minerals sporadically present are sulphide opaque minerals, apatite, zircon and secondary titanite, allanite, white mica, chlorite, epidote, carbonate, and prehnite.

11.4.4.9 Mafic Granulite (P_{3C}ag)

Inclusion of specific sites in this unit is as much a result of after-the-fact examination of stained slabs and thin sections as it is the outcome of field mapping. In the field, the rocks were assigned a range of names by various mappers, including two-pyroxene mafic granulite, amphibolite, microgabbronorite, leucogabbronorite, diabase and diorite. Gower *et al.* (1985) defined a 'fine-grained granulite, leuconorite' unit in the Paradise River map region, cautioning that it could include mafic dykes having a granulite-facies mineral assemblage. Although the rocks are commonly exposed as isolated outcrops, Gower *et al.* opted to group the occurrences into generalized areas rather than showing individual localities. Whether or not this delivers a misleading map pattern (which it would, if they are mostly dykes) requires further mapping to determine.

Rocks included in the unit (WBAC only, none in the SHBP intrusion) are generally black- or dark-grey-weathering, but, more rarely, light grey or brown. Typically, they are fine to medium grained (none are coarse grained) and homogeneous. A particular characteristic of the unit is the presence of white-weathering quartzofeldspathic stringers aligned parallel to the prevailing fabric. Such fabrics range from weak to mylonitic or even ultramylonitic. The rocks are invariably recrystallized and commonly garnet bearing, but sporadically retain traces of former coarser grained igneous textures. In the Paradise River region, the rocks are intruded by late-stage pegmatites associated with north- or east-side-down faults interpreted to be Grenvillian (Gower, 2005, 2012, field guide stop 2.6). Petrographic details are discussed below.

11.4.4.10 Amphibolite, Diorite and Gneissic Equivalents (P_{3C}am, P_{3C}dr)

The units P_{3C}am and P_{3C}dr have been used for those parts of the White Bear Arm complex where the rocks are sufficiently transformed by metamorphism, such that igneous rock terminology is difficult to apply. This is especially the case at the southeast end of the complex. Like their granulite-facies relatives, the rocks were bestowed a variety of names in the field. The inclusion here of the separately map-defined diorite unit reflects: i) the most common alternative name (to amphibolite) applied in the field, and ii) the underlying interpretation that both so-termed amphibolite and diorite were derived from gabbronoritic protoliths. This interpretation is not merely the author's prejudice, but is based on observations extracted from the field notes of various mappers, who recorded many examples of transitional relationships between amphibolite, diorite and relict gabbronoritic rocks. Commonly, the rocks are also referred to as amphibolite gneiss or (quartz) diorite gneiss, or, rarely, metagabbro, microgabbro or 'metabasic' gneiss. The unit designation given on the 1:100 000-scale maps modifies original field descriptions with stained slab and thin-section data, plus additional field data acquired during examination of roadcuts in the Charlottetown–Pinsent's Arm and Paradise River areas.

The rocks are black-, light- to dark-grey-, brown-, or buff-weathering, generally fine to medium grained, vary from massive to well banded, may show primary layering, and be weakly to strongly foliated, or mylonitic. A recurring feature in field descriptions is that the amphibolite–dioritic rocks are almost everywhere intercalated with felsic material referred to as leucosome, quartz–feldspar veins, tonalite or granodiorite, pegmatite, or aplite. It is white, creamy or, rarely, pink-weathering and fine to coarse grained. Evidence points to it being intimately related to the early history of the host mafic rocks, being inter-layered/leaved/laminated, forming lenses or pods, and being sheared, boudinaged or folded. In places, the felsic material is orthopyroxene- or garnet-bearing, or carries hornblende and/or biotite. The close association of these rocks with mylonitization, and with tectonic slivers of metasedimentary gneiss, point to hydration and melting of the original gabbronoritic protoliths to produce their amphibolitic and dioritic derivatives. They approach granulite-facies conditions, as indicated by the presence of orthopyroxene and garnet in leucosomes, which are suggested to be related to incongruent melting of the metamorphosed host rock. Remnant metamorphosed mafic dykes are preserved in places and later discordant pegmatites also occur.

Thin sections of rocks assigned to amphibolite (CG04-209B, CG86-580, CG86-601, CG86-659, MN86-139, MN86-267, MN86-365, NN84-546, SN86-119B, SN86-193, SN86-326, SN86-332, SN86-341, SN86-365, VN84-157, VN84-162, VN84-205B, VN85-298A) and diorite (MN86-355B, VN84-437) range from leucocratic to melanocratic, medium to coarse grained, weakly foliated to mylonitic, and from retaining vestiges of igneous texture to being thoroughly recrystallized. The wide mineralogical variation can be attributed to derivation from a wide range of previously described protoliths. Plagioclase is polygonal, poor to well twinned, and lightly to heavily altered. Minor quartz is present in over half of the thin sections. Amphibole is either polygonal or ragged, and leaf-green to blue-green. It may contain quartz blebs or opaque oxide inclusions, hinting at derivation from pyroxene. Amphibole has been entirely pseudomorphed to low-grade minerals in SN86-119B, which is a fault breccia. Polygonal clinopyroxene is present in NN84-546, orthopyroxene in SN86-332 and SN86-337B, and garnet in SN86-341. The dominant opaque mineral is an oxide, but sulphide is present in over half the thin sections (forming 15% of the opaque minerals in MN86-267). Buff, orange or brown biotite is a minor constituent in most of the samples. Apatite and zircon (MN86-139, MN86-267) are sporadically present. Secondary minerals (after biotite or amphibolite, and mostly only present in trivial amounts) include epidote, allanite, prehnite, chlorite and titanite. The two diorite thin sections have interstitial K-feldspar.

11.4.4.11 Metamorphic Zonation in Gabbronorite, Troctolite and their Leucocratic and/or Metamorphosed Equivalents

It is well known that coronitic textures in olivine gabbro are the result of reaction between olivine and plagioclase. It is also well known that the nature of the coronas varies in a systematic manner according to temperature and pressure conditions. At lower P–T, typical coronitic textures consist of an inner corona of fibrous orthopyroxene, and an outer corona of a clinopyroxene (or pargasitic amphibole under hydrous conditions) + spinel symplectite. At higher P–T conditions garnet is a coronal phase, and, as temperature and pressure continue to increase, coronal textures are replaced by granulite-facies polygonal aggregates of plagioclase and mafic minerals. Such transitions have been well documented in the eastern Grenville Province in the 1450–1420 Ma Shabogamo and Michael gabbros (*e.g.*, Wardle, 1982; Gower and Erdmer, 1988; this report).

The coronitic textures in the WBAC do not show an identical pattern to those in the Michael gabbro. This may be due to the WBAC having a less steep pressure trajectory than that for the Michael gabbro (although such remains to be quantitatively demonstrated). In particular, in the WBAC, garnet is not seen as a coronal mineral, whereas, in the Michael gabbro, it enters at zone 1.3 (using the scheme of Gower and Erdmer, which included zones 1.1 to 1.6 and Zone 2). Garnet occurs in metamorphosed mafic rocks (amphibolite and mafic granulite) in the WBAC, however.

The mineralogical variations were examined by the author with respect to their geographical distribution. Two approaches were adopted, using: i) field data, which provides more data points but less precise information (Figure 11.8A), and ii) petrographic information, which offers the reverse (Figure 11.8B). In the field, it is relatively easy to see coronal texture, or the presence of garnet. The appearance of garnet is interpreted to indicate higher metamorphic grade. If any examples exist of rocks being coronal and having garnet, they were not recorded in field notes. Figure 11.8A shows that, at the northwestern end of the WBAC, garnet is concentrated on the southwest side of the WBAC, and is also concentrated at its southeastern end. The pattern at the eastern end is, however, more complex, suggesting, to the author, a tectonic interleaving of garnet-bearing or coronitic-textured mafic rocks, a thesis supported by numerous interpreted thrusts in the region.

Based on thin sections, the progressive mineralogical changes are subdivided into four types, which are summarized in Table 11.5. The more detailed subdivision provided by petrographic data (Figure 11.8B) shows a pattern of progressive increase in metamorphic grade toward the southwest at the northwestern end of the body, but data are inadequate at its southeastern end to make any conclusions. Note that no consistent spatial distribution of type 1 samples *vs.* type 2 samples is evident. This may be genuine, and due to structural complications in the WBAC or some other cause, but it could be simply that some samples have been inappropriately assigned, given that the differences between types 1 and 2 are modest.

Petrographically, the most visually compelling change is the reaction of olivine with plagioclase to give an intervening inner orthopyroxene corona and outer amphibole + spinel corona. As the reaction proceeds, both coronas become broader and coarser grained, at the expense of olivine and plagioclase. In the final stages, olivine is replaced by a symplectite of orthopyroxene and an opaque oxide, commonly showing a 'fingerprint' symplectic habit. Plagioclase recrystallizes, first at grain boundaries, and, ultimately, completely. At the same time, primary plagioclase grains exsolve colourless inclusions, which increase in size and decrease in quantity. The inclusions (spinel and opaque oxides; Prevec, 1987) vanish from recrystallized plagioclase. In rocks lacking olivine, the same zonal scheme can be applied, based on mineralogical changes seen in other mineral phases that are similar in both olivine-bearing and olivine-absent assemblages. The most general change is a progressive decrease in primary phases. Igneous orthopyroxene and clinopyroxene are replaced by polygonal aggregates or hydrous mafic minerals, especially amphibole. Primary hydrous mafic minerals, such as amphibole and biotite (typically found mantling an opaque oxide) are replaced by recrystallized aggregates. Opaque minerals are also replaced by recrystallized aggregates and garnet makes its appearance in zone 3 as poikiloblastic grains that become polygonized in zone 4. Quartz and K-feldspar are interstitial primary phases in CG86-104 (zone 1); zircon was tentatively identified with them.

Prevec (1987) and Prevec *et al.* (1990) carried out a detailed investigation of the coronitic assemblages in a sample (SPM85-11) from the eastern end of the Sand Hill Big Pond intrusion. Based on mineral analyses of olivine, plagioclase and coronal orthopyroxene and amphibole (as spinel was too small to be analyzed, a composition of $Fe_{0.67}Mg_{0.33}Al_2O_4$ was used), the following reaction was proposed:

1.21 Olivine (Chrysolite) + Labradorite + (0.14 Fe + 0.47 Mg + 0.03 K)$_{fluid}$ =
0.85 Orthopyroxene (Bronzite) + 0.30 Pargasite + 0.06 Spinel + (0.13 Si + 0.55 Al + 0.16 Ca + 0.16 Na + 0.20 O)$_{fluid}$

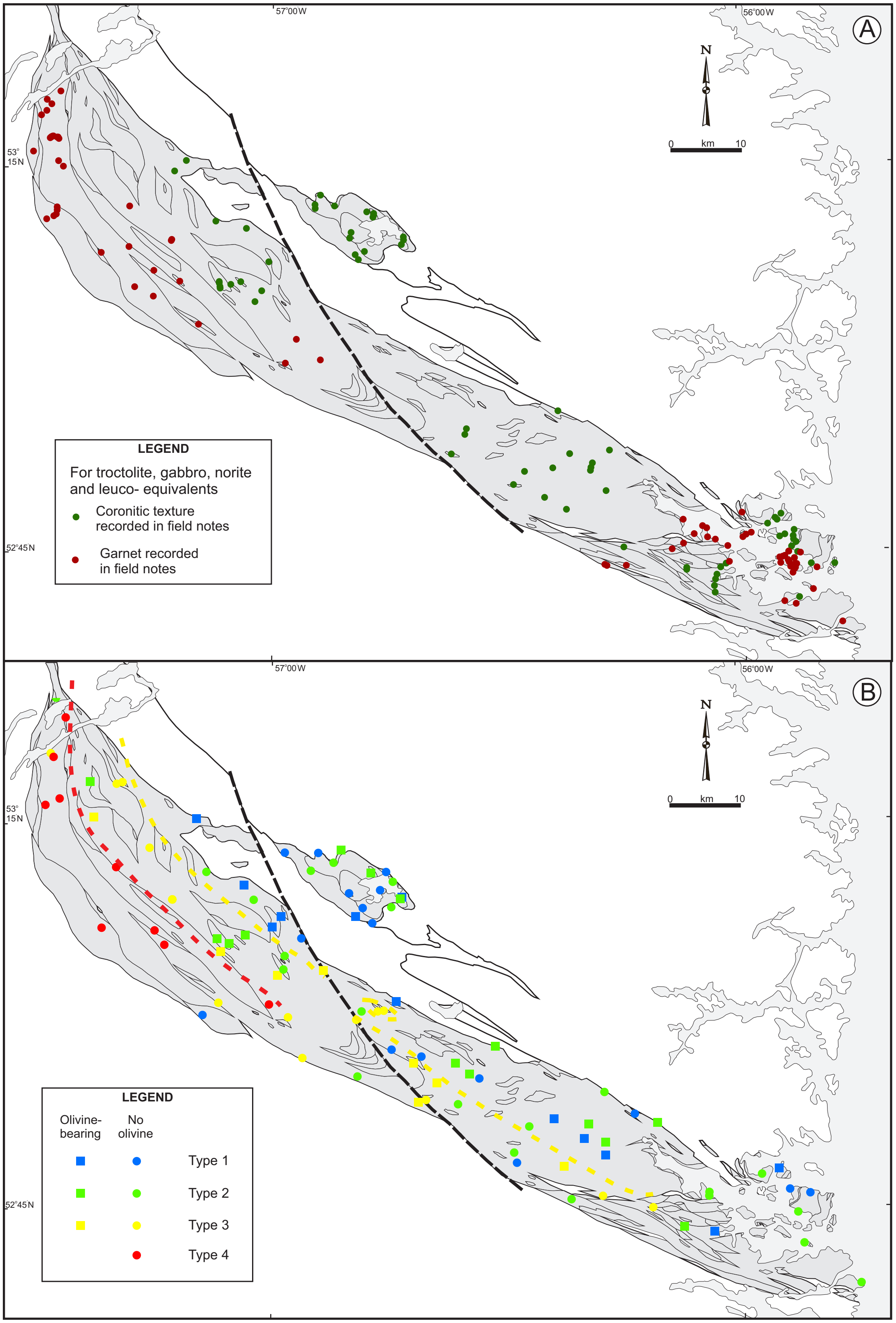


Figure 11.8. *Metamorphic zonation in gabbronorite, troctolite, and their leucocratic and/or metamorphic equivalents. A. Field distribution of coronites and garnet, B. Metamorphic zonation based on petrographic observations (*see *text).*

Table 11.5. Progressive mineralogical changes in White Bear Arm complex

Zone 1	Zone 2	Zone 3	Zone 4
Plagioclase Primary. Euhedral to anhedral; generally clear and free of inclusions.	**Plagioclase** Primary. Euhedral to anhedral; turbid due to tiny inclusions. Clear at grain boundaries, which are wavy and recrystallized.	**Plagioclase** Relict irregular-shaped primary grains, but mostly a polygonal mosaic. May be heavily impregnated with inclusions.	**Plagioclase** Completely recrystallized to polygonal mosaic. Inclusions may be abundant and large.
Olivine Primary. Narrow coronas - an inner corona of fibrous orthopyroxene oriented normal to olivine grain boundary. Outer corona of clinopyroxene + spinel symplectite, also fibrous and normal to olivine grain boundary.	**Olivine** Primary, but smaller cores and wider double coronas of orthopyroxene and clinopyroxene + spinel; fibrous, but more coarsely so.	**Olivine** Very small remnants of primary olivine. Mostly 'fingerprint' symplectite of opaque oxide and orthopyroxene. Broad coronas, but constituent grains are polygonal, rather than fibrous.	**Olivine** No olivine. Its former presence can only be discerned with difficulty by opaque oxide and orthopyroxene symplectite mosaics. Coronas very broad and made entirely of polygonal grains.
Clinopyroxene Primary. Colourless to brown; contains abundant exsolved opaque inclusions. Minor alteration to amphibole.	**Clinopyroxene** Primary, but generally colourless. Abundant opaque inclusions. Minor polygonization. Commonly mantled by amphibole	**Clinopyroxene** Relict primary with opaque inclusions. Colourless. Much is recrystallized to polygonal aggregates that may define former primary grains.	**Clinopyroxene** Completely recrystallized to polygonal aggregates.
Orthopyroxene Primary. Moderately pleochroic. Minor alteration to amphibole.	**Orthopyroxene** Primary. Strongly pleochroic. Minor polygonization. Mantled by amphibole.	**Orthopyroxene** Relict primary. Strongly pleochroic. Much is recrystallized to polygonal aggregates that may define former primary grains.	**Orthopyroxene** Completely recrystallized to polygonal aggregates.
Opaque mineral(s) Primary. Commonly mantled by dark green or brown amphibole and red-brown biotite.	**Opaque mineral(s)** Primary. Commonly mantled by amphibole or biotite that may be partly polygonal.	**Opaque mineral(s)** Partly recrystallized and mafic silicate fringes less common.	**Opaque mineral(s)** Recrystallized to polygonal grains.
Amphibole Primary. Dark-green or brown grains.	**Amphibole** Green and partly polygonal. Mantles pyroxenes and opaque oxide.	**Amphibole** Green, polygonal. Mostly dispersed.	**Amphibole** Green, polygonal, dispersed.
Biotite Primary. Red-brown flakes; typically mantling opaque oxide.	**Biotite** Primary and polygonal red-brown flakes; typically mantling opaque oxide.	**Biotite** Polygonal red-brown flakes. Weak association with opaque oxide.	**Biotite** Dispersed red-brown flakes.
Garnet No garnet.	**Garnet** No garnet.	**Garnet** Poikiloblastic or polygonal.	**Garnet** Polygonal.

On the reactants side of the equation, Prevec (1987) suggested that the required K could have been supplied by fluids from associated felsic units. He was more at a loss to offer a source for the Fe and Mg, but suggested that his amphibole analyses might be analytically enriched in these components due to inadvertent overlap of the electron microprobe beam onto the symplectically intergrown very small spinel. On the products side of the reaction, the Si can be eliminated and the Al reduced by adopting stoichometric labradorite. The remaining Al, plus Ca and Na can be accommodated in the coronitic amphibole. Prevec (*op. cit.*) concluded that his study supported a constant-volume diffusion model for corona formation, and that the reaction took place in a closed system, except for the introduction of hydrous fluids, and perhaps a small amount of K. No conclusion was reached whether the coronas formed during magmatic crystallization or post-crystallization cooling. His isotopic data dictates that, if K was introduced, such must have occurred during, or very shortly after, crystallization as there was no evidence for a later disturbance (specifically, Grenvillian).

The mineralogical pattern can be resolved into two factors, operative within the context that the WBAC is faulted along both its northeast and southwest sides. The first factor is an increase in metamorphic grade across the width of the White Bear Arm complex from northeast to southwest, but with complications introduced by southwest-verging or south-verging thrusts (northwestern and eastern ends, respectively). The positioning of major thrusts within the White Bear Arm complex is independently inferred from mylonite zones and slivers of pelitic gneiss that were caught up in the thrusting and acted as glide planes for it. The thrusting and southwestward-increasing metamorphic gradient is taken to be Labradorian. The second factor is an increase in metamorphic grade from southeast to northwest. The direction of progressive metamorphism in both cases is consistent with that deduced from mineral assemblages in the flanking metasedimentary gneisses. Those to the northeast of the White Bear Arm complex are at a lower grade than those to the southwest, and in both belts the grade of metamorphism increases to the northwest. The northwestward-increasing metamorphic gradient is interpreted to be Grenvillian.

Summary of thin sections for WBAC and SHBP intrusions; anorthosite, troctolite, norite, gabbro and their leucocratic equivalents, and mafic granulite.

Type 1, Olivine-bearing
Gabbro: CG84-369, CG85-241, GM85-153, JS86-153B, MN86-111. Gabbronorite: VN84-182, VN85-202. Troctolite: CG86-553A, GM85-233, GM85-237, JS86-089A, SN86-160.

Type 1, No olivine
Gabbronorite: CG84-349, CG85-146, CG85-286, CG86-104, CG87-167B, GM85-151, GM85-183, JS86-051, MN86-067, SN86-102. Leucogabbronorite: CG85-181, GM85-162, JS86-449. Norite: MN86-102. Leuconorite: CG85-285, CG86-567. Anorthosite: CG85-145.

Type 2, Olivine-bearing
Gabbro: CG84-140, SN86-086, SN86-155B, VN85-203. Leucogabbro: VN84-222A (Photomicrograph 11.1a). Gabbronorite: SN86-074, SN86-117, VN84-234. Norite: CG87-171B, MN86-070. Troctolite: MN86-156A, VN84-213, VN84-222C. Leucotroctolite: GM85-130.

Type 2, No olivine
Gabbronorite: CG84-124, CG85-189, CG86-292, CG86-685, CG87-167C, GM85-176, GM85-181, JS86-095, MN86-074, MN86-150, SN86-093, SN86-100, VN84-167, VN84-244, VN85-225. Norite: CG87-164A, JS86-438, MN86-393, SN86-191, SN86-343. Leuconorite: CG85-130A.

Type 3, Olivine-bearing
Gabbro: CG84-263, MN86-109. Gabbronorite: CG85-229A, CG86-108, GM85-173, SN86-175, SN86-180. Norite: VN84-219. Troctolite: SN86-164. Leucotroctolite: CG86-652.

Type 3, No olivine
Gabbronorite: CG84-271, CG84-350, CG85-234, CG85-235, CG85-238, JS86-040A, JS86-147, VN84-392A, VN84-396, VN85-224. Norite: MN86-145, SN86-179A. Granulite, mafic: CG84-147A, VN84-227A, VN84-227B, VN84-227C, VN84-227D.

Type 4, No olivine
Granulite, mafic: CG84-353, CG84-362, MC77-206A, NN84-543A, NN84-549, VN84-420, VN84-432, VN84-536, VN84-542. Granulite, intermediate: NN84-468, NN84-538.

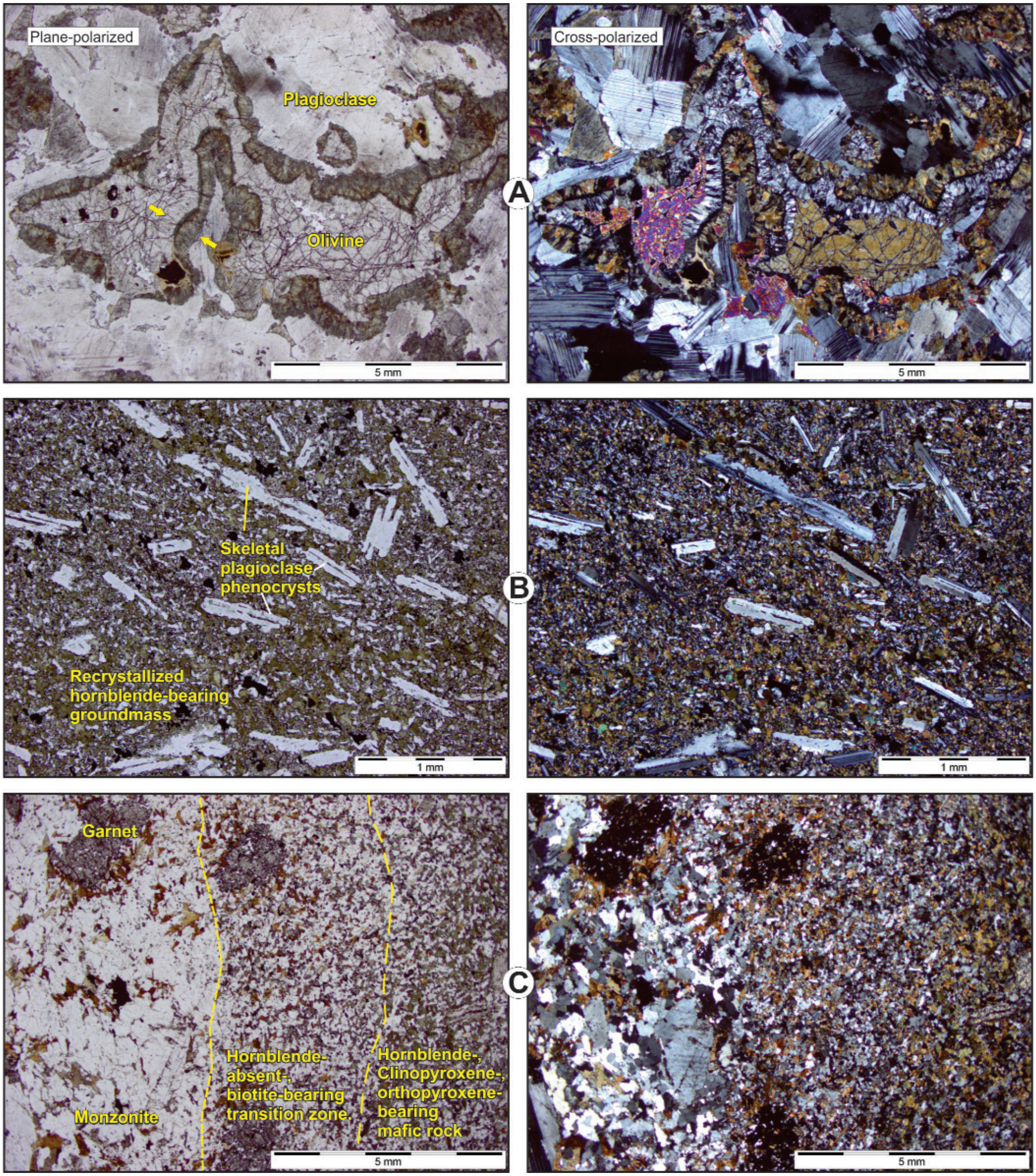
11.4.4.12 Mafic Dykes within White Bear Arm Complex (P_{3C}d)

Fine-grained mafic rocks are treated separately from their above-described coarser grained counterparts, as some of them were identified in the field as dykes. It is emphasized that all the rocks have been metamorphosed and cannot be confused with the late- or post-Grenvillian mafic dykes also present in the region. The rocks are grey-, black- or brown-weathering, and homogeneous. Where recorded as dykes, the widths were noted to be 0.25 to 3.0 m. The original emplacement orientations of the dykes have been modified by subsequent deformation, but tend to be at a high angle to the northwest trend of the White Bear Arm complex. Many are described in notes as planar or undeformed, although metamorphosed (perhaps an artifact of being more easily recognizable than their more tectonized equivalents?). A few are noted to be irregular or back veined.

On the basis of acicular and skeletal plagioclase phenocrysts evident in stained slabs, four localities are represented by small polygons (rather than dyke symbols) on the Paradise River 1:100 000-scale geological map (CG84-383, CG84-389, CG84-390, and, less convincingly a dyke, CG84-392). Depiction in this manner reflects their interpretation as dykes, but lack of knowledge of the dyke trend (hence denying usage of the P_{3C}d dyke symbol).

Thin sections included here are CG84-255, CG84-383, CG84-407A, CG86-154, JS86-089B, JS86-145, JS86-148, JS86-153A, JS86-380, MN86-349B, NN84-540, SN86-156, SN86-329B, VN84-407, VN85-220, and VN85-226. Of these 16 samples, those established as dykes in the field are listed in Table 11.6.

The mineral assemblage includes plagioclase, clinopyroxene, orthopyroxene, amphibole, an opaque oxide (rarely, trace sulphide), red- or orange-brown biotite, and apatite. Other sporadic minerals are: i) quartz inclusions in amphibole (both derived from the breakdown of clinopyroxene (JS86-148), ii) stable metamorphic garnet in CG84-255, iii) secondary titanite, rutile, epidote and white mica in JS86-380, and iv) serpentine after olivine or orthopyroxene in VN84-407.



Photomicrograph 11.1. *Some features of White Bear Arm complex. A. White Bear Arm complex olivine-cored coronitic texture. Colourless inner corona orthopyroxene, green outer corona pargasitic amphibole + spinel (between arrows) (VN84-222A), B. Example of recrystallized mafic dyke associated with White Bear Arm complex. Dyke is interpreted to be co-genetic (SN86-156), C. Boundary between mafic enclave and monzonite in White Bear Arm complex,* cf. *Plate 11.5B (CG84-381C).*

Table 6. Metamorphosed mafic dykes in the White Bear Arm complex

Sample	Trend	Metamorphic facies	Special features
JS86-089B	090/?	Orthopyroxene amphibolite	Quenched plagioclase microphenocrysts
JS86-153A	090/50	Hornblende 2-pyroxene granulite	Relict clinopyroxene and plagioclase phenocrysts
JS86-380	190/75	Amphibolite	Strongly zoned plagioclase phenocrysts
MN86-349B	210/65	Amphibolite (relict igneous)	Strongly zoned primary plagioclase
SN86-156	232/76	Amphibolite	Quenched plagioclase
SN86-329B	110/90	Amphibolite	Relict quenched and strongly zoned plagioclase
VN84-407	040/?	Amphibolite (relict igneous)	Extensive alteration of all minerals

Plagioclase, typically, is subhedral to anhedral, but near primary, in that recrystallization is confined to wavy grain borders. Three key plagioclase characteristics suggesting emplacement as dykes are strong zonation, skeletal (quenched) form, and presence of phenocrysts (all of which imply rapid cooling of the magma) (Photomicrograph 11.1B). Apart from the examples listed in Table 11.6, strongly zoned plagioclase was recorded in CG84-383, and plagioclase phenocrysts in CG84-383, NN84-540 and VN85-226. Relict primary orthopyroxene and clinopyroxene contain opaque oxide inclusions and fringed by, or more extensively altered to, amphibole ± quartz. As indicated in Table 11.6, metamorphic grade is variable from amphibolite to granulite facies. Sub-amphibolite-facies retrogression is extensive in JS86-380 and VN84-407.

11.4.4.13 Monzonite and Quartz Monzonite (P_{3C}mz, P_{3C}mq, P_{3C}gp)

In the WBAC, a major distinction exists between monzonitic rocks (monzonite, quartz monzonite (and their megacrystic variants) addressed here *vs.* granitic rocks (granodiorite, granite, alkali-feldspar granite, and quartz syenite), reviewed in the next section. The monzonitic rocks form major bodies and are part of the mafic to felsic magmatic continuum, whereas the granitic rocks are volumetrically minor and mostly associated with metamorphism and deformation.

The monzonitic rocks are grey-, brown-, creamy-, buff-, or (rarely) pink-weathering. They are fine to coarse grained, vary from massive to strongly deformed, and exhibit equigranular, seriate or K-feldspar megacrystic textures (augen/porphyroclasts where deformed). The monzonitic rocks are commonly more deformed than their associated mafic counterparts, suggesting preferential strain imposition. The megacrysts are typically less than 2 cm across, but may be up to 6 cm (*e.g.*, VN84-411). Mantled feldspars (plagioclase rims on K-feldspar cores) are found in many places.

Both sharp and transitional contacts with mafic rocks in the WBAC were recorded. Examples of sharp contacts were seen at CG84-229, CG84-239 and CG84-381. At CG84-381, seriate to megacrystic monzonitic rocks intrude mafic rocks resulting in an agmatite that shows well-developed reaction rims in the mafic rocks at the mafic-felsic interface (Plate 11.5A, B; Gower *et al.*, 1985). Elsewhere, the monzonitic rocks also contain irregular gabbronorite or amphibolite enclaves. Some of these have K-feldspar megacrysts rimmed by plagioclase, and large quartz crystals identical to those in the host monzonite. Although monzonitic rocks intruding mafic rocks is the most common relationship seen, mafic rocks intruding monzonitic rocks are also present, either as planar dykes or displaying magma mingling characteristics (*e.g.*, pillowed or bulbous contacts; CG84-408). Rarely, mafic enclaves show chilled margins (texturally distinct from the reaction rims alluded to earlier). Layered units showing transition from gabbronorite to monzogabbro to monzonite were observed in coastal areas (*e.g.*, CG86-557). Clearly, mafic and monzonitic magmatism are intimately associated and several periods of emplacement of both magma types occurred. A simple chronology of emplacement has no validity, albeit, overall, that there was a gradual evolution from mafic to felsic magmatism.

Twenty-three samples were examined in thin section (CG84-261, CG84-274, CG84-275, CG84-276B, CG84-348, CG84-364, CG381B, CG84-381C, CG84-407B, CG85-239, CG85-240A, CG86-110, CG86-516, CG86-677, JS86-056, MC77-199A, MN86-043, SN86-072B, VN84-427B, VN84-431, VN84-540, VN85-221A, VN85-228). One of the most striking features of the collection is the severity of deformation to which they have been subjected. About half of them were recorded as mylonitic when first described. Following re-examination, many of the remainder could be more-or-less so-described, as they are extensively recrystallized, although retaining plagioclase, K-feldspar and, less commonly, quartz porphyroclasts. The severity of the deformation seen in the thin sections of monzonitic rocks *vs.* that seen petrographically in gabbronoritic and related rocks, is consistent with field evidence mentioned above. The mineral assemblage comprises anhedral/polygonal plagioclase, K-feldspar and quartz in all samples. K-feldspar includes both microcline and finely exsolved perthite, depending on sample. Mafic minerals are biotite, amphibole, garnet, clinopyroxene and orthopyroxene. Biotite is present is all but three samples and is typically buff or orange-brown. Amphibole (in half of the samples) mostly has ragged, relict form and is leaf-green. Garnet is present in 15 of the 23 thin sections examined and commonly forms a symplectite with quartz. Mostly it occurs as ragged, irregular, recrystallized aggregates, but is locally porphyroclastic or coronitic (thus contrasting with the lack of garnet coronas in the mafic rocks). Clinopyroxene and orthopyroxene are present in a few thin sections. Accessory min-

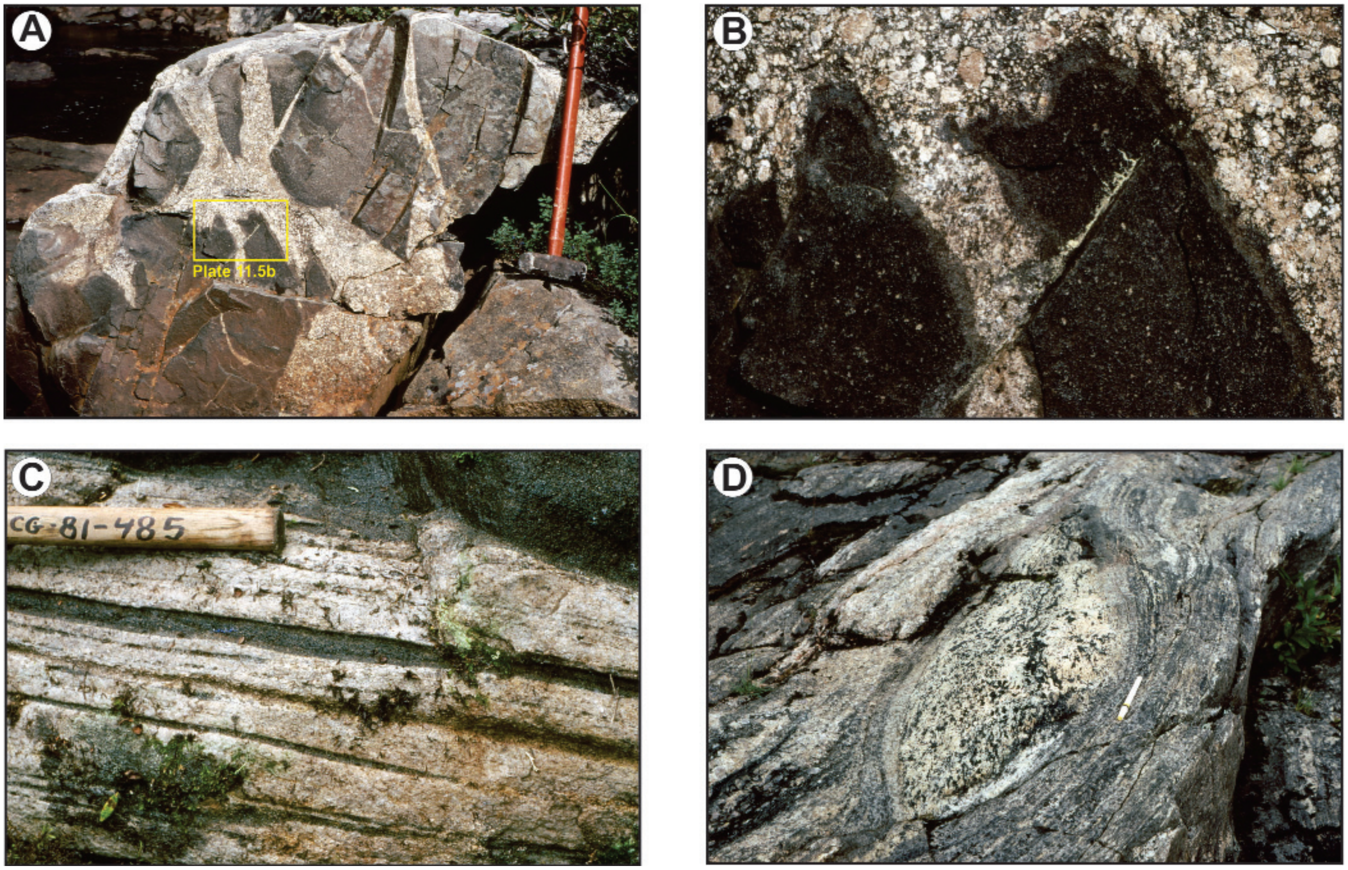


Plate 11.5. *White Bear Arm complex (WBAC), continued; and WBAC possible correlatives. A. K-feldspar megacrystic monzonitic rocks agmatically invading mafic rocks, WBAC (CG84-381/VN84-189), B. Close-up of part of A showing reaction rims between monzonitic and mafic rocks, WBAC (CG84-381/VN84-189), C. Well-banded gneiss derived from leucogabbronorite, WBAC correlative(?) (CG81-485), D. Boudin of leucogabbronorite in gneiss of similar composition, WBAC correlative(?) (CG84-442).*

erals include an opaque oxide, zircon, allanite, apatite, with secondary rutile, titanite, chlorite, epidote and white mica being sporadically present. Allanite is an atypical bright-orange in these samples. Thin section CG84-381C captured the reaction boundary between monzonitic and mafic rocks (Plate 11.5B; Photomicrograph 11.1C). Dark minerals in the mafic part are hornblende, clinopyroxene, together with minor orthopyroxene and biotite. In the reaction zone, hornblende is absent, biotite is greatly increased, pyroxenes decreased and garnet present.

11.4.4.14 Granodiorite, Granite, Alkali-feldspar Granite and Quartz Syenite (P_{3C}gd, P_{3C}gr, P_{3C}ga, P_{3C}yq)

The key feature pertaining to granitic rocks associated with the WBAC is their intimate relationship with intense deformation, hence their concentration in areas of thrusting at the northwest and southeast ends of the body. The rocks are most commonly pink- or red-weathering, fine to coarse grained, extremely deformed, and form thin sheets interleaved with metamorphic derivatives of the WBAC (mylonitized and/or migmatized amphibolite, mafic granulite and 'dioritic' gneiss). Such interleaving is sufficiently intimate to be captured in some thin sections (*e.g.*, NN84-543B, VN84-192). The wide range of granitoid compositions reflects the heterogeneity that is to be expected in such a dynamic environment. Nevertheless, there is probably some terminology bias, especially with respect to granodiorite and alkali-feldspar granite, which, are seemingly confined to the eastern end of the WBAC. This is probably a distribution more apparent than real, a consequence of better exposure and names used by individual mappers.

A large and diverse selection of thin sections is available (CG04-201B, CG85-229B, CG85-236, CG85-240B, JS86-047, JS86-376, JS86-394, MC77-137A, MC77-137B, MN86-044, MN86-204, MN86-346, NN84-543B, SN86-371B, SN86-385C, VN84-192, VN84-205A, VN84-226, VN84-238, VN84-241, VN84-402, VN84-430). All contain plagioclase, K-feldspar, quartz, biotite and an opaque oxide (except no K-feldspar seen in MN86-346, no biotite in VN84-205A, no opaque oxide in VN84-192). Other major minerals in several thin sections are amphibole and garnet. Orthopyroxene is present in CG85-236, and, as pseudomorphs, in CG85-236. Apatite and zircon are present in most samples, allanite in about 50% of the samples, and secondary white mica, chlorite and epidote sporadically present.

The association of these rocks with metamorphic derivatives of WBAC rock types and linkage to deformation suggest to the author that they are mostly the product of melting during severe tectonism, the melting partly creating channels to facilitate ductile deformation, and/or the thrusting generating sufficient heat to initiate melting.

11.4.5 WHITE BEAR ARM COMPLEX CORRELATIVE(?) AND BARRON LAKE GRANITOID ROCKS

11.4.5.1 White Bear Arm Complex Correlative? (P_{3C}ln, P_{3C}an)

A northwest-trending lenticular body of metamorphosed leucogabbronorite and anorthosite is situated in the vicinity of the lower part of White Bear River, southwest of Sandwich Bay (Figure 11.1). Based on somewhat inadequate mapping, the body is inferred to have a strike length of 25 km and to be mostly 3–4 km wide (Gower *et al.*, 1982b). The lenticular body is on strike with the WBAC and separated from it by about 10 km at their closest points. The author considers it to be a tectonically dismembered part of the WBAC. Note that the depiction of a 5-km-long lens of the same unit on the northeast side of the 25-km-long body is based on single data station (GF81-243) that, although described as quartz diorite to granodiorite in the field, proved to be garnet-bearing metaleucogabbronorite in stained slab.

Various names were applied to the rocks in the field, including meta-anorthosite, metaleucogabbro, leucoamphibolite, and diorite. Stained slabs show the rocks to be mostly plagioclase and lacking in K-feldspar or quartz, and point to anorthositic and leucogabbro protoliths. The rocks are white-, pale-grey- or pale-rose-weathering, fine to coarse grained, well-banded gneisses (Plate 11.5C), being dominantly leucocratic but interlayered with subsidiary melanocratic zones that, in the field, were termed amphibolite or meladiorite. The protolith is best inferred from weakly deformed leucogabbro boudins preserved within their highly tectonized host rocks (CG84-442, CG84-443; Plate 11.5D). The extremely tectonized state of the rocks at these specific localities is due to the presence of major dextral, strike-slip faults (interpreted to be Grenvillian). It is very likely that the whole body is a fault-bounded tectonic lens. Field relationships with other rock types are meagre. At locality CG81-485, the leucogabbronoritic gneiss appears to be discordantly intruded by a metamorphosed mafic dyke, which is also strongly deformed. A discordant pegmatite was recorded at VO81-187. A key field characteristic is the ubiquitous presence of garnet, which received mention in field notes at 90% of the sites. At GF81-244, garnet was noted as over 5 cm in diameter and, at MC77-173, as occurring in pods up to 10 cm across.

In thin sections of leucogabbroic rocks (CG81-486A, GF81-222, MC77-173, VO81-190), the mineral assemblage is plagioclase, colourless to pale green clinopyroxene, pale green hornblende (all polygonal), scapolite and garnet (which poikiloblastically encloses plagioclase in part). Prehnite occupies late-stage veins in three of the samples. Field notes of all (four) mappers who examined parts of the body record green rims in feldspar marginal to garnet. In thin section these are seen to be symplectic vermiform intergrowths of plagioclase and orthopyroxene (pseudomorphed to a serpentine mineral) (Photomicrograph 11.2A). Plagioclase in the symplectites is strongly zoned, but not elsewhere. Petrographic evidence implies (*cf.* Prasad *et al.*., 2005)

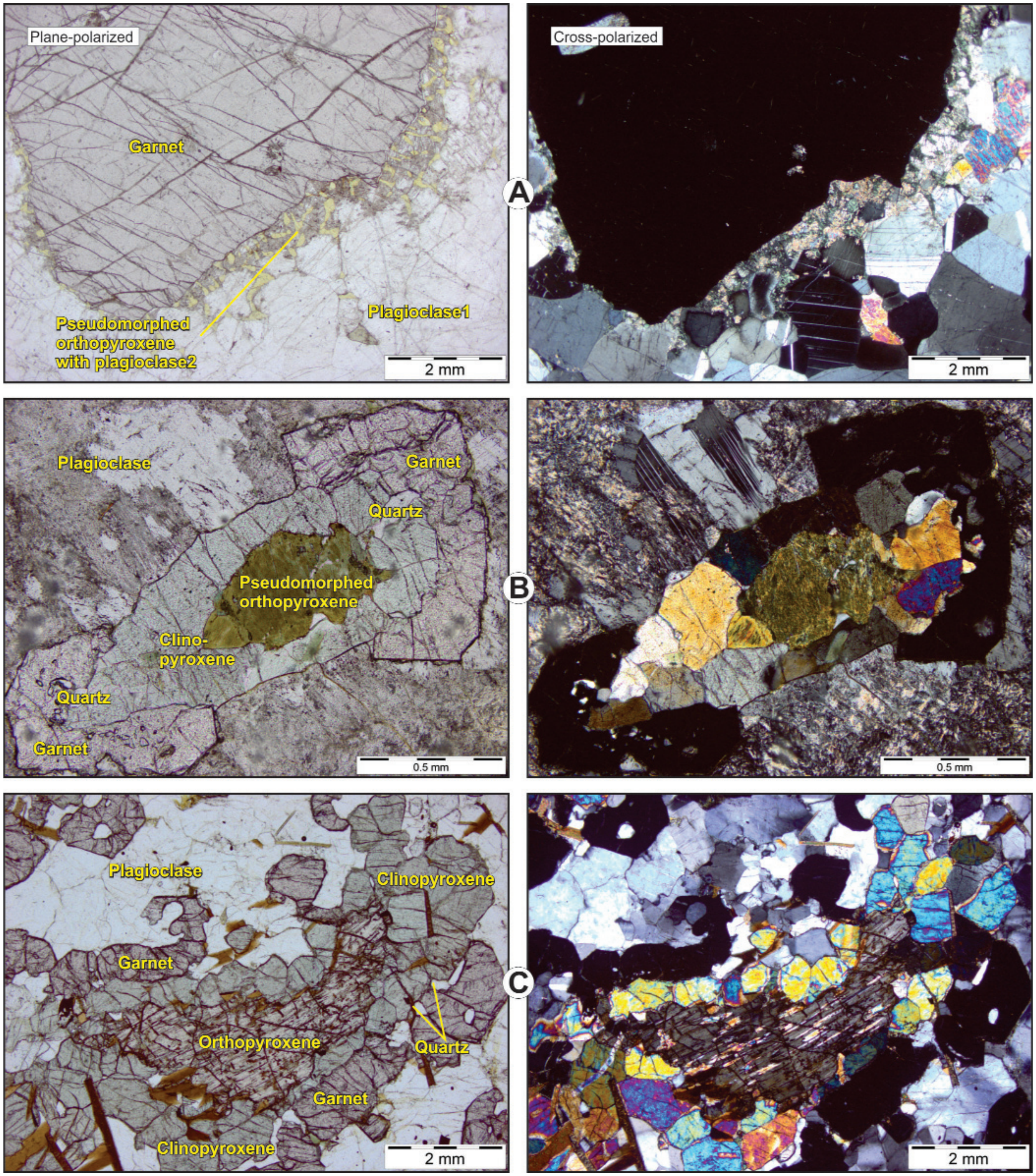
Garnet + Plagioclase1 = Orthopyroxene + Plagioclase2

There is no indication that either clinopyroxene or hornblende is involved in the reaction, although, independently, rims of hornblende replace clinopyroxene margins. Note that no quartz or opaque minerals (commonly included in potentially analogous reactions in the literature) were recorded in any of the thin sections. Symplectic textures fringing garnet in high-grade mafic rocks are well known and generally interpreted as decompression features (*e.g.*, Liu *et al.*, 2013). Such is likely the case here although no quantitative geothermobarometric data are available that might provide endorsement. Decompression is consistent with the earlier made suggestion that this body might have been derived from the southern side of the WBAC, which would imply vertical movement, as well as up to 100 km of horizontal displacement.

A fifth thin section from the same body is an ultramafic rock interlayered with leucogabbro (CG81-486B). It consists of clinopyroxene, orthopyroxene, garnet, amphibole, scapolite and minor plagioclase. Orthopyroxene occurs as a stable high-grade phase in this sample, as well as in symplectic intergrowth with plagioclase marginal to garnet. Orthopyroxene is only partly pseudomorphed (indirectly making interpretation of its former presence in the other thin sections more tenable).

11.4.5.2 Barron Lake Granitoid Rocks (on map as P_{3B}gr or P_{3C}gr)

The Barron Lake granitoid rocks refer to three 5- to 10-km-long by 1-km-wide slivers flanking WBAC correlative unit described above (but not otherwise located on Figure 11.1). The rocks are addressed here because of their spatial association with the WBAC correlative unit, but there is no compelling evidence that the two are otherwise related (or even that the three slivers related to each other). The Barron Lake granitoid rocks could equally well be assigned as Lake Melville terrane granitoid gneiss, and the conflicting designation of some of the outcrops (as P_{3B} *vs.* P_{3C} granitoid rocks) reflects this equivocation. It would be easy to dismiss these poorly understood occurrences as inconsequential, but they are considered to deserve mention because their location in the regional framework seems anomalous to the author.



Photomicrograph 11.2. *High-grade metamorphic reactions in Labradorian mafic rocks. A. White Bear Arm complex correlative(?) Garnet + plagioclase1 reacting to give orthopyroxene + plagioclase2 (GF81-222), B. Mount Gnat mafic granulite belt. Orthopyroxene + plagioclase reacting to give clinopyroxene + garnet + quartz (CG79-960), C. Mount Gnat mafic granulite belt. Orthopyroxene + plagioclase reacting to give clinopyroxene + garnet + quartz (RG80-047B).*

Field labels given to the six localities at which the rocks were observed include diorite, granodiorite, monzonite and granite; slab names are mostly granite or granodiorite; thin sections were termed syenite to alkali-feldspar granite (GF81-239) and monzonite (GF81-242). The rocks are described in field notes as strongly foliated or gneissic. Garnet was noted in field notes at three of the localities and orthopyroxene in one thin section (and possibly as a pseudomorphed mineral in the other thin section).

11.4.6 SANDWICH BAY (NORTHWEST) MAFIC INTRUSION (P_{3C}am, P_{3C}ln)

The first recognition of this mafic intrusive body appears to be by Eade (1962), as it is neither shown on the maps of Christie (1951) or Kranck (1953), nor on the unpublished geological compilation of Brinex based on their 1950s mapping (*cf.* Piloski, 1955). On the Brinex map, the area is indicated as underlain by granite. The outline of the body, as depicted by Eade, is roughly similar to that shown on the current 1:100 000-scale geological maps. As his direct observations seem to be limited to two data stations in the central part of the body, Eade's depiction was presumably based on aerial photographic interpretation. Information reported here utilizes the mapping and sampling of Gower *et al.* (1982b). The name is newly introduced. The area is termed 'Mealy Mountains' on NTS topographic maps, but, because of inevitable confusion with the much grander Mealy Mountains south of Lake Melville, that name is not used. No geochronological information is available for the intrusion.

The predominant rock is gabbronorite to leucogabbronorite that has been subjected to amphibolite-facies, grading into granulite-facies metamorphism. In the context of subsequent petrographic evaluation, the various field names applied by mappers (gabbro, norite, two-pyroxene gabbro, metagabbro, pyroxenite, metaleucogabbro, anorthositic gabbro, amphibolite, leuco-amphibolite and diorite) are all reasonably appropriate. The rocks are black-, grey- or brown-weathering, generally medium grained (locally coarse grained), and show a complete spectrum of fabrics, from massive to mylonitic, all of which may be displayed within small areas. Some of the reported rock-type variation can be explained as related to primary igneous layering (indistinct to well defined), which was recorded at several outcrops (CG81-101, CG81-103, CG81-109, GF81-033, GF81-035, VO81-172). At GF81-033, 2- to 5-cm-wide layers rich in mafic minerals, alternate with plagioclase-rich layers up to 1.5 m thick. Pyroxenite lenses elongate parallel to layering were seen locally (*e.g.*, GF81-289). Rarely, pyroxene or plagioclase phenocrysts were noted. Leucocratic material, forming mesh networks, veinlets or irregular patches also seem to be a feature of the body. Granodioritic to granite rocks of uncertain extent (but probably minor overall) were noted locally (GF81-122, VO81-171).

In thin section, the rocks range from gabbronorite to diorite. The gabbronorite, in addition to having primary plagioclase, strongly pleochroic orthopyroxene and pale-green clinopyroxene, contains some primary igneous hornblende, and red-brown biotite mantling pyroxene and the opaque oxide. Minor apatite and sulphide may be present (CG81-105, GF81-033, GF81-121, GF81-285). Sample CG81-105 has been mylonitized, having only relict primary igneous ovoids of plagioclase, orthopyroxene and clinopyroxene remaining in a matrix that includes polygonized aggregates of these minerals, together with polygonized hornblende, biotite and opaque minerals.

Of the dioritic rocks examined in thin section (GF81-125, RG80-571, RG80-578), the first-listed sample is of special interest in that it has an assemblage not commonly seen in eastern Labrador, namely cumulus plagioclase and intercumulus primary igneous hornblende. The other two samples were probably originally similar dioritic rocks, but are now deformed and partially recrystallized, such that plagioclase and hornblende form relict primary kernels within polygonized matrices. Samples GF81-125 and RG80-571 also show narrow symplectic clinopyroxene–plagioclase (sodic?) rims between primary plagioclase and hornblende, whereas RG80-578 has poikilitic garnet.

In addition to granitoid rock GF81-122 within the main part of the Sandwich Bay (northwest) mafic intrusion, several other, mostly quartz- and K-feldspar-bearing rocks are found farther southeast, in the southern part of Sandwich Bay (CG81-127, CG81-140, CG81-233, CG81-276, MC77-097A), that may/may not be linked to the same body. The closest compositional analogue is sample CG81-140, which is a leucogabbro. The rocks, which are very tectonized, are unlikely to have any simple relationships to other rocks in the vicinity, and are left unexplained.

The status of the Sandwich Bay (northwest) mafic intrusion with respect to other mafic bodies in eastern Labrador is uncertain. A glance at a regional geological compilation map of eastern Labrador might suggest that these rocks could be indirectly linked to those of the WBAC. Several contrasts exist, however; in the Sandwich Bay (northwest) mafic intrusive body: i) olivine is absent, ii) hydrous primary minerals are characteristic, iii) garnet is rare, and iv) the prograde reaction:

$$\textit{Hornblende} + \textit{Plagioclase1} \pm (\textit{Quartz?}) = \textit{Clinopyroxene} + \textit{Plagioclase2}$$

is evident. Alternative correlatives might be with the Dykes River mafic intrusion and/or the Porcupine Strand (west) mafic intrusions.

11.5 LAKE MELVILLE TERRANE

11.5.1 MOUNT GNAT MAFIC GRANULITE BELT (P_{3C}ag, P_{3C}am, P_{3C}rg, P_{3C}ln)

Gower and Owen (1984) coined the name Mount Gnat granulite belt as a subdivision of the Lake Melville terrane that forms a 10- to 15-km-wide corridor along the northeast flank of the northern part of the terrane. The intent was to set apart this zone of high-grade rocks, but the name did not receive much usage by either the author or others (although it remains viable). A variant of it is put to somewhat different usage here, being applied to the high-grade mafic rocks that form a significant component of the belt. Note that the other major associated rock type in the belt is termed 'The Backway K-feldspar megacrystic granitoid belt', which is addressed in the next chapter. It is suspected to be of similar age, but no isotopic data are available for either unit. Both units experienced similar high-grade metamorphism.

In field notes, the rocks are most commonly termed amphibolite, amphibolite gneiss, (meta)gabbro or (meta)diabase, with some mention of (meta)leucogabbro, anorthosite, ultramafite, diorite and quartz diorite. Surprisingly, in retrospect, they were rarely termed mafic granulite, although petrographic work (*see* below) subsequently confirmed the prevalence of granulite-facies metamorphic assemblages. The rocks are dark- to light-weathering (reflecting the ultramafic to anorthositic compositions), vary from fine to very coarse grained, and have fabrics that cover the spectrum from massive, through foliated to intensely mylonitic. Some rocks retain relict igneous ophitic textures despite their high-grade state. Typical is a severely deformed lensy to continuously banded gneissic fabric, which may be accentuated by concordant quartzofeldspathic veins. A characteristic feature of the rocks is the pervasiveness of garnet, which may also be quite large (>1 cm diameter) and abundant (commonly between 10 to 30%, but up to 50%).

Petrographic studies on these rocks were conducted during the early stages of the project before there was much familiarization with rocks in the region. As a result, a hodgepodge system of rock nomenclature developed, which has required retroactive standardization (never easy) in an attempt to achieve some consistency. It should be kept in mind that all the rocks are thoroughly metamorphosed, having polygonal, granoblastic fabrics and only rarely retaining any vestige of primary origin. In essence, rocks probably having gabbroid or leucogabbroic protoliths are termed mafic or mafelsic granulite, except where the name amphibolite is an alternative, and questionably better, choice. Other associated rocks (typically of more extreme composition), have retained their igneous protolith names (ultramafite, anorthosite, monzodiorite, diorite and quartz diorite). Note that the spectrum of rock types is similar to other 'P_{3C}' anorthositic to mafic units, hence their grouping here, despite lack of geochronological control.

The mafic to mafelsic granulite group is the largest (CG79-957, CG79-959, CG79-960, CG80-480, CG80-482, CG80-768, CG80-811B, NN80-590, RG80-014, RG80-033, RG80-034, RG80-034, RG80-047B, RG80-048A, RG80-049B,RG80-107A, RG80-110, RG80-214, RG80-281, RG80-302B, RG80-307A, RG80-480, RG80-481A, RG80-484, RG80-515B, SG68-010). The characteristic assemblage is well-twinned plagioclase, pale-green clinopyroxene, markedly pleochroic hypersthene, garnet (with opaque, quartz or biotite inclusions), green-brown hornblende, red- or orange-brown biotite, an opaque oxide and(or) sulphide and apatite, together with minor quartz, K-feldspar (about 50% of thin sections), and scapolite (RG80-034 and CG80-811B). Not all minerals are present in every thin section. More rarely, trace zircon and secondary white mica, epidote, chlorite and serpentine are seen. In most cases, hornblende and biotite appear to be part of the stable metamorphic assemblage. Some metamorphic reactions are evident, the most obvious being (CG79-959, CG79-960, RG80-047B; Photomicrographs 11.2B, C):

Orthopyroxene + Plagioclase = Clinopyroxene + Garnet + Quartz

The amphibolite group CG79-655, RG80-012, RG80-040A, RG80-288, RG80-485A, RG80-486A) is distinguished from the granulite group by lack of orthopyroxene and presence of more hornblende, but even these two mineral criteria are not clear-cut, as CG79-655 contains serpentine pseudomorphs that are probably after orthopyroxene. Five of the six samples also contain garnet (lacking in RG80-012) and four have clinopyroxene (lacking in CG79-655, RG80-040A). The remainder of the mineral assemblage is similar to that seen in the granulite and, collectively, comparable or near-comparable pressure–temperature conditions to those experienced by the rocks termed granulite are indicated.

Of the more extreme compositions, a lone ultramafic rock (RG80-494A) contains a retrograde assemblage of tremolite, chlorite, carbonate and an opaque mineral (suggesting a pyroxenite protolith), and two samples have anorthositic compositions (RG80-216, RG80-494B) and, simple mineral assemblages of plagioclase with minor hornblende, biotite (green-buff), and opaque minerals.

The associated granitoid rocks (CG80-485, NN80-662, RG80-048, RG80-049, RG80-481, RG80-488), which have been termed diorite, quartz diorite and monzodiorite, are all characterized by K-feldspar and quartz, in addition to plagioclase, orange-brown biotite, hornblende (lacking in NN80-662), garnet (lacking in NN80-662, RG8-481), opaque minerals, apatite, zircon, plus sporadic secondary minerals. Given the highly tectonized state of the belt, there is no compelling reason to consider these 'more granitic' rocks as being genetically related (although they could be, as such rocks are common associates in less-deformed equivalents of these rocks).

11.5.2 SPILLOVER MAFIC–INTERMEDIATE ROCKS (P_{3C}am/P_{3C}rg)

The Spillover unit is a newly created name for a group of mafic to intermediate rocks in the Lake Melville terrane (Figure 11.1). On the basis of present structural interpretation, they do not have any collective feature that strongly associates them either as a cohesive unit or provides clear-cut linkage to other mafic or intermediate rocks in the area. The rocks were first mapped by Gower *et al.* (1981, 1982b). The name 'Spillover' has its roots in the indentor tectonic model of Gower *et al.* (2008a), which envisages northeast-verging structural 'spillover' in this district. No isotopic data are available.

The rocks are described in field notes as amphibolite, metagabbro, diorite or leucoamphibolite. They are grey-weathering, medium to coarse grained and mostly massive to weakly foliated (except CG80-815, which is mylonitic). Anastomosing granitic dykes and veins of streaky pegmatitic material are commonly present and may be locally intimately interbanded with the mafic material to give an overall gneissic appearance. Garnet is common, reaching 0.5 cm in diameter in places. A fresh-looking fine-grained, uniform, massive metadiabase, noted to intrude strongly foliated amphibolite, was recorded at CG81-533.

Two thin sections (CG81-529, CG80-814) are both diorite to amphibolite. They consist of a relict igneous assemblage of plagioclase, quartz, biotite, hornblende, garnet (in CG81-529), an opaque oxide, apatite, zircon (in CG81-529), allanite, and sporadic secondary epidote, chlorite and white mica (no K-feldspar or pyroxene present).

Their metamorphosed but largely unmigmatized state is the main criterion for grouping the rocks as late Labradorian. The rocks differ from the nearby Mount Gnat mafic granulite belt in that they are not granulite, and differ from the Sandwich Bay (northwest) mafic intrusion in that they lack layering. An alternative correlation is with the Rigolet quartz diorite or the Earl Island domain, but isolated from both as tectonic slivers.

11.6 MEALY MOUNTAINS TERRANE

11.6.1 MEALY MOUNTAINS INTRUSIVE SUITE

The Mealy Mountains intrusive suite (MMIS) is an archetypal AMCG (anorthosite–monzonite/mangerite–charnockite–granite) complex. It was emplaced between 1655 and 1625 Ma. Within the area addressed in this report, the suite underlies an area roughly 8500 km^2, but its total extent is approximately double when its western part is included (Figure 11.9). In addition, anorthositic rocks in the Cape Caribou River district and monzonitic rocks Double Mer White Hills have both been interpreted as allochthonous correlatives of the MMIS, now isolated from it by the Neoproterozoic Lake Melville rift system (neither are included in Figure 11.9). The MMIS must also underlie parts of the Lake Melville rift system.

The first geological mention of rocks now assigned to the MMIS was by Kindle (1924), inasmuch as he noted boulders of labradorite on the shores of Lake Melville that he presumed to have come from the mountains above. The Mealy Mountains were explored for their mineral potential

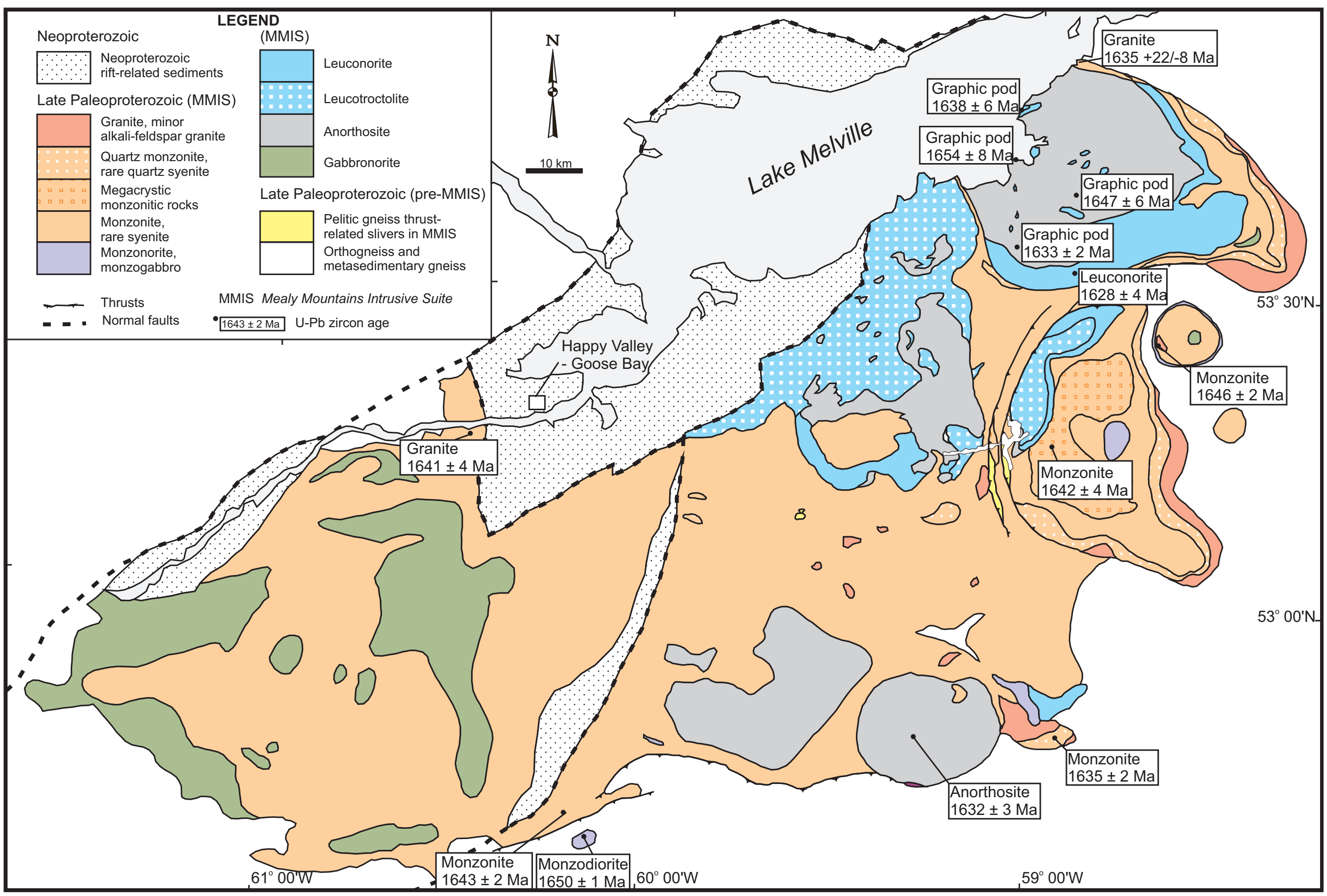


Figure 11.9. *Regional map of Mealy Mountains intrusive suite. Note that the eastern and western parts (divided by longitude 60°W) were mapped by entirely different groups of geologists, so the differences evident might be more apparent than real.*

by Frobisher Exploration Limited and Nalco in the early 1950s (Evans, 1951; MacDougall, 1953). The extent of the anorthositic rocks, as mapped by Evans, was incorporated into Christie *et al.*'s (1953) map. Anorthositic rocks are also shown along the south shore of Lake Melville on the map of Kranck (1953). A petrographic study was completed by Gillett (1956) on samples collected by Kranck. The eastern part (east of longitude 60°W) was mapped at 1:500 000 scale by Eade (1962) and the western part at 1:250 000 scale by Stevenson (1967a, b), and the two parts combined in a compilation sketch map of the MMIS by Fahrig *et al.* (1974). The name Mealy Mountains complex was applied by Emslie (1976), following his mapping of the northeastern part in 1975. It was modified to Mealy Mountains intrusive suite by Gower *et al.* (1981).

The history of 1:100 000-scale mapping of the eastern MMIS is rather more complex than for most areas of eastern Labrador and clarification may be helpful in understanding the subsequent text. The map regions involved and contributions made to mapping, as indicated by the data stations from various geological mapping projects, are shown in Figure 11.10. The MMIS, east of longitude 60°W, is covered by six 1:100 000-scale map regions. Maps for the MMIS for the northern two (Lake Melville and English River regions) rely almost entirely on the mapping of Emslie carried out in 1975, with minor additions by Emslie in 1995. Mapping by the author (Gower *et al.*, 1981, 1982b) focussed on the gneissic rocks to the east of the Mealy Mountains and only included part of the northeast lobe of the MMIS. The rest of the MMIS within the English River map region was compiled from the unpublished mapping of Emslie. The author has, however, visited other sites at various times within these areas, especially in 2009.

Mapping at 1:100 000 scale of the central two map regions (Kenemich River and Southeast Mealy Mountains) was carried out in 1995 by Nunn and van Nostrand (1996a) and Gower and van Nostrand (1996), respectively. Emslie had previously conducted some mapping in both areas in 1975 (mostly in the Kenemich River region). Emslie also contributed to the mapping of the Kenemich River region in 1995. Nunn's field notes were subsequently lost and all samples discarded (no thin sections or chemical analyses were obtained). A preliminary map was produced (Nunn and van Nostrand, 1996b). The lack of Nunn's notes and absence of samples has seriously hampered synthesis, but the loss is partially mitigated by having van Nostrand's and Emslie's field notes (1975 and 1995), plus information gained during helicopter traverses conducted by the author across the region in 2007. The southern two map regions (Crooks Lake and Eagle River) are beyond the southern limit of Emslie's mapping and were mapped entirely by the author. The distribution of units perhaps suggests that the author has subdivided the anorthositic rocks less and monzogranitic rocks more than other mappers.

West of longitude 60°W (Figure 11.9, but outside the scope of this report), 1:100 000-scale mapping of the MMIS was completed by James (1999), Wardle and Crisby (1987), and Wardle *et al.* (2000a, b) in NTS areas 13C/NE, 13F/SE, 13C/NW, and 13F/SW, respectively. From Figure 11.9, it would appear that there are major differences between the eastern and western parts of the MMIS. The author has only seen a few roadcuts on Highway 510 in the western region and does not know to what extent the differences are genuine, rather than due to the two parts having been mapped by entirely different groups of geologists.

Geochemical and isotopic studies of the MMIS have been carried out by Ashwal *et al.* (1986), Hegner *et al.* (2010), Bybee *et al.* (2014; *see* also Comment by Vander Auwera *et al.*, 2014, and Reply by Bybee *et al.*), Bybee *et al.* (2015), and Bybee and Ashwal (2015).

In the Dome Mountain intrusive suite, in the Goose Bay area, an amphibolite hosting a Dome Mountain monzonite dyke yields a concordant zircon age of 1641 ± 2 Ma (Figure 11.9), interpreted to be metamorphic, although a slightly older, concordant 1636 ± 3 Ma grain may indicate time of emplacement of its protolith (Bussy *et al.*, 1995).

Within the area addressed in this report, the various lithological components are addressed in order of: i) anorthositic rocks, ii) monzonitic rocks, and iii) granitic rocks. In the case of the anorthositic rocks, the association of anorthosite with leucotroctolite and/or leuconorite is intimate enough for all three rock types to be considered collectively within the individual intrusions in which they occur. In the case of the monzonitic and granitic rocks, the limits of individual bodies are not so obvious, so treatment is done on an area-by-area basis. The various named intrusions and informally labelled areas are indicated in Figure 11.11.

11.6.1.1 Anorthosite, Leucotroctolite, Leuconorite (P_{3C}an, P_{3C}lt, P_{3C}ln)

Five separate anorthositic areas have been mapped in the MMIS, namely: i) Kenemich massif, ii) Etagaulet massif, iii) Bow Tie intrusion, iv) Rocky Pond anorthosite, including the Vulcan anorthosite, and v) Crooks Pond anorthosite. The Kenemich massif was first distinguished as a separate body (but not named) by Emslie (1976). Emslie (1976, page 166) wrote "… leucotroctolite is restricted to the southwestern part [Kenemich massif] of the complex whereas anorthosite and leucogabbro are dominant in the topographically higher northeast part [Etagaulet massif]." The squared brackets are the author's inserts. The first pub-

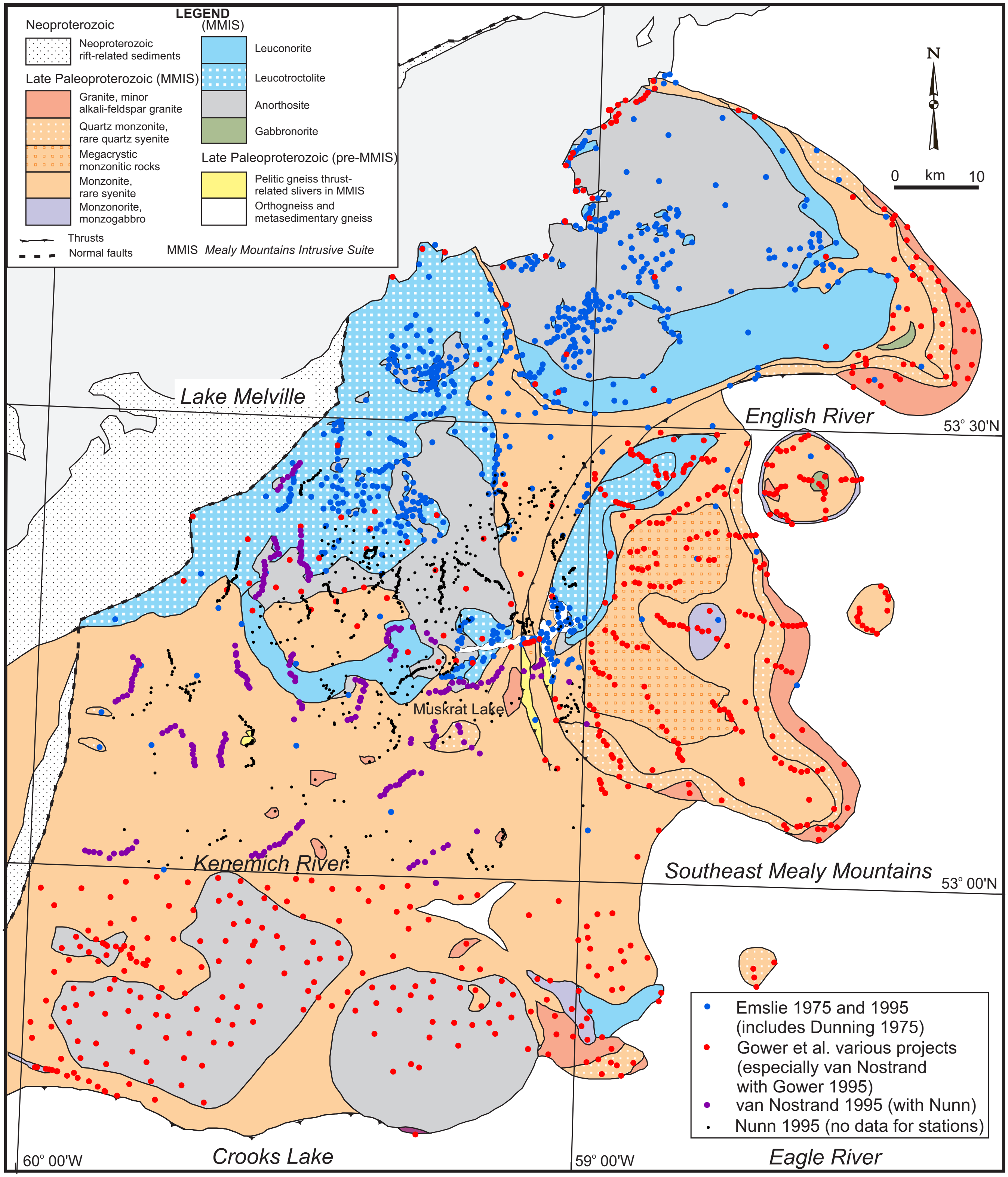


Figure 11.10. *Mapping in the eastern half of Mealy Mountains intrusive suite.*

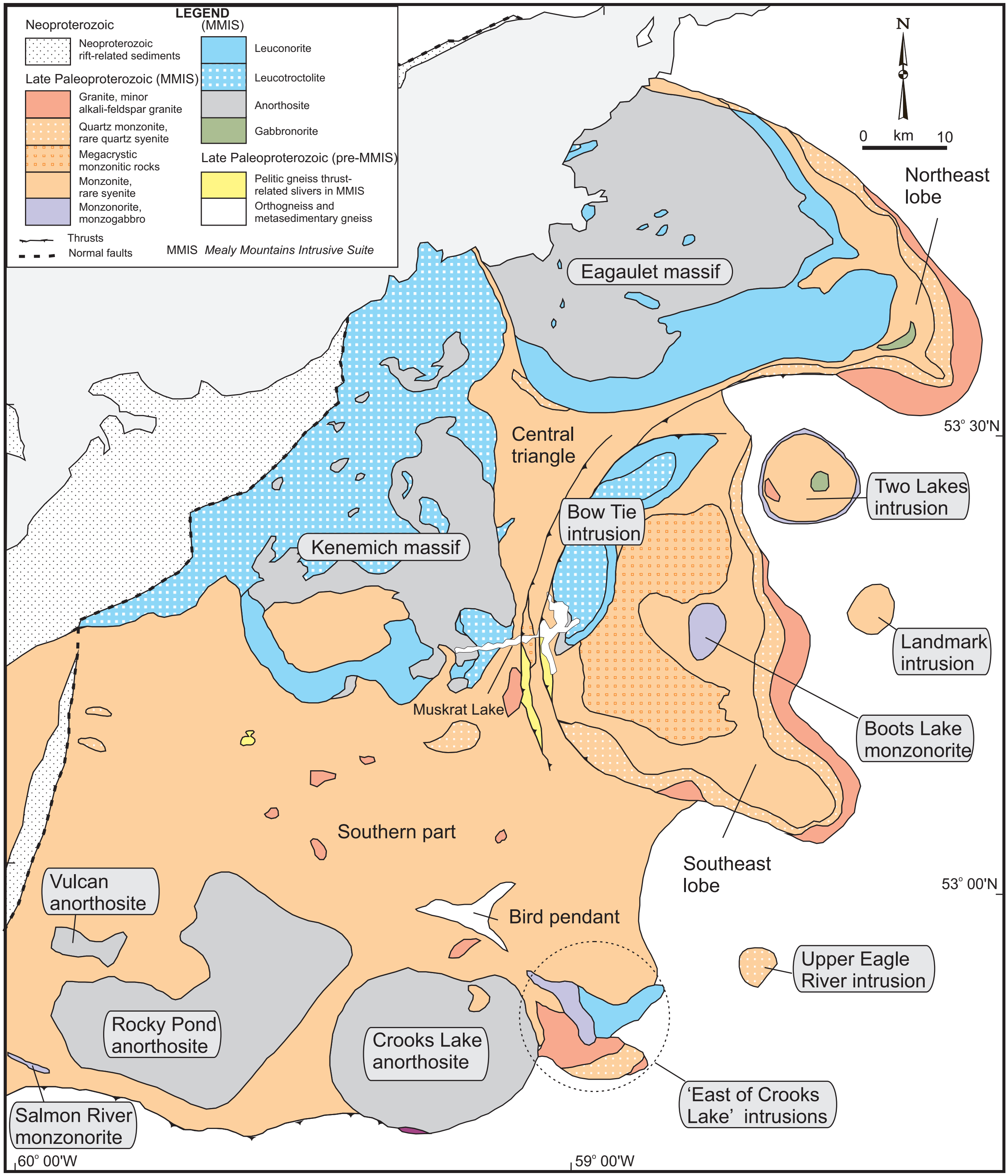


Figure 11.11. *Names used in text refer to various parts of the MMIS.*

lished usage of the names Kenemich and Etagaulet massifs, of which the author is aware, was by Emslie and Bonardi (1979). The names were used as established terms by Ashwal *et al.* (1986).

Bybee *et al.* (2014) mentioned a Sm–Nd isotopic array for anorthosite whole-rock compositions that, although not defining an isochron, indicated an age of 1653 ± 150 Ma. Sm–Nd, Rb–Sr and Pb–Pb isotopic data are given by Bybee and Ashwal (2015).

Kenemich massif. The present field description is based mostly on the 1975 and 1995 notes of Emslie, and the 1975 notes of his senior assistant (G. Dunning), with minor supplementary information from the 1995 notes of van Nostrand, and two helicopter traverses across its southern part carried out by the author in 2007. It deserves to be said that the field notes of Emslie and Dunning make a huge contribution to field knowledge of the MMIS, especially the Kenemich and Etagaulet massifs. Without their perceptive observations, little would be known about the field setting of these rocks.

Anorthosite in the Kenemich massif is found mostly in its southeast part. The anorthosite is grey-, dark-grey-, white- or brownish-weathering, massive, and coarse grained to very coarse grained. The variation in colour is thought to be due to tiny inclusions of Fe–Ti oxides. Plagioclase is most typically in the 2–10-cm size range. Uncommonly, it is finer grained, but, conversely, in many instances, crystals are 15 to 30 cm across and may be over 60 cm across. The very large crystals tend to form pods several metres in diameter, and one instance was noted of a pod 100 m long containing plagioclase crystals over 50 cm across (ECD75-168). Blue feldspar chatoyancy was seen at ECD75-148, but is the only recorded example. Emslie's field notes make a tacit distinction between plagioclase lamination, due to oriented tabular plagioclase crystals (and locally seen in the very coarse-grained anorthosite pods), and primary igneous layering, which is present in the enveloping finer grained anorthosite. Layering is expressed by variations in grain size and intervening leucotroctolite pod strings and layers. Colour index is 5–10, the mafic component being made up of olivine, clinopyroxene, orthopyroxene and magnetite. In rare instances, pyroxene crystals approach those of plagioclase in size. Magnetite clusters up to 12 cm long were recorded (*e.g.*, ECD75-166). Trace sulphide was recorded at ECD75-216 and ECD75-223. Small patches (less than 30 cm across) of myrmekitic granite were noted at ECD75-240. It is the only recorded instance of a granitoid pod in anorthosite in the Kenemich massif (plus two in the associated leucotroctolite). Other noteworthy features (because of their rarity) are enclaves of fine-grained, basic/intermediate, pyroxene granulite (EC95-002, EC95-004) or anorthosite (EC95-075), and minor monzonitic veins or dykes. The latter were noted, for example, at EC95-111 (1 m wide), TN95-025 (7–10 cm wide), and ECD75-200 and ECD75-240 (width not specified).

Leucotroctolite in the Kenemich massif is white-, grey- or dark-grey-weathering, massive and coarse grained to very coarse grained. Colour index is around 10–20. One key feature mentioned repeatedly in field notes is primary igneous layering. It is hard to make generalizations regarding the nature of the layering as there is such a wide range of styles. In places, it is merely expressed as a lamination defined by tabular plagioclase crystals. Apart from plagioclase crystal orientation, layering is defined by grain size and compositional variations. The latter include: i) alternations of anorthosite, leucotroctolite or, less commonly, troctolite layers, and ii) oriented pod-strings of olivine-, orthopyroxene- or oxide-rich-leucotroctolite. Layering may be on a relatively delicate scale of 1 to 2 cm width, or as broader units between 5 and 40 cm, which, in turn, may belong to larger layered units anywhere between 5 and 80 m thick. At some localities, layers are restricted to pods, but elsewhere are continuous over horizontal distances of 100s of metres. Generally, layering dips at shallow angles (less than 20°). Commonly, the attitude is fairly uniform over several square kilometres. Collectively, within the Kenemich massif, layering defined an east–west antiformal structure flanked by less-well-defined synforms (Figure 11.12, based on Emslie's and Dunning's field notes). A repeatedly described feature is large pods or patches of very coarse-grained anorthosite, which range up to 10s of metres across. Margins of the pods were described as 'sharp' in some instances. They are mainly characterized by very coarse plagioclase (typically 10–30 cm long, but at least twice this size was recorded). The plagioclase is accompanied by coarse-grained orthopyroxene and/or oxide minerals, with olivine less common (and apatite rarely). Some pods were noted to be oriented parallel to the layering and to have their own internal layering. Granitic patches, 1 m across, were noted at ECD75-185 and ECD75-206. Sulphide, including chalcopyrite, was recorded as a 2 x 3 m gossan at EC95-166 and in a pyrrhotite- and pyrite-bearing 'dioritic (?)' inclusion at ECD75-028. Leucotroctolite is intruded by oxide-rich anorthosite dykes at ECD75-187 and ECD75-193 (60 cm wide), and by leuconorite at EC95-003. More commonly, leucotroctolite is intruded by monzonite dykes (also termed felsic dykes in field notes). Many have widths less than 10 cm and the widest observed is 1.5 m. Some were noted to have fine- to medium- grained margins and pegmatitic centres. The dykes were recorded at EC75-130, EC95-087, EC95-114, ECD75-185, ECD75-186, ECD75-194, ECD75-197, ECD75-203, ECD75-205, ECD75-210, ECD75-213, ECD75-215, ECD75-230, ECD75-237, ECD75-238, and ECD75-241. At ECD75-186

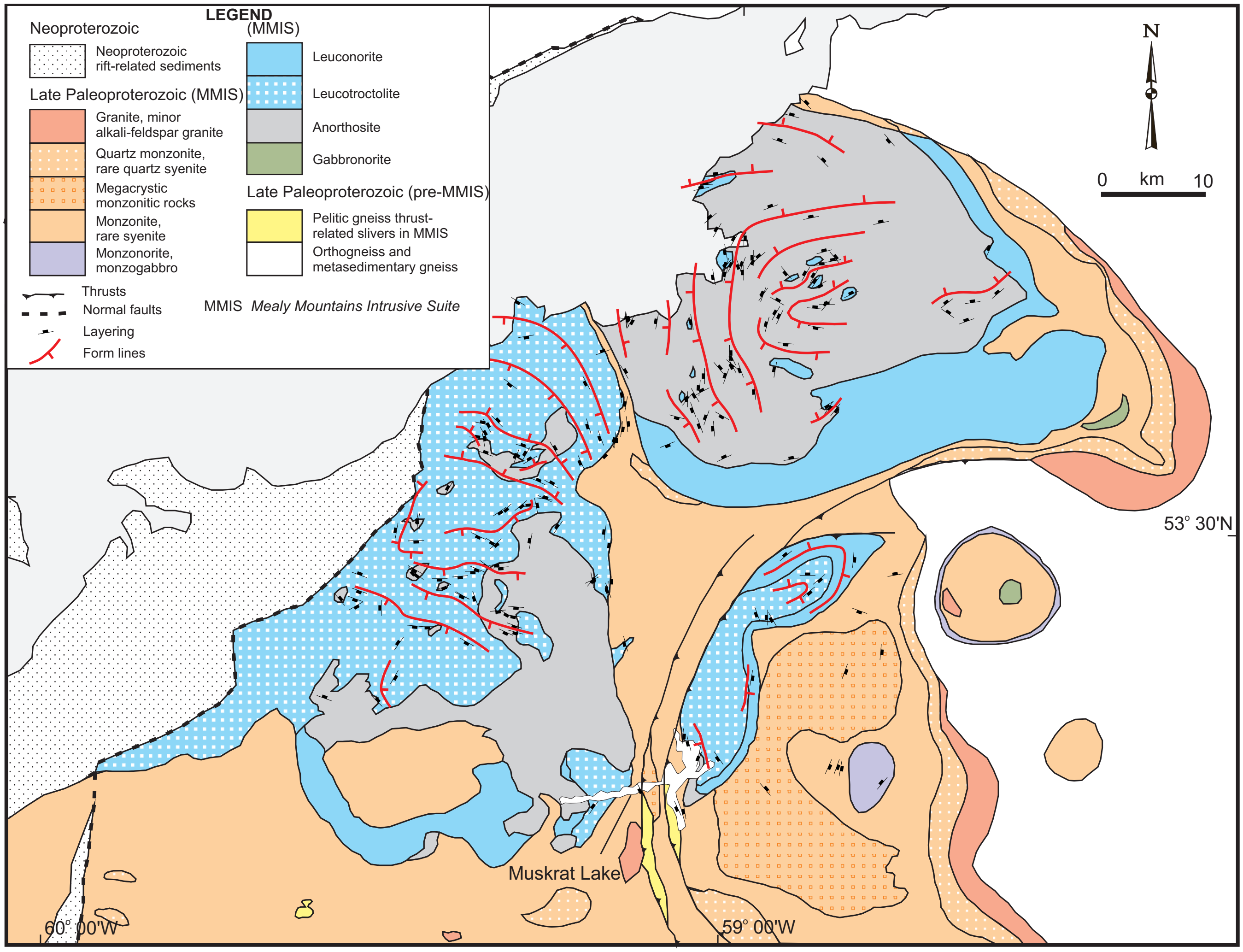


Figure 11.12. *Primary igneous layering in Kenemich, Etagualet and Bow Tie units.*

and ECD75-215, the monzonite dykes are discordantly intruded by Mealy dykes, thus demonstrating that they predate 1250 Ma (but, realistically, most would accept that they are an intrinsic part of the MMIS).

Unlike anorthosite and leucotroctolite, leuconorite in the Kenemich massif is not common. It is found in two areas. The first is along the eastern fringe of the Kenemich massif, very close to the contact with monzonitic rocks (EC95-014, EC95-021, EC95-051, EC95-140, EC95-171). The second is in a region west of Muskrat Lake, where all the other occurrences were mapped (22 data stations), except for two within leucotroctolite (EC95-071, EC95-118). The 22 occurrences west of Muskrat Lake are of interest inasmuch as they fall within a donut-shaped aeromagnetic low. The southern half of this aeromagnetic anomaly is mapped as leuconorite, whereas the northern half is designated anorthosite. The core is monzonite. Although, lacking adequate constraints from field descriptions or samples, the author cannot restrain himself from speculating that the aeromagnetic signature indicates the existence of a 30-km-diameter ring intrusion. If so, then the north and south parts are related, despite having been depicted as different rock types on the 1:100 000-scale map. If a ring intrusion exists, it is not entirely surprising that such a body would pass unrecognized during mapping, as field descriptions do not identify any distinguishing characteristics that would readily discriminate it from the rest of the Kenemich massif. The rocks are recorded as white-, grey- or dark-grey-weathering, massive and coarse grained to very coarse grained. Grain size is typically 1 to 2 cm with plagioclase megacrysts up to about 10 cm. Colour index is around 15. Other features include clots of pyroxene and oxide minerals up to 10 cm across. Possibly significant features that might point to it being a separate intrusion are: i) no mention of layering (although it was reported from the two isolated leuconorite occurrences elsewhere in leucotroctolite; EC95-071, EC95-118), and ii) only one mention of anorthosite pods, at EC95-

076 (note that anorthosite pods do occur in an isolated leuconorite occurrence EC95-071). Even the anorthosite pods at EC95-076 can be explained away, as this locality is at the very border of the hypothesized ring intrusion and might not be part of it.

If any published petrographic information exists for anorthosite, leucotroctolite and leuconorite from the Kenemich massif, the author is unaware of it. Because the massif has never been part of the author's mapping objectives, he did not attempt to access petrographic and microprobe data acquired by Emslie. That such data exist is indicated by Emslie and Bonardi's (1979) description of the rocks as labradorite and labradorite-olivine ($An_{49}Or_3$; Fo_{68}-Fo_{56}) adcumulates in which the essential minerals show little or no zoning. Minor intercumulus minerals were noted to be orthopyroxene, clinopyroxene, magnetite, ilmenite, biotite and apatite. Microprobe data for pyroxene pairs indicates temperatures of 870–1060°C.

Four thin sections were prepared from the author's own samples collected during 2007 helicopter traverses; namely, from anorthosite (CG07-074), leucotroctolite (CG07-094, CG07-099) and leucogabbronorite (CG07-082). Minerals present are anhedral, primary igneous plagioclase, colourless to pale-brown clinopyroxene and an oxide opaque mineral (present in all thin sections), plus orthopyroxene (CG07-082, CG07-099), and olivine and foxy-brown biotite (both in CG07-094, CG07-099). Hercynite is present in CG07-099. There are no coronas mantling olivine.

Etagaulet massif. Anorthosite occupies the core of the Etagaulet massif. It is grey-, dark-grey- or purplish-grey-weathering, massive and coarse grained to very coarse grained. Key features of the anorthosite are: i) pods of very coarse-grained anorthosite, ii) primary igneous layering, iii) orthopyroxene megacrysts, and iv) pegmatitic granitic pods.

The coarse-grained anorthosite pods range in size from a few centimetres across up to 160 by 80 m. Plagioclase in the pods is commonly noted to be 10 to 25 cm across, but crystals up to 75 cm long were seen. The main associated minerals are equally large orthopyroxene crystals and an opaque oxide. At many sites, very coarse-grained anorthosite pods are found within finer grained, commonly laminated or layered anorthosite (*e.g.*, EC75-145, EC75-153). At EC75-143, a dyke of grey-laminated anorthosite is recorded as cutting very coarse-grained anorthosite, and, at EC75-146, Emslie (field notes) wrote that 'contacts are quite clear and sharp and there is no doubt that the very coarse-grained rock is older'.

Layering in the Etagaulet massif is due to compositional contrasts between layers, grain-size variations, grain-shape differences, or plagioclase colour contrasts (Emslie, 1976). Layering in the Etagaulet massif collectively defines an east-west-elongate, west-closing partial domal structure (Figure 11.12). Emslie (1976) noted that layering attitude is consistent over large areas. Going beyond Emslie's (1976) report, further details can be extracted from his field notes. He wrote (for locality EC75-165), "Excellent layers, absolutely parallel over a thickness of 30–40'. Eight individual layers on 300' long face along strike. Some are slightly mafic enriched; others are essentially pure plagioclase. Thickness of individual layers varies from 3 to 6'." At EC75-040, an 85-m-thick layered section has layers defined by slight grain-size and colour-index differences. At EC75-250, layers intersect a large mass of grey anorthosite at a small angle and not deflected by it. Layering was also observed to be defined by a poikilitic pyroxene 'spotted' rock (EC75-042, EC75-148; EC95-131); by leucogabbro layers (EC75-049); by a 60-cm-thick layer having a lower oxide-rich part and an upper pyroxene-rich part (EC75-154); by 5- to 15-cm-thick coarse plagioclase layers; by troctolitic pods (ECD75-037); by graded layers (ECD75-045); and to be locally folded (due to slumping?) (EC75-104). To this author, Emslie's field evidence consistently points to the pre-existing pods of very coarse-grained anorthosite settling through a magma chamber that, as the magma crystallized, was subject to periodically subtly fluctuating pressure and temperature conditions resulting in concomitant crystal precipitation and layering.

Large orthopyroxene crystals (also referred to as megacrysts and giant crystals) occur: i) as an integral part of the very coarse-grained anorthosite pods, in subophitic relationship with plagioclase, ii) as isolated megacrysts in very coarse-grained anorthosite, iii) as clusters of giant crystals in orthopyroxene pods (up to 10 by 3 m; EC75-157), and iv) in a 7 by 1 m 'vein' of orthopyroxene and opaque minerals. Their field distribution is given in Figure 11.13, which shows that almost all are found in the Etagaulet massif. The crystals are commonly larger than 30 cm across and may be considerably larger – up to 1 m reported by Emslie (1976). They are also repeatedly described as rounded or subrounded and hosting exsolved plagioclase lamellae parallel to (100). Emslie (1976) noted that some megacrysts with plagioclase lamellae have overgrowths of orthopyroxene free of plagioclase lamellae that are intergrown with adjoining plagioclase crystals. He commented that the field evidence is consistent with the megacrysts having been brought up from depth after initially crystallizing under higher pressures.

The orthopyroxene megacrysts have been investigated by Bybee *et al.* (2014), and have been determined to be HAOM-type (high-Al orthopyroxene megacrysts). High Al in orthopyroxene is the basis for a well-calibrated geobarometer (Emslie *et al.*, 1994), which, at the Al content levels in the MMIS, imply crystallization at 8.7 to 9.7 ± 0.4 kb (one result at 4.5 kb), hence formation in the lowermost

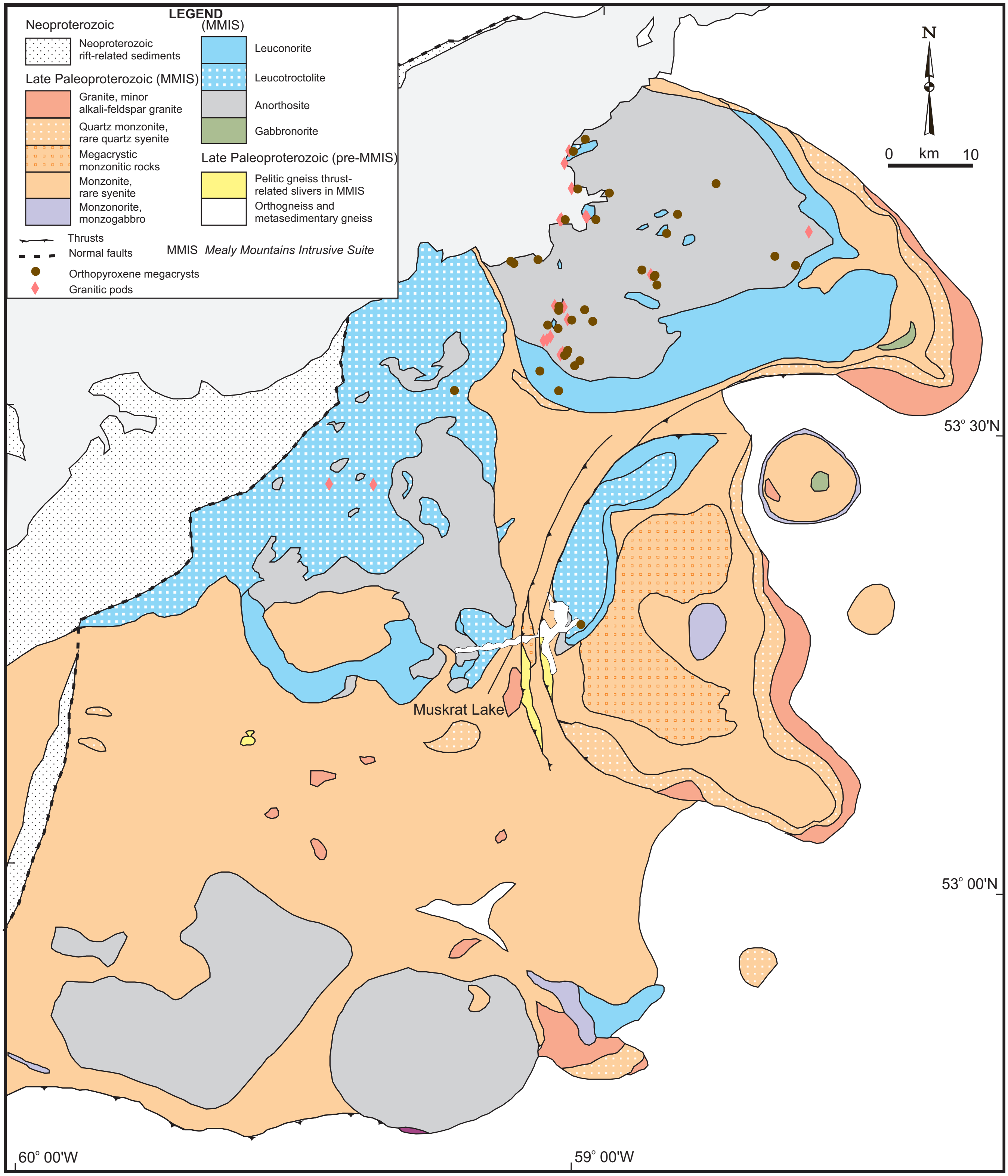


Figure 11.13. *Location of orthopyroxene megacrysts and granitic pods in MMIS.*

crust. Bybee *et al.* (2014) reported a Sm–Nd isochron age of 1765 ± 12 Ma for high-Al orthopyroxene megacrysts from the MMIS. This age is roughly 115 to 130 million years older than the 1650–1630 Ma time of emplacement for the MMIS. Bybee and Ashwal (2015) advance the hypothesis that mantle-derived magma pond at the mantle–lower crust interface. Here, the magma undergoes significant differentiation and solidification, and this is when the orthopyroxene megacrysts formed (at *ca.* 1765 Ma). This was followed by slow ascent of plagioclase-rich, largely crystalline, magmatic bodies (with entrained orthopyroxene megacrysts) that arrived at their final emplacement levels between 1650 and 1630 Ma, at which time the final residual liquid (pegmatitic pods – *see* next paragraphs) solidified.

The pegmatitic granitic pods (also termed graphic or myrmekitic granite) are typically pink- or brick-red-weathering, coarse grained, and are found in pods that range in size from a few centimetres across to large bodies (*e.g.*, 30 by 12 m at EC75-189). Their distribution is given in Figure 11.13. They are illustrated by Bybee *et al.* (2015), and one example is shown in Appendix 2, Slabs.11.6. The granitic pegmatite pods commonly exhibit graphic intergrowths of K-feldspar and quartz and have associated plagioclase, orthopyroxene, opaque minerals and, rarely, garnet (CG09-018). There are indications of a spatial association with orthopyroxene megacrysts. Xenoliths of gneiss and amphibolite are associated with pegmatitic granite at EC75-189. Pegmatitic granite was also noted to occur as 3 intrusive dykes at EC75-248 (widest 10 cm); as 2 dykes at ECD75-043 (widest 20 cm); as a 30-cm to 2-m-wide zone cutting very coarse-grained anorthosite that contains giant pyroxene at EC75-157; and as a magnetite-rich quartz-feldspar dyke at ECD75-121. A granitic pod measuring 3 by 1.5 m within a very coarse-grained anorthosite is noteworthy in that it contains blue quartz (ECD75-125).

As in other AMCG suites, the pegmatitic pods are valuable in that they carry macroscopic zircon, which, commonly, can be simply extracted directly from hand samples. Three U–Pb ages, from leuconorite-hosted pegmatitic pods (CG09-016A, CG09-026B, and CG09-033B), have near-concordant results of 1654 ± 8, 1647 ± 6 and 1638 ± 6 Ma, each based on five zircon fractions and having lower intercepts of 1099 ± 80, 1051 ± 120 and 1138 ± 15 Ma, respectively (Figure 11.9). A fourth, almost concordant, U–Pb age of 1632.8 ± 1.8 Ma and a lower intercept of 106 ± 160 Ma, based on four zircon fractions, was obtained from a pod (CG09-018D) within an olivine-bearing anorthosite from the same area (Bybee *et al.*, 2015).

Other sporadic features in these anorthositic rocks include: i) rusty-weathering troctolite pods (EC75-188, 100 by 50 m; ECD75-037, ECD75-038, ECD75-093), ii) oxide or pyroxene-oxide patches and pods, and iii) rare gossans (*e.g.*, EC75-162, at which chalcopyrite and pyrrhotite were recorded).

Emslie and Bonardi (1979) describe the rocks as adcumulates with cumulus andesine antiperthite ($An_{49}Or_8$–$An_{41}Or_8$), hypersthene (Mg_{65}–Mg_{50}), and minor magnetite–ilmenite, all with little or no zoning. Intercumulus minerals are clinopyroxene, magnetite–ilmenite, biotite and apatite. Microprobe data for pyroxene pairs indicate temperatures of 810–930°C.

The only petrographic data for the Etagaulet massif in the author's collection comes from three anorthosite samples collected during Erdmer's (1984) mapping in the Lake Melville area (MW82-019, MW82-021.1, MW82-021.2). The rocks contain primary igneous plagioclase, intercumulus orthopyroxene and an opaque oxide. In addition, MW82-021.1 and MW82-021.2 samples contain clinopyroxene, which is lacking in MW82-019, but contains foxy-brown primary biotite. Minor chlorite, carbonate and serpentine (all after orthopyroxene) are present in MW82-019.

Leuconorite in the Etagaulet massif forms an envelope around the east and south sides of the anorthosite core. One sample (CG09-021) of leuconorite has a U–Pb zircon age of 1628.0 ± 3.5 Ma based on five fractions, three of which are near concordant and the other two moderately discordant. The lower intercept is 1119 ± 39 Ma, suggesting modest Pb loss during early Grenvillian orogenesis.

Leuconorite similarities with anorthosite outweigh differences. It is grey-weathering, massive and coarse grained to very coarse grained. By definition, leuconorite has a higher colour index than anorthosite, but, in these rocks, it is not hugely different, typically being in the 10 to 20 range. Like anorthosite, leuconorite contains pods or blocks of very coarse-grained anorthosite (but perhaps fewer and/or smaller?) and shows plagioclase lamination and layering. Emslie (1976), at one site (EC75-053), describes a block of anorthosite that shows layers compressed beneath it and also draped over it. At a second site (EC75-205), he records patches of giant plagioclase having individual crystals 2 and 1.5 m long. At a third site (EC75-205), an intrusive mass of sulphide-bearing gabbro or diorite is noted as containing subangular anorthosite blocks, one of which contains a 5 m by 2 m patch of pegmatitic granite. Layering is not reported so commonly in leuconorite as in anorthosite, although it is described as excellent at EC75-050. Giant orthopyroxene crystals with plagioclase lamellae are common (*e.g.*, EC75-051, EC95-038, EC95-150), and is found in pods (EC75-234, EC95-038, 5 by 1.5 m) or as plagioclase–orthopyroxene giant-crystal aggregates (EC75-235). Pegmatitic granitic pods are reported from data stations EC75-193, EC75-205, and EC75-232 (the latter two are the same locations as EC95-085 and EC95-086). One difference between anorthosite and leuconorite is that leuconorite is intruded by a probable dyke of diorite or monzodiorite at EC75-159 and by monzonite dykes at EC95-137. Granulite xenoliths are recorded at EC95-030 and EC95-137. Leuconorite is present at these sites, which are very close to the contact with monzonite (less than 0.7 km from it, as drawn on the 1:100 000-scale map). Field notes may be read to imply that the xenoliths are in monzonite rather than leuconorite. Site EC95-030 is of particular interest in that strongly foliated and streaky layered quartz monzonite with lenticles of blue-grey quartz are noted. Further, the streaky quartz monzonite carries xenoliths of leuconorite and dark-pyroxene granulite lenses. The author has visited the other site mentioned (EC95-137, which is equivalent to CG09-019) and discovered remnants of cordierite-bearing anhydrous metasedimentary gneiss and wonders if the 'blue-grey quartz' at EC75-030 might also be cordierite.

Leucotroctolite in the Etagaulet massif is only recorded sporadically in field notes, and, even at localities where it is present, it is commonly a subsidiary rock type. Except for the presence of olivine and being a bit rusty-weathering, it does not seem to have any particular defining features. All key features already noted for anorthosite and leuconorite are present; namely pods of very coarse-grained anorthosite, plagioclase lamination, layering, giant orthopyroxene crystals with exsolved plagioclase lamellae, and an example of a pegmatitic granitic pod (CG09-033, near EC75-202).

Southeast of the Etagaulet massif anorthositic rocks, a small crescent-shaped area of gabbro is depicted on the 1:100 000-scale map. This occurrence is based on: i) a data station of Eade (EA61-006), at which he identified gabbro, describing it as medium to coarse grained, having 70–80% plagioclase, and mafic minerals that are either amphibole or pyroxene, and ii) a strong positive aeromagnetic anomaly in the area. The author has not seen the outcrop and, despite feeling compelled to acknowledge it on his map, has reservations concerning its depiction. The high proportion of plagioclase may mean it should be included with the nearby leuconorite, and the positive magnetic anomaly could have other causes, especially given that the supposed body is within monzonitic rocks, which characteristically have a strong magnetic signature.

Bow Tie intrusion. The 'Bow Tie' intrusion (name is newly introduced here; taken from its mapped shape) is located northeast of Muskrat Lake and measures roughly 30 by 7 km, elongate in a northeast direction. The boundaries of this body are well defined as it forms both a topographic and aeromagnetic low. A small part of the body is shown on the map of Eade (1962), but the full extent of the body (more-or-less) was first indicated on a sketch map by Emslie (1976) and, later, in a somewhat more detailed map by Emslie *et al.* (1984). Its present outline is based on mapping by Gower and van Nostrand (1996; east of longitude 59°W) and Nunn and van Nostrand (1996a, b; west of longitude 59°W).

Primary layering (Plate 11.6A) indicates that the body has an elongate domal form. The core of the dome is occupied by leucotroctolite, which is enveloped in an outer zone of leucogabbronorite. Each unit includes some of the other, and both include minor anorthosite. The western boundary of the body is interpreted by Gower (2010a; Southeast Mealy Mountains map region) to be a west-verging reverse fault (mylonite was seen at CG95-233) that has excised leuconorite from the northwest flank of the intrusion.

Leucotroctolite in the core is pale- to dark-grey-weathering, coarse to very coarse grained and mostly massive. Olivine is fairly easy to detect in outcrop as it weathers to orange, rust or chocolate-brown. Most outcrops lack layering, or show it only indistinctly. Plagioclase lamination is locally present. Plagioclase commonly exceeds 15 cm long and crystals over 60 cm were recorded. Olivine is typically less than 5 cm, but crystals over 10 cm long were seen. Magnetic opaque grains were seen up to 5 cm across. Orthopyroxene is also common in places and, typically, less than 2 cm but locally over 25 cm long. Olivine may be rimmed by orthopyroxene and/or a magnetic opaque mineral. Some outcrops show considerable variation in both grain size and texture, particularly due to clusters of olivine crystals, or leucocratic patches that in a few instances also contain quartz. Including the associated anorthosite, colour index ranges from 0 to 35.

Thin sections from three samples of the leucotroctolite unit (CG95-243, CG95-271, CG95-276) all show the same mineral assemblage, namely fresh, well-twinned plagioclase, olivine, orthopyroxene, an opaque oxide, biotite and minor hercynite. Olivine is entirely serpentinized in CG95-243, partially so in CG95-276 and pristine in CG95-271. Olivine in contact with plagioclase lacks coronal textures, but where orthopyroxene is sufficiently abundant it completely envelopes olivine. Orthopyroxene is weakly pleochroic, lacks exsolution lamellae and is intergrown with the opaque oxide. Biotite is red-brown, poikilitic in places and commonly contains opaque mineral inclusions.

The leuconorite is pale- to dark-grey- or locally, buff-weathering, coarse to very coarse grained, and typically massive and homogeneous. Primary layers, defined mostly by alternation of layers of leuconorite and anorthosite and, less commonly, leucotroctolite, range between 2 to 20 cm wide and have diffuse boundaries. A plagioclase lamination, interpreted to be primary, was observed in places. Plagioclase commonly exceeds 10 cm in length and over 30 cm long is not unusual. Orthopyroxene is typically less than

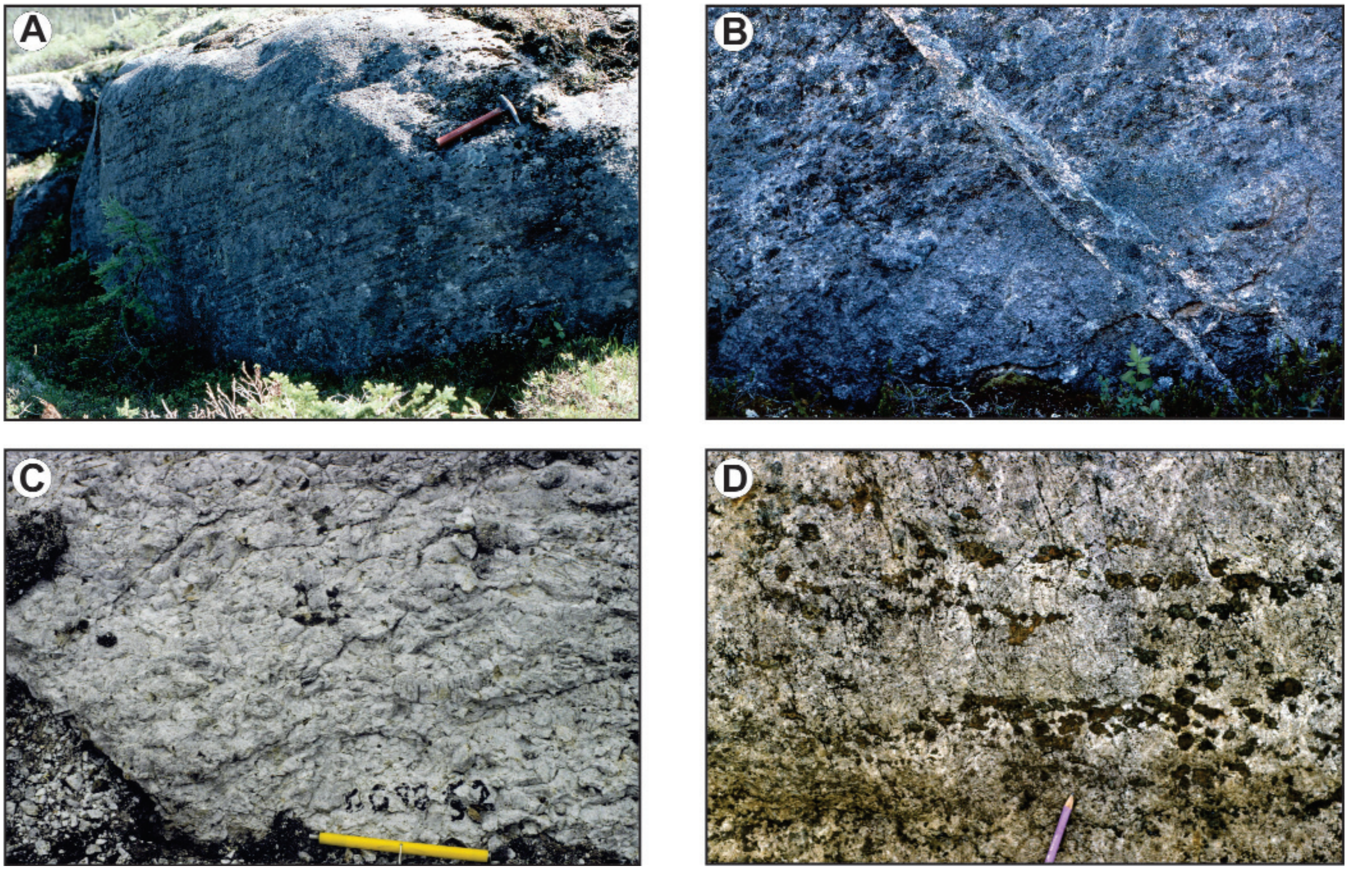


Plate 11.6. *Some features of anorthositic members of the Mealy Mountains intrusive suite (MMIS). A. Primary igneous layering in Bow Tie leucogabbronorite, MMIS (CG95-249), B. Monzonite dyke intruding Bow Tie leucogabbronorite, MMIS (CG95-249), C. Anorthosite in Rocky Pond anorthosite, MMIS (CG98-052), D. Olivine with coronas defining diffuse layering in Rocky Pond anorthosite, MMIS (CG98-216).*

5 cm, but may be locally larger. Colour index is mostly less than 30. Monzonite dykes, 2 to 5 cm wide, discordantly intrude layered leuconorite–anorthosite (Plate 11.6B).

Petrographic study of five thin sections from the leuconorite unit adds only marginally to the information above. One gabbronorite (CG95-248), two leucogabbronorites (CG95-234, CG95-238) and two anorthosites (CG95-246, CG95-249) were examined. They differ little, except in the proportions of minerals present. Plagioclase is well twinned, fresh, antiperthitic, anhedral and shows significant variation in grain size. Some deformation is indicated from bent and buckled twin lamellae. Both orthopyroxene (non-pleochroic or only weakly so) and pale-green clinopyroxene are present in all sections, albeit very sparse in the two anorthosite samples. Both show lamellae structure. An oxide opaque mineral, red-brown biotite, traces of hercynite and apatite (in gabbronorite and one leucogabbronorite) make up the remainder of the mineral assemblage. Biotite most commonly forms radially oriented flakes around the opaque oxide, but it occurs independently in the gabbronorite.

Rocky Pond anorthosite. The Rocky Pond anorthosite is an irregular-shaped body that was first mapped, described and named by Gower (1999). A much smaller anorthosite body, termed the Vulcan anorthosite by Gower (1999), was mapped to the west of the Rocky Pond anorthosite. The Vulcan anorthosite takes its name from mineral claims in the area held at the time by Vulcan Minerals Inc. The Vulcan body is shown as separate from the Rocky Pond anorthosite, but high resolution aeromagnetic data obtained by Vulcan Minerals Inc. suggest that the Vulcan anorthosite is connected by a narrow neck on its southeast side to the Rocky Pond body, in which case it would be a lobe of that intrusion and the term ‘Vulcan’ would become redundant. In any case, if not connected at surface, it seems likely that they are only separated by a vertically thin layer of monzonite and are linked at depth. The description below applies to both named units.

The rocks are creamy-, buff-, grey- and white-weathering, coarse grained to very coarse grained, massive and homogeneous. Anorthosite is the overwhelmingly dominant rock type (Plate 11.6C), but minor leucotroctolite and rare leuconorite are also present. Plagioclase crystallized early, occurring as well-twinned crystals up to 25 cm long, typically having euhedral shape and forming cumulates.

The dominant mafic mineral is clinopyroxene, occurring as poikilitic crystals up to 15 cm across. Olivine is up to 2 cm across and locally defines diffuse layers (Plate 11.6D). A vertical, 15-cm-wide monomineralic seam of ortho(?) pyroxene was recorded at CG98-156. No indications of layering were seen at that outcrop and it is suspected that the seam is an injected vein. Magnetite forms clusters up to 10 cm across at CG98-232. Quartz veins, 1 cm wide, were seen at CG98-255, which is close to an inferred late-stage, brittle fault. Interstitial, anhedral K-feldspar (possibly both primary and secondary), characterize the Vulcan anorthosite (which may be an argument for regarding it to be a separate body).

Eight samples of the Rocky Pond anorthosite were examined in thin section (CG98-053, CG98-087, CG98-110, CG98-146, CG98-155, CG98-160, CG98-210, CG98-232), plus two from the Vulcan anorthosite (CG98-095, CG98-137). Only one contains fresh olivine (CG98-110), although not-very-diagnostic serpentine and Fe-oxide pseudomorphs suggest its former presence in three other samples examined (CG98-146, CG98-160, CG98-210). The fresh olivine in sample CG98-110 is separated from plagioclase by an inner colourless corona (*cf.* orthopyroxene) and an outer green corona (*cf.* symplectic intergrowth of pargasitic amphibole plus spinel), and similar coronas are present around olivine pseudomorphs in CG98-210. Sample CG98-110 also has primary orthopyroxene and symplectic intergrowths of orthopyroxene and an opaque mineral in a texture very similar to that seen at one site in the mafic intrusion underlying the southern part of the region (CG98-302A). This is the only sample examined in thin section from the Rocky Pond anorthosite that contains primary orthopyroxene. From outcrop and hand samples, its presence is suspected elsewhere, however. Clinopyroxene in the remainder of the samples is a colourless, high-relief variety, forming anhedral, intercumulus grains between plagioclase crystals. Plagioclase in all the samples forms anhedral to euhedral, mostly interlocking, unrecrystallized grains that are typically well twinned and antiperthitic. Interstitial K-feldspar is present in CG98-095. Apatite and an opaque oxide are present (dominantly magnetite from outcrop tests, but a few small grains of sulphide were seen in thin sections CG98-137, CG98-146), and hercynite is ubiquitous primary accessory mineral. Epidote/clinozoisite, white mica, prehnite, chlorite, minor blue-green amphibole, hematite, carbonate and possibly albite (uncertain identification) are pervasive secondary products, although not abundant. The prehnite occurs in late-stage fractures, associated with carbonate.

Crooks Lake anorthosite. The Crooks Lake anorthosite is a roughly circular, 20-km-diameter body, with which minor leucogabbro, leuconorite and leucotroctolite are associated. The body was first mapped, described and named by Gower (1999). Only the northern half of the Crooks Lake intrusion is exposed (*see* pattern of data stations in Figure 11.10), but the extent of the pluton can be confidently delineated from aeromagnetic patterns, particularly by a ring of high magnetic anomalies that coincides with the rim of the body (unlike the Rocky Pond anorthosite, which has no such magnetic characteristic). The cause of the anomalies is uncertain, but may be due to a mafic/ultramafic border (*see* later paragraph in this section).

Outcrops within the Crooks Lake anorthosite typically weather white or grey but, rarely, are tinged brown, purple, or pink. The anorthosite is massive, homogeneous and is mostly fresh, but grades into rubbly material at some sites. Considerable variation in grain size exists, but, overall, the rocks are generally coarse to very coarse grained and unrecrystallized. Plagioclase forms well-twinned, anhedral to euhedral crystals commonly exceeding 10 cm. Crystals are locally aligned to give a crude primary igneous lamination. Orthopyroxene is subordinate to clinopyroxene, and both interstitial to plagioclase. Poikilitic pyroxene normally occurs as grains several centimetres across, although crystals up to 1 m were seen. Olivine, by contrast, is rare. Magnetite (late crystallizing), typically mantled by mafic silicate, is ubiquitous and, rarely, is found in small pods. Minor sulphide (suspected to be pyrite), apatite, biotite, amphibole and chlorite were seen on a small island in Crooks Lake, but not elsewhere. Greenschist-facies minerals, related to alteration adjacent to a late-stage brittle fault, were seen on the northwest side of the body.

A sample near the centre of the body was selected for dating (CG98-218B). The sampled material came from a coarse-grained to pegmatitic pod surrounded by anorthosite and containing plagioclase, pyroxene, magnetite all exceeding 15 cm in length, with which pockets of apatite are associated. On the basis of three fractions, an age of 1632 ± 3 Ma was obtained. A zircon fraction (3 grains) and a single baddeleyite grain both gave concordant results and a third fraction (3 baddeleyite grains) was 3.1% discordant (Gower *et al.*, 2008b).

Six samples from the Crooks Lake anorthosite were examined in thin section (CG98-047, CG98-068, CG98-073, CG98-102, CG98-108, CG98-218B). Primary minerals are well-twinned, antiperthitic plagioclase, anhedral, intercumulus clinopyroxene, red-brown biotite (only in CG98-047), apatite, hercynite and opaque minerals (oxide, except CG98-047, which contains minor sulphide). Despite having been seen in outcrop and hand sample, no olivine or orthopyroxene were confidently identified in any thin section from the body (orthopyroxene is questionably present in CG98-068, CG98-073). Secondary minerals are epidote, biotite (orange-green-brown fibrous flakes generally enveloping opaque oxides), white mica and prehnite. Prehnite was most confidently recognized in CG98-068 where it shows classic bow-tie habit.

Simplicity of outcrop pattern of the Crooks Lake anorthosite is disrupted by a small area of syenite in the northeast part of the intrusion, the extent of which is interpreted from two outcrops that coincide with a magnetic high. Textures in the syenite are subtly distinct from the monzonite surrounding the Crooks Lake intrusion, suggesting that these rocks represent an independent block within the anorthosite. Outcrop relationships between the syenite and anorthosite were not observed. The rocks are buff-grey-weathering, medium to coarse grained and recrystallized. Enclaves or minor intrusions are lacking.

In thin section (CG98-059), the mineral assemblage is anhedral, fine stringlet K-feldspar, equant clinopyroxene and an oxide opaque mineral. Ovoid, relict plagioclase crystals, up to 1 cm in diameter, are evident in stained slabs and parts of two of these were captured in the thin section. They consist of recrystallized well-twinned plagioclase peppered with small oxide opaque grains, some of which are also found in the adjacent perthite. The recrystallized plagioclase is clearly xenocrystic, although formation of the small oxide grains presumably postdates inclusion of the xenocryst/xenolith in the syenite.

A single outcrop of metapyroxenite was located on the south side of the Crooks Lake anorthosite. The rock is brown- to black-weathering, medium to coarse grained.

In thin section (CG98-122), it consists of clinopyroxene, olivine, apatite, a magnetic opaque mineral, and minor leucoxene.

The outcrop is coincident with one of the magnetic highs situated on the circle defining the margin of the Crooks Lake intrusion, but whether the whole of the high magnetic rim is due to a border of ultramafic rocks is uncertain, as, elsewhere, close to the border, parts of the high magnetic rim coincide with anorthosite on the ground. It should also be kept in mind that although magnetic patterns might suggest a genetic link between the metapyroxenite and the Crooks Lake anorthosite, the metapyroxenite could be, alternatively, part of the layered mafic intrusion exposed farther south.

Contrast between Rocky Pond and Crooks Lake anorthosite and implications. The Rocky Pond anorthosite has an irregular, blocky outline overall, in contrast to the circular border of the Crooks Lake body. Also, the Rocky Pond anorthosite lacks the margin-defining positive magnetic aureole that characterizes the border of the Crooks Lake body. These features can be explained in terms of differing ages of emplacement. The emplacement sequence of the major lithological components of the MMIS is, initially, anorthositic rocks, then monzonitic rocks, then granitic rocks. The 1632 Ma age for the Crooks Lake anorthosite would seem to contradict the body of field evidence, however, as ages for the monzonitic and granitic rocks are between 1646 to 1635 Ma. The author suggests the circular outline and magnetic aureole point to it being a diapiric intrusion that is indeed anomalously young compared to other anorthositic rocks in the MMIS.

East of Crooks Lake leucogabbronorite. Among the varied rock types east of Crooks Lake is a small area depicted as leucogabbronorite on the 1:100 000-scale map. The few outcrops in the area are grey- or buff-weathering, fine to medium grained, and homogeneous. The rocks contain a higher proportion of K-feldspar than in typical leucogabbronorite and not all contain orthopyroxene, so the name 'leucomonzogabbro' also applies in some instances.

Two thin sections from the leucogabbronorite are available. Sample CG97-021A contains plagioclase, perthitic K-feldspar (very minor), orthopyroxene, clinopyroxene, pale-brown to orange-brown biotite, an oxide opaque mineral and apatite. Sample CG97-296, which was collected from an isolated knoll 9 km northeast of CG97-021A, contains plagioclase, perthitic K-feldspar, clinopyroxene, hornblende, orange-brown biotite, an oxide opaque mineral, apatite and zircon. Both rocks are recrystallized. It seems likely that there is a close genetic relationship with an equal-sized area of monzonorite mapped to the west.

11.6.1.2 Monzonorite (P_{3C}mn)

Monzonorite is not an abundant rock type in the MMIS. It has been mapped as a discrete unit in only three small areas. Elsewhere, where it is included in the unit designator string (29 localities – 50% of the total), in over half it is listed as P_{3C}mz/P_{3C}mn, which implies that it is the less-favoured name alternative to monzonite. At a few sites, the unit designator is given as P_{3C}dr/mn (*i.e.*, as an alternative to 'dioritic' rocks). From these scattered sites, the only noteworthy feature that might be relevant, as extracted from Emslie's 1975 field notes, is mention of a 2-m-wide body, thought to be a dyke, termed diorite or monzodiorite (EC75-159). Note that monzonorite may not be the preferred term for some readers: overlapping names include jotunite and ferrodiorite. For example, jotunite is equated with pyroxene monzodiorite by Emslie (1975) and with ferrodiorite by Emslie (1978a). Details of the three mapped bodies of monzonorite are given below.

Boots Lake monzonorite. Despite the Boots Lake body (author's informal name for the lake and hence also the intrusion; Figure 11.11) having been crossed on only one traverse and two helicopter stops made elsewhere within it (one by Emslie in 1975), its outline can be inferred from its obvious donut-shaped high magnetic signature. From sparse measurements of layering in the vicinity, the body may have a basin shape.

The rocks are buff- to brown- and crumbly-weathering, massive to very weakly foliated, homogeneous and locally indistinctly layered. The mineral assemblage is plagioclase, clinopyroxene, orthopyroxene, a magnetic opaque mineral, K-feldspar, minor hornblende and quartz. The K-feldspar occurs either interstitially or as large crystals up to 3 x 1 cm. The magnetic opaque mineral is locally concentrated into clusters several centimetres across. Elliptical mafic enclaves up to 15 cm long were seen at one site (Plate 11.7A). Inasmuch as field description for the monzonitic rocks (P_{3C}mz) west of the Boots Lake monzonorite includes mention of monzonoritic layers, a compositional variant of it

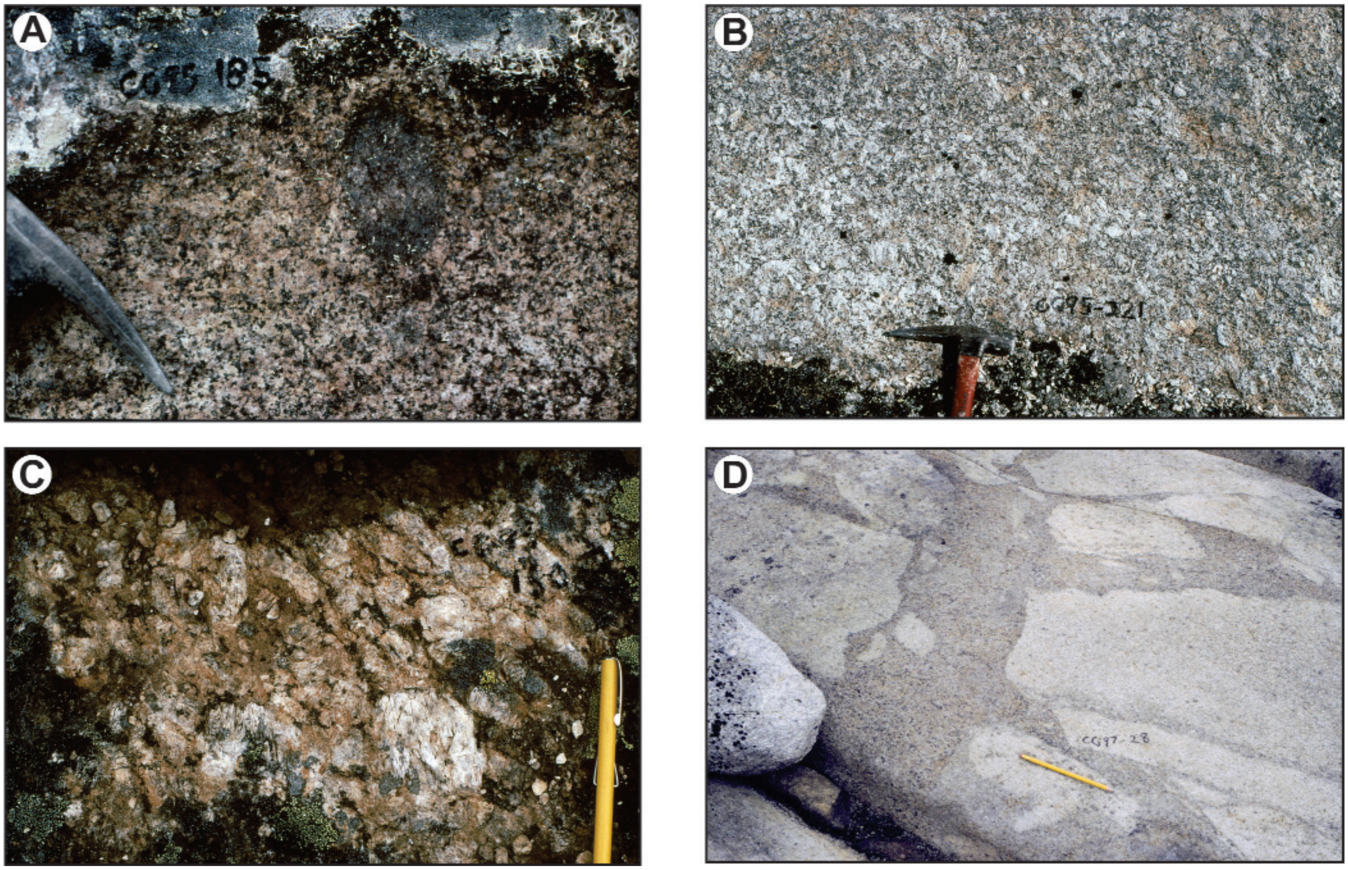


Plate 11.7. *Some features of monzogranitic members of the Mealy Mountains intrusive suite (MMIS). A. Mafic enclaves in Boots Lake monzonorite, MMIS (CG95-185), B. Typical monzonite, MMIS (CG95-221), C. Very coarse-grained monzonite, MMIS (CG95-150), D. Agmatite resulting from injection of granite into monzonite, MMIS (CG97-028).*

may bulge westward (CG95-179, CG95-180, CG95-181). Stained slabs of samples collected at these localities are more potassic, however.

A sample from the Boots Lake body examined in thin section (CG95-186) is less fractionated than typical for this unit and should not be taken as representative of it. It was separately distinguished on the 1:100 000 map as gabbronorite. It contains olivine, and lacks K-feldspar, hornblende, and quartz. The olivine is fresh, except for Fe-oxide-filled fractures. Orthopyroxene is very minor, but equant, colourless clinopyroxene is common. Exsolved opaque oxides are present in the centre of many clinopyroxene grains. Biotite forms red-brown poikilitic flakes/aggregates around the opaque oxide. Minor hercynite and apatite are also present.

East of Crooks Lake monzonorite. Monzogabbronorite occurs in a cluster of varied rock types east of the Crooks Lake anorthosite that also includes leucomonzonorite, leucogabbronorite, gabbronorite, monzonite and granite. Outcrop is rather sparse in that area and field relationships between the various rock types are not known. The monzonorite is buff-, pink- creamy- or grey-weathering, fine to medium grained and massive. Individual samples are homogeneous, but textural and compositional variations between outcrops suggest more complexity than the current 1:100 000 map depicts. Irregular veins of clinopyroxene- and K-feldspar-rich material were seen at one site.

A thin section (CG97-020) is monzogabbronorite comprising plagioclase, perthitic K-feldspar, minor quartz, orthopyroxene, clinopyroxene, pale-brown to orange-brown biotite, an oxide opaque mineral and apatite.

Salmon River. This area refers to monzonorite localities mapped on the Trans-Labrador Highway where it crosses the western margin of the area addressed in this report (*i.e.*, 60°W). Monzonorite is found in roadcuts along a 6 km stretch of the highway, half of which are west of 60°W. On fresh surfaces, the rock is pale-grey or purplish. It is fine to coarse grained, homogeneous and generally massive. Locally, it has a weak foliation or lineation. The rocks are intruded pegmatitic veins generally less than 10 cm wide. The distribution of K-feldspar, as seen in stained slabs, gives the rocks a distinctive mottled texture.

The mineral assemblage (thin-section CG09-047B) is plagioclase, K-feldspar, clinopyroxene, orthopyroxene, orange-brown biotite, an opaque oxide and apatite (all relict igneous or metamorphic).

11.6.1.3 Dioritic Rocks (P_{3C}dr)

A rather ill-defined assortment of rocks in the MMIS is covered by the term 'diorite'. All occurrences are small and are not included in MMIS figures. The main cluster of rocks to which the name has been applied is found in the Muskrat Lake area in the central MMIS. The remaining, rather scattered, occurrences are to the northeast, in the Etagaulet massif and around its southern border. Any preconception of calc-alkaline affinity that the name diorite normally implies should be put aside.

Muskrat Lake area. Almost all information available to the author concerning dioritic rocks in the Muskrat Lake area comes from Emslie's 1975 field notes, in which the term diorite is commonly hyphenated with another rock type, typically as diorite–gabbro or diorite–monzonite. The diorite–gabbro combination is applied to rocks at the southern end of the Bow Tie anorthositic body, whereas diorite–monzonite is used elsewhere.

The diorite is described as rusty-buff, medium grained (1–3 mm), massive or streaky textured, and having a colour index around 20. Biotite-rich gneiss enclaves up to about 30 cm are mentioned at one outcrop (EC75-013) and fine-grained streaky inclusions of 'probable paragneiss' mentioned at another (EC75-033). Field notes include the suggestion that the rocks might be a border facies of pyroxene quartz monzonite (EC75-006 and EC75-016), or, in one instance, a dyke (EC75-017). In the same general area, at ECD75-028, a pyrrhotite- and pyrite-bearing 'diorite(?)' is suspected to be an inclusion within leucotroctolite that is strongly sheared in part.

The author examined outcrops on Muskrat Lake with Emslie and Nunn in 1995, and revisited the district in 2007. The main object of the author's 2007 visit was to search for further instances of pelitic gneiss in connection with the author's hypothesis that their occurrence in the area is due to interthrusting with the MMIS (Section 7.3.6.2). Two of Emslie's diorite localities were examined during the 2007 visit, samples were collected and thin sections prepared.

A thin section from one of them (EC75-032/CG07-086) contains polygonal plagioclase, clinopyroxene, orthopyroxene, red-brown biotite, and an opaque oxide. The rock is interpreted to be granulite or, less likely, micronorite. At the other site (EC75-033/CG07-086), a sample was interpreted to be metasedimentary gneiss, as it contains plagioclase, K-feldspar, quartz, orthopyroxene, cordierite, an opaque oxide and hercynite. Note that this is the outcrop at which Emslie recorded probable paragneiss inclusions and thus his interpretation has been confirmed.

Given the close spatial relationship between the 'dioritic' rocks and metasedimentary gneiss, it is the author's position that the 'dioritic' rocks in this area are hybrid products resulting from contamination of MMIS magmas with metasedimentary gneiss. In this context, comparison is invited with an association of 'dioritic' rocks with metasedimentary gneiss at the southeast end of the Paradise metasedimentary gneiss belt (Hawke Bay complex – Section 12.3.2).

Etagaulet massif and surroundings. Similarly to the Muskrat Lake area, the source of information for 'dioritic' rocks in this area is Emslie's field notes (both those of 1975 and 1995).

In anorthositic rocks of the Etagaulet massif, two instances of diorite are mentioned where intrusive relationships were seen. At data station EC75-168, a 45-cm-wide, fine- to medium-grained, oxide-rich dyke of pyroxene diorite or monzodiorite is stated as having sharp, straight margins, and, at data station EC75-205, an intrusive mass of sulphide-bearing gabbro or diorite containing anorthosite blocks is recorded. At a third locality (EC75-056), a name correction to ferrodiorite was made in the notes, perhaps giving some clue as to Emslie's later thinking regarding the context of these rocks.

In the leuconoritic and monzonitic units farther south, the rocks are referred to as monzonite or monzodiorite, but there is no mention that they are dykes. On the other hand, layered pyroxene granulite xenoliths are reported at data station EC95-048, and abundant inclusions in a heterogeneous, streaky outcrop at data station EC95-116.

The term monzodiorite is also applied to outcrops EC95-033, EC95-034, EC95-035 and EC95-046 on the southern side of the northeast lobe, but, in contrast to other occurrences, these are noted to be garnet bearing. The author has not mapped this area, but has visited it (CG09-022, CG09-023) and, based on field character, concluded that the rocks are high-grade metasedimentary gneiss. This conclusion is supported by extensive petrographic data from cordierite±orthopyroxene metasedimentary gneiss along strike where 1:100 000 mapping was carried out, about 5 km to the east.

The fact that some of the dioritic rocks are dykes, that others are associated with xenoliths (of metasedimentary gneiss?) and that yet others are 'intact' metasedimentary gneiss implies that a single, simple origin cannot apply. A dominant thread, however, seems to be the involvement of metasedimentary gneiss.

11.6.1.4 Monzonite (P_{3C}mz)

Monzonite is the most extensive unit in the MMIS, underlying about half of the suite's mapped area. It is found spatially between anorthositic units (including leucotroctolite and leuconorite) and quartz-rich units (quartz monzonite and granite). The interface with anorthositic units represents a lithological change over quite short distances (*cf.* CG81-592, EC95-050), whereas transition into quartz monzonite is much more gradual. In the following summary, reference is made to five areas in which monzonite is extensive, namely Northeast lobe, Central triangle, Muskrat Lake, Southeast lobe and Southern part (Figure 11.11). The overall appearance of the unit is similar enough throughout, however, that a single description suffices.

Monzonite weathers creamy, buff, brown, rusty, grey or white (rarely pink – a colour that is correlated with adjacency to brittle faults). Outcrops that initially seem fresh and solid are commonly very badly weathered, so that attempts at sampling produce little more than rock crumbs, even tens of centimetres inside of initially exposed surfaces. The monzonite, being Fe rich, simply rusts away. Such tendencies are exacerbated by the typically coarse-grained or very coarse-grained nature of the material. K-feldspar is chiefly responsible for the coarse grain size, commonly being in the 1–2 cm diameter range. As further addressed below, K-feldspar can be much larger (3–5 cm diameter is not uncommon) leading to a seriate or megacrystic aspect. More rarely, plagioclase forms abnormally large crystals. Quartz is absent or an accessory phase. The rocks are characteristically very homogeneous and massive (Plate 11.7B), but locally carry a weak foliation. Departures from homogeneity are due to layering, single-mineral-rich pods, minor granitic intrusions and enclaves. In an otherwise rather monotonous unit, all of these provide interest from a reconnaissance mapping perspective. Layering is not common and is typically rather diffuse (defined by concentrations of magnetite at CG95-181, CG98-003, CG98-022, CG98-140, TN95-072; and unspecified mineral(s) at CG98-017, CG98-080, CG98-091, CG98-132). Magnetite also occurs in single-mineral-rich pods (up to 8 by 3 cm at CG95-177, EC75-018, VN98-198). Other pod-forming minerals are quartz (CG95-231, EC75-117, ECD75-015, R61-041, TN95-071), and alkali-feldspar (CG98-133, ECD75-015). Sporadic minor intrusions include quartz-rich veins (CG95-155, CG95-281, EC95-136), pegmatite (CG95-310, CG97-295, CG98-004, CG98-230, EC75-015, TN95-212), and aplitic to coarse-grained monzonite (CG95-199, EC75-021, EC75-175, EC95-005, EC95-007, EC95-136, TN95-196, TN95-216). The identified localities represent a complete list of homogeneity departures (excluding enclaves – next paragraph), as gleaned from field notes for several hundred localities, thus emphasizing the uniformity of the monzonite.

The enclaves can be divided into two types, namely: i) other magmatic rocks forming the MMIS, and ii) metamorphic rocks. Enclaves of other magmatic rocks in monzonite are anorthosite (EC75-178), leuconorite (EC95-079) and a few examples of texturally distinct monzonite (*e.g.*, CG95-198, CG98-076). Enclaves of metamorphic rocks are common in monzonite in a north-trending zone, extending from south of Muskrat Lake, then along the western side of the Central triangle and continuing north into the septum between the Kenemich and Etagaulet massifs, but are rare elsewhere (Figure 11.14). There is a gap in occurrences in the centre of the north-trending zone, which the author thinks most likely an artifact of lack of information (the area was traversed, but the data were recorded in Nunn's now-lost field notebooks). In Emslie's field notes, the enclaves are usually recorded as fine-grained pyroxene granulite, or fine-grained mafic granulite. In the author's notes, although granulite is applied to some enclaves, elsewhere they were termed amphibolite (CG98-010, CG98-026), schlieric mafic rock (CG10-002), or interpreted to have a metasedimentary gneiss protolith (CG07-092, CG07-110, CG07-111, CG07-112, CG09-041, ECD75-015). It is the author's interpretation that many of the metamorphic enclaves are derived from anhydrous high-grade metasedimentary gneiss. There is a clear spatial association with remnants of metasedimentary gneiss in the Muskrat Lake area. Such may also be the case farther north, given that the author discovered two additional cordierite-bearing metasedimentary gneiss remnants in the Central triangle area (CG09-019, CG09-041).

U–Pb geochronological evidence for the enclaves having a supracrustal protolith was delivered by Gower *et al.* (2008b). A sample, of what was thought to be monzonite, was collected at locality GN95-392 (Figure 11.14) with the objective of augmenting knowledge of the age of emplacement of the MMIS. It yielded unexpectedly old zircons having discordant $^{207}Pb/^{206}Pb$ ages between 1737 and 1709 Ma. As a result, the outcrop was revisited, at which time it was discovered that the monzonite contained abundant enclaves. It was surmised that, in all probability, it was one of the enclaves that had been sampled (the enclaves are very similar in appearance to the monzonite). The monzonite was then resampled at a locality 7 km to the northeast known to be free of enclaves (CG95-154 – K-feldspar megacrystic monzonite; Figure 11.9). The second sample yielded an age of 1642 ± 4 Ma, consistent with other U–Pb age determinations from MMIS monzonite. It was then argued that, if the discordance in the zircons from GN95-392 was due to Pb loss around 1642 Ma, then meaningful upper intercept ages would project to between 1914 and 1770 Ma. Gower *et al.* (2008b) concluded, in conjunction with petrographic appearance, that the sample most likely had a pre-1770 Ma supracrustal protolith.

Thin sections of monzonite are available from the Northeast lobe (CG81-592, CG81-600, GF81-168), Southeast lobe (CG95-179,

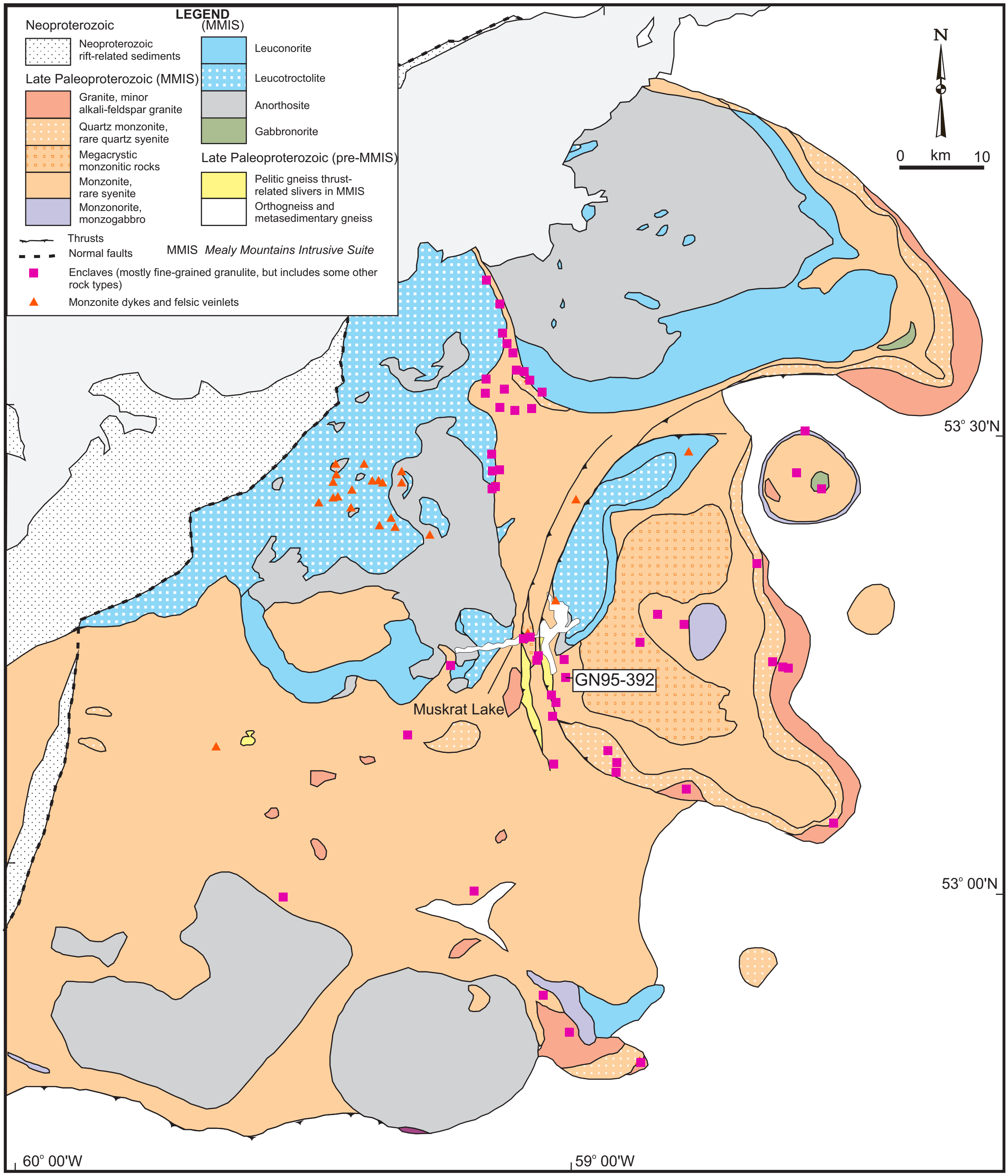


Figure 11.14. *Distribution of monzonite dykes and enclaves in monzonite in MMIS.*

CG95-198, CG95-221, CG95-224, CG95-311, VN95-157, VN95-188, VN95-207), and Southern part (CG07-070, CG07-076, CG10-004B, CG97-001, CG97-009, CG98-001, CG98-003, CG98-005, CG98-010B, CG98-022, CG98-054, CG98-079, CG98-081, CG98-092, CG98-098, CG98-113, CG98-214, CG98-230). Monzonite from the Northeast lobe has plagioclase as a separate phase in all thin sections, whereas it is only sporadically present in the other two areas. K-feldspar occurs as perthite throughout, but some microcline is present in the Northeast lobe. Minor quartz is found in the Northeast and Southeast lobes, but is very rare in the Southern part. Inverted pigeonite is consistently present in the Southeast lobe, and found sporadically in the Southern part. Clinopyroxene is present in all three areas. A key petrographic feature is the presence of fayalite in the southwest Southern part (CG98-001, CG98-003, CG98-005, CG98-079, CG98-081, CG98-092, CG98-113; and interpreted to be formerly present, but now replaced by opaque oxide in CG98-054, CG98-214). The two localities where the fayalite has been replaced are the most distant from the cluster defined by the other sites. The northern margin of this cluster is artificial as it is the Crooks Lake 1:100 000-scale map boundary, and no petrographic data are available for the Kenemich map region to the north. Excluding cases of uncertain petrographic identification, the presence of fayalite correlates with the absence of orthopyroxene, and the two minerals are probably related by the reaction:

Fayalite + Quartz = Orthopyroxene

Dark-green amphibole is found in the Northeast and Southeast areas, but is largely lacking in the south. Orange-brown or red-brown biotite (minor and mostly metamorphic, or secondary) is found throughout. Other minerals common to all areas are an opaque oxide and apatite. Zircon was recorded in most thin sections from the Northeast and Southeast lobes, but only rarely from the Southern part. Chlorite, carbonate, white mica and serpentine are rare secondary minerals.

11.6.1.5 Quartz Monzonite (P_{3C}mq)

Quartz monzonite in the MMIS is a transitional unit between monzonite and granite, relying almost entirely for its identification in the field on an estimation of quartz content between 5 and 20% of the felsic minerals. Its transitional nature is emphasized by being a sandwich unit between monzonite and granite, and by having gradational contacts with them. Most quartz monzonite occurs in the Northeast and Southeast lobes, but scattered occurrences are found in the Central triangle and the Southern part.

The rocks are brown- buff-, rusty-, creamy-, white- or pink-weathering, massive to weakly foliated, generally coarse grained (although medium and very coarse grained varieties occur), mostly homogeneous, and equigranular to K-feldspar megacrystic. As iterated in the next section, the division between megacrystic *vs.* simply having large K-feldspar crystals is not sharp. In field notes, K-feldspar megacrysts are generally noted as sparse, but, in rare instances, they form up to 10% of the rock and are up to 3 cm in diameter. A composite label P_{3C}mq/P_{3C}gp in the unit designator string identifies examples. White rims (probably albite) around large K-feldspars were noted sporadically. Blue quartz was recorded at a few localities, particularly in the East of Crooks Lake area.

Age relationships between quartz monzonite and other rock types were determined in places using either enclaves or minor intrusions. Enclaves of the following rock types were recorded in quartz monzonite; fine-grained granulite (*e.g.*, CG95-187, CG95-206, CG95-207, CG98-063, EC95-012, EC95-032), anorthosite (EC75-100), leuconorite (EC95-012), and a migmatitic rock (TN95-200). The last-listed locality noted that the enclaves are 2–3 m across and are characterized by 0.5- to 2-cm-wide quartz-feldspar zones between 3–50-cm-wide zones of fine-grained material. Quartz monzonite was seen to be intruded by minor granitoid dykes at CG95-207, CG97-028, EC95-007, TN95-051 and VN95-164.

Four thin sections of quartz monzonite are available from the Northeast lobe (CG81-598, CG81-616, GF81-165, NN80-139A) and three from the Southeast lobe (CG95-207C, CG95-216, CG95-298). In addition, one fine-grained granulite enclave (CG95-207A) and one minor granite intrusion (CG95-207B) were examined petrographically. The quartz monzonites from both lobes have plagioclase (relict igneous and metamorphic, lightly altered, well twinned) with the exception of CG95-216, which lacks plagioclase and is better termed quartz syenite (and, arguably, could have been assigned to a separate unit). Perthite and/or microcline and quartz are present in all thin sections. The mafic minerals differ between the two lobes, however. Orange-brown biotite is present in the Northeast lobe, but is mostly absent from the Southeast lobe, and inverted pigeonite characterizes the Southeast lobe, but not the Northeast lobe. Hornblende and clinopyroxene are sporadically present in both lobes. Other minerals in both lobes are an opaque oxide, apatite and zircon. Garnet necklaces, coronal to feldspar, are present in CG81-616 (Northeast lobe).

11.6.1.6 K-feldspar Megacrystic Monzonite, Syenite and Granite (P_{3C}gp)

K-feldspar megacrystic granitoid rocks underlie an extensive area east of Muskrat Lake; underlie a smaller area in a thrust-bound slice at Muskrat Lake; and have been sporadically recorded as a subsidiary lithological variant in association with quartz monzonite throughout the northeastern part of the MMIS. Except in the Muskrat Lake area, the megacrystic rocks seem to be little more than being a textural variant of the monzonitic rocks.

East of Muskrat Lake. The rocks are buff-, creamy-, pale-grey- or brown-weathering, generally coarse grained, weakly to moderately foliated and homogeneous. The rocks were generally referred to as monzonitic in the field. Stained slabs and thin sections show, however, that the mineral assemblage is overwhelmingly dominated by K-feldspar, hence syenite might be a better name, although not one generally favoured by AMCG nomenclature specialists. In addition, despite being labelled megacrystic, included are seriate-textured, porphyroclastic and very coarse-grained variants (Plate 11.7C). The division between megacrystic and non-megacrystic is far from clear cut, and seemed more applicable in the field than to stained slabs. The K-feldspars are blue grey, but locally have a narrow white fringe. In size, they range up to 5 x 5 cm, but, more commonly, are 3 x 2 cm. Shapes vary from ovoid to subhedral; truly euhedral megacrysts are not common. The 'megacrysts' are set in a coarse- to fine-grained matrix that commonly is reduced to no more than interstitial material between large K-feldspars. Textural evidence, especially the localization of polygonal albitic plagioclase, indicates that the finer grained matrix is the result of recrystallization. Despite extreme grain-size variations, the rocks are, overall, remarkably homogeneous, a feature emphasized in the field by lack of minor intrusions and sparse enclaves. The enclaves that are present are rarely more than a few centimetres long, typically elliptical, rather melanocratic, and consist of fine-grained granulite. Rare veins or pods of quartz showing gradational margins with their host monzonite occur sparsely. The largest seen is 2 x 0.5 m and is fringed with large pink K-feldspar.

A sample of this unit (CG95-154) has yielded an age of 1642 ± 4 Ma, which is interpreted to date time of emplacement, based on four single concordant zircons (Gower *et al.*, 2008b).

In all thin sections (CG95-151, CG95-154, CG95-226, CG95-229, CG95-264, VN95-152, VN95-154, VN95-204) the mineral assemblage is deemed to be igneous, with some metamorphic recrystallization. The overwhelmingly dominant mineral is stringlet/bead perthite. Apart from alkali-feldspar megacrysts, the assemblage includes colourless, pale-green or brown inverted pigeonite, a magnetic opaque mineral, minor dark green amphibole (mantling both pyroxene and opaque oxide), red-brown biotite (rare, mantling opaque oxide), apatite and zircon. Fayalite is present in one thin section (CG95-226). Plagioclase and quartz are present in two thin sections (CG95-151, VN95-204), but absent from the remainder. Plagioclase forms a separate coarse-grained phase in rocks in the southwest part of the region, locally mantling perthitic feldspar cores showing poor stains that may be mesoperthite.

Muskrat Lake. Information here regarding the lensoid area of K-feldspar megacrystic granitoid rocks at Muskrat Lake is based mostly on a traverse carried out by the author in 2007 on the south side of the west-southward-trending arm of Muskrat Lake, augmented by some earlier information from Dunning's 1975 field notes (in a partly overlapping area also along the shores of Muskrat Lake). The extension of the unit to the north and south of the lake, as shown on the 1:100 000 map, is speculative. A traverse was completed north of Muskrat Lake by Nunn during 1:100 000 mapping in 1995, but that information is now lost. Nunn and van Nostrand (1996a, b) show a much larger area as being underlain by K-feldspar megacrystic granitoid rocks, extending both north and south of Muskrat Lake. This was modified by the author on his 1:100 000 map to non-megacrystic monzonite, based on his own data from adjacent areas to the east, in conjunction with information from Eade's 1961 field notes and Emslie's 1975 and 1995 field notes. Note, however, that, utilizing these notes, the unit designator string in the data base offers P_{3C}mz/P_{3C}gp, implying, as an alternative, that field observers considered some of the rocks could be regarded as megacrystic.

Based on the rocks exposed on the shores of Muskrat Lake and stained slabs, it is clear that the rocks are quite distinct from the K-feldspar megacrystic rocks farther east. In the field, the rocks were described by the author as buff-weathering, massive to strongly foliated monzonite (near mylonitic at CG07-089). In contrast to the previously described unit, the K-feldspar megacrysts are quite distinct, ranging up to 4 cm across, and set in a medium- to coarse-grained matrix. The presence of plagioclase and quartz also distinguishes these rocks from most of the megacrystic rocks east of Muskrat Lake, as do fairly common enclaves of fine-grained granulite up to 1 m long. The description given in Dunning's field notes, in addition to noting the above features, also mentions the existence of minor granitic veins and records alignment of the megacrysts parallel to the prevailing foliation, and variable state of deformation of the megacrysts from euhedral to rounded or broken (all in keeping with the unit being a tectonic sliver – author).

A thin section (CG07-089) from the unit contains plagioclase, K-feldspar (stringlet perthite) and interstitial quartz, together with mildly pleochroic orthopyroxene, opaque oxide, and apatite. No hydrous mafic minerals are present. The assemblage has a polygonized, granulite facies aspect.

Given the above-outlined distinct features and the possibility that it is a tectonic sliver, questions can be raised whether or not these rocks are really part of the MMIS.

K-feldspar megacrystic granitoid rocks elsewhere in MMIS. These occurrences have been included in other monzonitic units, but they are considered to deserve mention here to emphasize that the distinction between megacrystic and non-megacrystic is not clear-cut. In all cases, the rock is pyroxene monzonite to quartz monzonite. Pertinent areas are the Central triangle, Eastern lobe, and Southern part. In the Central triangle, the rocks described by Emslie contain scattered perthite phenocrysts 1–2 cm across. At one outcrop (EC95-012), the megacrysts are mentioned as forming 25% of the rock. In the Northeast lobe, the phenocrysts are recorded by Emslie as 3–5 cm across (*e.g.*, EC95-027) and the texture to be coarse grained to porphyritic. In the Southern part, van Nostrand's 1995 field notes mention sporadic instances of megacrystic rocks 15–20 km southwest of Muskrat Lake as having megacrysts 1–3 cm across, whereas, 38 km west of Muskrat Lake, the megacrysts are recorded as 2–10 cm across (TN95-189, TN95-196). None of the sites in the Southern part were indicated as megacrystic on the sketch map of Nunn and van Nostrand (1996b). If anything is to be gleaned from these observations, it might be that the size range of the megacrysts seems to be specific according to area, a feature that, presumably, might have some petrogenetic significance.

11.6.1.7 Alkali-feldspar Granite, Granite and Quartz Syenite (P_{3C}ga)

Alkali-feldspar granite, granite and quartz syenite in the MMIS is found at the eastern border of the MMIS in three areas, namely: i) Northeast lobe, ii) Southeast lobe, and iii) East of Crooks Lake. The unit separates monzonitic rocks toward the interior of the MMIS from granulite facies near-anhydrous metasedimentary gneiss that the MMIS intrudes along much of its eastern margin. The spatial association of alkali-feldspar granite with anhydrous metasedimentary gneiss is taken by the author to imply genetic linkage.

Border areas where the alkali-feldspar granite is apparently lacking may be due to either i) faults or thrusts where the granite may well have been tectonically removed (English River area and north of the Two Lakes satellite intrusion), or ii) have not been mapped (northwest of the Two Lakes satellite intrusion), or iii) the country rocks are not exposed, so their nature and relationship to the MMIS is not known (east of Crooks Lake), or iv) are genuinely absent.

Northeast lobe. Alkali-feldspar granite and related rocks in the Northeast lobe were first mapped by Gower *et al.* (1982b). The granite is crescent shaped, tapering at either end from a maximum width of about 4 km. The tapering at both ends is interpreted to be due to excising by faults. The granite is pink-weathering, generally very coarse grained (3–6 cm grain size is not uncommon), and massive or weakly foliated. It is intruded, rarely, by granitic pegmatite. The mineral assemblage is dominated by K-feldspar and quartz, with lesser plagioclase. Stained slabs show both K-feldspar and plagioclase as euhedral or subhedral crystals partially or completely enveloped in quartz.

Pyroxene granite from this subunit has a U–Pb age of 1635 +22/–8 Ma, based on five moderately discordant zircon fractions (Emslie and Hunt, 1990; sample EC75-239).

In thin section (CG81-557, CG81-574, CG81-597, CG81-610A, CG81-614, GF81-146, GF81-170, GF81-171, GF81-173), plagioclase is seen to be poor to well twinned and lightly to severely altered; K-feldspar is mostly perthite, but some microcline is also present; quartz ranges from unrecrystallized to polygonal; biotite is orange- or red-brown and is present in all but three thin sections (GF81-146, GF81-171, GF81-173); amphibole is green to dark-green and has anhedral, ragged form; clinopyroxene is present in CG81-574 and GF81-171; orthopyroxene is present in the thin sections lacking biotite; garnet is seen in CG81-174 and GF81-171; other minerals are an opaque oxide, zircon, and, sporadically, titanite, allanite, and secondary chlorite, white mica and carbonate. Trace hercynite is present in GF81-171. Of the thin sections examined, GF81-171 is somewhat anomalous. It has some of the characteristics of the adjacent anhydrous metasedimentary gneisses and, perhaps, is a partially digested metasedimentary remnant.

Southeast lobe. Alkali-feldspar granite in the Southeast lobe has been briefly described by Gower and van Nostrand (1996). It has a crescent-shaped form similar to that of the Northeast lobe, and is interpreted to be truncated and largely excised in its southern part by a major fault. The granite pinches out at its northern end, such that quartz monzonite is directly in contact with high-grade anhydrous metasedimentary gneiss. Given the granite's presence elsewhere begs the question why it is not here also. The first three explanations for absence given above do not seem to apply, leaving the author to think that it is truly lacking.

In field notes, the rocks are described as buff- or creamy-weathering, coarse grained, and massive to strongly foliated. K-feldspar is typically in the 1–3 cm range and quartz about 0.5 cm (up to 1 cm recorded at CG95-327). Enclaves of fine-grained banded gneiss, typically elongate parallel to the border of the pluton, are common in the southern part of the granite (*e.g.*, data stations CG95-187, CG95-207, CG95-316). They show considerable variation in both size and density of occurrence (up to about 20% of the rock). The largest seen were 3 by 0.5 m, but 10 to 20 cm is more common. The enclaves are fine grained and homogeneous to banded, and may be injected by granite in a *lit-par-lit* manner. Some pink, fine- to medium-grained granite is sporadically present and, in places, appears to have gradational borders with the coarse-grained granite, but, elsewhere, looks more clearly intrusive.

Several thin sections were examined (CG95-159, CG95-168, CG95-190, CG95-294, CG95-310A, B, C, CG95-316, VN95-164A). Plagioclase is generally lightly altered and poorly twinned: K-feldspar is mostly perthite; quartz varies from unrecrystallized to polygonal, biotite is orange-brown and mostly secondary/metamorphic; amphibole is dark-green to brown and mostly metamorphic; relict igneous clinopyroxene is present in CG95-159, CG95-190, and CG95-316. Inverted pigeonite is found in all samples, except CG95-294 and CG95-310C; pseudomorphed fayalite is present in CG95-168 and garnet in CG95-294. An opaque oxide, apatite and zircon are almost universally present. Other minerals sporadically present are titanite, allanite, and secondary chlorite, epidote, and serpentine. Two enclaves were examined in thin section (CG95-187, CG95-207A) and are extremely similar. The felsic minerals are moderately to well-twinned plagioclase, poorly twinned K-feldspar and quartz having a granoblastic, polygonal texture with text-book examples of straight boundaries and 120° triple junctions. The mafic silicates are pale-green clinopyroxene, weakly pleochroic orthopyroxene and orange-brown biotite. Both pyroxenes form small, equant subhedral grains. Accessory minerals are an opaque oxide, apatite and tiny zircons. This mineral assemblage compares most closely to that in CG95-285A, which is high-grade metasedimentary gneiss.

East of Crooks Lake. Granite mapped east of Crooks Lake (Gower, 1998, 1999) is buff-, grey- and pink-weathering, medium to coarse grained (but mostly coarse grained), massive to (rarely) weakly foliated, mildly recrystallized and homogeneous. The granite at one locality has clearly been injected into the monzonite (CG97-028), forming an agmatite in which blocks of monzonite are partially or completely enveloped by granite (Plate 11.7D). The monzonite at this locality has been dated to be 1635 ± 2 Ma (*see* earlier; Gower *et al.*, 2008b).

At the easternmost outcrop in this area (CG97-030), numerous enclaves of presumed country rock were observed. Lithological types include well-banded quartzofeldspathic gneiss, fine-grained quartzofeldspathic rock (derived from aplite or felsic volcanic rocks?), and amphibolite. This locality is close to a topographic contrast between hills to the west and flat marshland lacking outcrops to the east. The break in topography, coupled with the presence of enclaves, is taken as evidence for the margin of the MMIS in this area.

Thin sections of the granite (CG97-030, CG98-065, CG98-107) contain stringlet perthite; poorly twinned, extensively sericitized, sodic plagioclase; strained quartz (recrystallized in part); orange-brown biotite, orthopyroxene, clinopyroxene, an opaque oxide, apatite, and zircon; and very minor secondary biotite, titanite and chlorite. Much of the orthopyroxene has been altered to bastite.

Two isolated granite outcrops were found north of Crooks Lake. At one site, the rock is a pale-pink to white- weathering, indistinctly foliated, homogeneous alkali-feldspar granite (thin section CG98-039) containing K-feldspar, quartz, sodic plagioclase, clinopyroxene, amphibole, magnetite and apatite. The granite closely resembles the other rocks described in this section. At the other site, 6 km to the northeast, amphibolite is interbanded with fine-grained granite in enclaves within monzonite. The enclaves are lensoid, 5–40 cm long and 5–10 cm wide. The amphibolite (thin section CG98-026) contains plagioclase, hornblende, orange-brown biotite, apatite and oxide opaque mineral and K-feldspar (at the margins of amphibolite lenses). The fine-grained granite (same thin section) is mostly made up of K-feldspar and quartz, with very minor plagioclase, oxide opaque mineral, clinopyroxene and a serpentine pseudomorph, possibly after orthopyroxene. The clinopyroxene and orthopyroxene(?) are found at the interface between the granite and amphibolite and within the granite, possibly representing dehydration products from amphibole breakdown. Given that an area of gneissic country rocks was mapped nearby (Bird pendant) it is possible that both the granite and amphibolite are related to the gneiss.

Muskrat Lake area. Apart from the above-described areas, the only other occurrence of Unit P_{3C}ga in the MMIS is in the Muskrat Lake area, where the granite is depicted as small structurally bound slivers associated with K-feldspar megacrystic granitoid units and metasedimentary gneiss. Information for these is based entirely on field notes (Dunning in 1975 and van Nostrand in 1995) and, although seemingly the most appropriate unit from the descriptions, other rock-type options may apply, in particular Unit P_{3C}gp (K-feldspar megacrystic granitoid rocks). The presence of alkali-feldspar granite in this area is, however, consistent with its association with metasedimentary gneiss.

11.6.1.8 Granite (P_{3C}gr)

Unit P_{3C}gr in the MMIS covers a small group of granitic rocks that are not readily accommodated in the alkali-feldspar granite unit addressed above. These have not been separately distinguished in the MMIS figures. Most of the areas where the unit is shown in the MMIS are small, isolated occurrences within the vast area of quartz monzonite that makes up much of the southern part of the MMIS. Awareness of them is mostly based on information from Nunn and van Nostrand (1996a, b). In their post-field-season report, they (Nunn and van Nostrand, 1996a) include them as part of a unit of 'granite, pyroxene granulite, and minor glassy rocks'. On the preliminary 1:100 000-scale map of Nunn and van Nostrand (1996b), they are represented as Unit 1e (medium-grained, equigranular foliated granite) or Unit 3c (medium- to coarse-grained, locally K-feldspar megacrystic, foliated granite to quartz monzonite). The 1995 field notes of van Nostrand record pink, white or brown, fine- to coarse-grained, equigranular to streaky textured, massive to weakly foliated biotite and hornblende quartz monzonite to granite.

A few other occurrences in the MMIS have been given the P_{3C}gr unit designator; one from Emslie (EC95-007), and a few based on the author's visits in 2007 and 2009. Emslie's notes mention 3- to 8-cm-wide felsic veinlets intruding quartz monzonite north of Muskrat Lake. The author described his own examples, south of Muskrat Lake, as coarse-grained, homogeneous quartz monzonite to granite containing fine-grained, homogeneous to banded enclaves that were concluded to be of probable metasedimentary origin – an interpretation supported by their location as an along-strike, southward extrapolation from the metasedimentary gneiss slivers in the Muskrat Lake area.

11.6.1.9 Isolated Intrusions East of MMIS

Two Lakes intrusion. The Two Lakes satellite intrusion (informal name for the lakes and hence the intrusion; Figure 11.11) is a nearly circular pluton of variable composition. The central part of the pluton coincides with a topographic basin and a magnetic high.

A sample of pyroxene monzonite close to the western border of this pluton was dated by Emslie and Hunt (1990; data station EC75-080). A concordant/near-concordant age of 1645.5 ± 1.5 Ma, based on three multigrain zircon fractions, was interpreted to be the time of crystallization of the rock. A Sm–Nd whole-rock analysis from sample CG95-128, from the same locality, yielded values of T_{DM} = 1997 Ma and εNd (1.64 Ga) = +0.06.

The border of the intrusion comprises a narrow zone (less than 0.5 km wide) of partially to totally recrystallized leucogabbronorite. Despite being seen on all traverses that crossed the margin, it remains an assumption that it is as continuous as interpreted. The border rocks are weakly to moderately foliated and locally have a banded appearance due to grain-size variation. In the field, they superficially resemble monzonitic rocks in the interior of the pluton, but staining has confirmed that the feldspar is almost entirely plagioclase. In one sample, plagioclase occurs as corroded crystals averaging 1 x 0.5 cm in a fine-grained mafic–felsic matrix, hence giving the rock a megacrystic texture. Enclaves of granulite were locally observed in this border phase.

Three samples of the border phase were examined in thin section (CG95-209, VN95-094A, VN95-123A). Plagioclase is anhedral, well-twinned and polygonized, except in VN95-094A, which contains some subhedral, zoned, antiperthitic, primary grains. Both orthopyroxene and clinopyroxene are present. Orthopyroxene is weakly pleochroic, forming anhedral, equant grains and showing exsolution parallel to 010, but does not show the characteristic inverted pigeonite exsolution parallel to 001 like that in the monzonitic rocks. Clinopyroxene also forms equant grains and contains abundant opaque inclusions as well as exsolution lamellae. Dark-green hornblende (not seen in VN95-094A) and orange-brown biotite are also present, as well as accessory opaque oxide, apatite and zircon. The slight mineralogical differences recorded in VN95-094A can perhaps be ascribed to this locality being the farthest from the margin of the pluton. An enclave of granulite examined in thin section (VN95-120B) contains plagioclase, orthopyroxene, clinopyroxene, biotite, an opaque oxide and apatite.

It is hard to capture descriptively the textural and compositional variability demonstrated by stained slabs from the interior part of the pluton. In outcrop, most rocks look like typical brown-, creamy- or buff-weathering monzonite, which is generally medium to coarse grained, massive to moderately foliated and homogeneous. Monzonite is deemed to be the best overall label, but the rocks include a texturally wide spectrum of granite, monzonite and syenite. Quartz varies between 0 and 25%; perthitic alkali feldspar exceeds plagioclase in most rocks and reaches over 95% of the rock in some samples. Alkali feldspar locally forms megacrysts up to 2.5 cm long, but these are generally sporadic and little of the pluton can be designated as porphyritic. The feldspar is partly recrystallized to polygonal aggregates separated by necklaces of K-deficient feldspar. Mafic minerals rarely exceed 10% of the rock and consist mostly of clinopyroxene, some orthopyroxene, lesser amphibole and minor biotite. A magnetic opaque mineral is ubiquitous. Coarse-grained norite, in blocks tens of metres across (autoliths?) and decimetre-sized mesocratic fine-grained enclaves (suspected to contain cordierite and to be xenoliths) are also present. Small patches of pink, medium-grained, massive granite consisting almost entirely of quartz and K-feldspar most likely indicate minor intrusions, but contacts were not seen so genetic relationships are unknown.

Thin-section study of four samples (CG95-128, CG95-133, CG95-145, CG95-208) adds little to the above description but shows the K-feldspar to be fine stringlet or bead mesoperthite, the orthopyroxene to contain exsolution lamellae, and accessory minerals to include apatite, zircon and, in CG95-128 and CG95-208, allanite.

Rocks in the centre of the pluton are somewhat texturally similar to those at the border, but tend to be more melanocratic. Most are buff- to grey-weathering, medium- to coarse-grained, weakly foliated to massive mela-monzonite to gabbronorite. They are almost devoid of K-feldspar (except for very minor interstitial material) and contain clinopyroxene, orthopyroxene and hornblende, in addition to plagioclase, which is the dominant mineral. A magnetic opaque mineral is locally abundant. The rocks have a relict igneous texture but show signs of recrystallization. On the basis of one outcrop in the outer part of this core zone having a composition between the monzonorite and the surrounding more felsic rocks, it seems likely that the boundary between the two is transitional.

Two thin sections from the core zone (CG95-140, CG95-333A) are dissimilar. In CG95-140, both ortho- and clinopyroxene are present and show exsolution lamellae, whereas, in CG95-333A, pyroxene has been entirely replaced by mosaics of ragged-green amphibole, orange-buff biotite, an opaque oxide and quartz. In addition, in CG95-333A, titanite mantles the opaque mineral. In both rocks, some of the plagioclase forms subhedral, zoned, relict igneous grains. Apatite is also present in both.

Landmark intrusion. Even before the area was mapped, the distinct cone-shaped hill rising 200 m above the surrounding plain (a well-known landmark for pilots flying between Goose Bay and Paradise River) gave reason to suspect the rocks underlying the area might be different from their surroundings. The pluton (informally named here) is also defined by a magnetic high. Inward dips in the surrounding gneisses suggest that the intrusion might be funnel shaped. The intrusion comprises creamy-, brown- or rusty-weathering, medium to coarse grained, massive to moderately foliated monzonite to syenite. Because the foliation is local, it is suspected to be related to post-intrusion deformation, rather than emplacement. The rocks are dominantly even textured, but some larger euhedral alkali feldspars impart a megacrystic appearance here and there. The feldspar in some samples is almost entirely perthitic K-feldspar, but, in others, plagioclase is equally abundant, or more so. Associated minerals include clinopyroxene, amphibole, biotite, a magnetic opaque mineral (at above normal concentrations for monzonite in the region), minor quartz (less than 5%), and possibly orthopyroxene. At least some of the amphibole appears to be retrograde after pyroxene. Colour index is less than 15. A few small enclaves of fine-grained mesocratic material were seen near the northern border of the pluton.

Three samples were examined in thin section (CG95-086, VN95-167, CG95-173). Plagioclase is poorly to moderately twinned, weakly zoned and lightly sericitized. K-feldspar is very finely exsolved perthite – so fine that it looks homogeneous at low magnification. Quartz is interstitial. The pyroxene is pigeonite showing poorly developed exsolution textures. Samples VN95-167 and VN95-173 both contain dark-green hornblende and orange-brown biotite, in contrast to CG95-086, which lacks amphibole and has red-brown biotite. Accessory minerals are an opaque oxide, apatite and zircon. The weakly zoned plagioclase and uninverted(?) pigeonite suggest relatively rapid ascent.

Upper Eagle River intrusion. Five outcrops of homogeneous monzonite in the north-central part of NTS map area 13B/15 have been inferred to be a satellite intrusion linked to the Mealy Mountains intrusive suite (Figure 11.11). The informal name is newly introduced here. The rocks are creamy to buff-grey-weathering, medium to coarse, grained, weakly to moderately foliated and contain a few pegmatitic veinlets. Note that the rock is depicted as a late- to post-Grenvillian pluton on the map of Wardle *et al.* (1997). That representation is based on the presence of a magnetic high in the area, given that such anomalies are characteristic of late- to post-Grenvillian plutons elsewhere in the region. The foliation and recrystallization make this interpretation unlikely, but the rock has yet to be dated.

A thin section (CG97-275) from one of the outcrops contains stringlet perthite, orthopyroxene, clinopyroxene, orange-brown biotite, an opaque oxide and zircon. The perthite shows extensive grain boundary recrystallization to polygonal aggregates.

11.6.2 DOUBLE MER WHITE HILLS (MMIS CORRELATIVE?)

The Double Mer White Hills area is situated north of Double Mer (Figure 11.1). It has generally been included as part of the Lake Melville terrane. As noted in the introduction to the Mealy Mountains intrusive suite, a reasonable interpretation is that the rocks underlying the Double Mer White Hills are genetically part of the MMIS, but were transported northward as an allochthonous block during Grenvillian orogenesis, and were subsequently separated from the rest of the MMIS by the Neoproterozoic Lake Melville rift system. To be fair, however, there is no compelling evidence that such must have been the case, which is sufficient reason for addressing them separately here.

The first to recognize the distinctiveness of the rocks in Double Mer White Hills area was Stevenson (1970; his Unit 4a), who termed them plagioclase–quartz–pyroxene granulitic gneiss. The area was subsequently mapped at 1:100 000 scale by Gower (1984, 1986). The uncoloured map published at that time has been superseded by an updated, colour version (Gower, 2010a; Double Mer map region), but Gower's (1986) report remains the main source of geological information for the area.

Correlation with the MMIS is supported by comparable ages of emplacement. An unpublished U–Pb age has been obtained for monzonite sample CG83-178 (D. Corrigan, and G. Dunning, personal communication, 2009). Based on four zircon analyses and anchored at a lower intercept of 1000 Ma, four near-concordant points yield an age of 1633 ± 5 Ma. A Sm–Nd whole-rock analysis from sample CG83-181, from a site 1.1 km to the south-southeast of CG83-178, yielded values of T_{DM} = 1861 Ma and εNd (1.63 Ga) = +1.05.

The rocks present can be grouped into three broad, overlapping and transitional lithological classes, namely: i) leucogabbronoritic and dioritic granulite ii) monzonitic granulite, and iii) granitic granulite; to which may be added, iv) a few deformed and metamorphosed mafic dykes.

11.6.2.1 Leucogabbronoritic and Dioritic Granulite (P_{3C}ag, P_{3C}am, P_{3C}dr, P_{3C}ln)

The rocks in this group are mostly either leuco- or mesocratic granulite. In a few instances the rocks are mafic granulite, but rarely extensive enough to be mappable at 1:100 000 scale. The rocks are grey-weathering (rarely buff or black) and fine to medium grained. They have a strong to intense foliation and lineation and most could be alternatively termed mafelsic granulite mylonite. The rocks are interpreted to have gabbronoritic, leucogabbronoritic, anorthositic and dioritic protoliths. Noting a doubtfully valid example of primary layering at CG83-085, they may be highly tectonized remnants of formerly layered igneous rocks.

Thin sections (CG83-085, CG83-091A, CG83-092, CG93-146B, CG83-155, CG83-159, CG83-192) have varied mineral assemblages, but all contain polygonal, irregular plagioclase, garnet, an opaque oxide, and apatite. Clinopyroxene (mid-green) and(or) orthopyroxene are major phases. Most samples also have red-brown or orange-brown biotite (CG83-104B excluded), dark green hornblende (CG83-146B excluded) and quartz (CG83-085, CG83-146B excluded). Scapolite is common in CG83-155 and CG83-159. Zircon, allanite and minor K-feldspar are present in some samples and sporadic secondary titanite and chlorite are also seen.

11.6.2.2 Monzonitic Granulite (P_{3C}mz)

The monzonitic rocks are mostly pale-grey-weathering, but also may be mid grey, brownish, white or (rarely) pink. They are generally fine to medium grained, but retain crystal aggregates indicating recrystallization from much coarser grained rocks. Almost universally, the rocks are very strongly foliated and lineated – mylonitic is a generally appropriate descriptor. The strong fabric is emphasized by a streakiness that resembles (and may once have been) igneous layering. Despite the deformational fabric and vaguely apparent banding/layering, the rocks are remarkably homogeneous overall. Grain-size differences and rare hints of a formerly K-feldspar megacrystic texture provide some variation. Sparse concordant, isoclinally folded and mildly discordant pegmatites and quartz-feldspar veinlets provide a little more. The rocks are brecciated and altered to low-grade mineral assemblages related to brittle faulting associated with the Double Mer half-graben.

Although relatively straightforward to recognize as a unit in the field, assigning a sensible lithological pigeon hole is not so easy. The rocks were mostly suggested in field notes as likely having a leucogabbronoritic protolith. Common K-feldspar, seen in numerous stained slabs, discourages this conclusion, suggesting, instead, monzonite. It was for this reason the unit designator on the 1:00 000-scale map is shown as P_{3C}mz/P_{3C}ln, which is essentially equivalent to Gower's (1986) Unit '6l/m'.

A large thin section collection exists for the monzonitic granulite (CG83-044, CG83-047*, CG83-088, CG83-094, CG83-096*, CG83-157, CG83-167, CG83-173, CG83-181*, CG83-185, CG83-190, CG83-200*, CG83-326, CG83-343, CG83-363*, CG83-374, CG83-383, CG83-390*, CG83-398, SG68-228, SG68-234, SG68-237, SG68-281, SG68-282). Asterisks indicate the samples for which mineral analyses were reported by Gower (1986). The mineral assemblage is characteristic of medium- to high-pressure granulite, consisting of polygonal/irregular plagioclase, poorly/untwinned K-feldspar (more rarely, obvious perthite or microcline), polygonal quartz, red-brown or orange-brown biotite, dark-green or green-brown hornblende, pale to mid-green clinopyroxene, strongly (pink to green) pleochroic orthopyroxene, garnet (in about 60% of thin sections), and opaque oxide, apatite, zircon, with very rare allanite, plus secondary white mica, chlorite and epidote.

Gower (1986) carried out geothermobarometric analyses on six of the samples (CG83-047, CG83-096, CG83-181, CG83-200, CG83-363, CG83-390) yielding pressure and temperature estimates of *ca.* 10.5 kb and *ca.* 825°C, respectively (*cf.* Chapter 21).

11.6.2.3 Granitic Granulite (P_{3C}gr, P_{3C}gp, P_{3C}ga, P_{3C}gd, P_{3C}mq)

Granitic granulite in the Double Mer White Hills area is mostly pink-, pale-grey-, white- or puce-weathering, fine to medium grained and strongly to intensely foliated and lineated, but retains evidence of having recrystallized from coarser grained rocks. The rocks grade into mylonite and it is possible that the linear zone of folded granitic granulite in the eastern half of the district marks a thrust. Locally, very thin lenses of amphibole-rich material or amphibolite are present. In the northeast part of the area, a K-feldspar megacrystic unit is depicted on the 1:100 000-scale map of Gower (2010a; Double Mer map region). The encompassed rocks differ in having inhomogeneously distributed lenses of recrystallized K-feldspar up to about 1 cm long, which, at best guess, are considered to be former megacrysts. Another variant is pink, coarse-grained alkali-feldspar granite situated at the southeast closure of a fold in the area. Granodiorite and quartz monzonite compositions are also listed in unit designator strings, but these are very minor.

No obvious differences were seen between the K-feldspar megacrystic (CG83-062, CG83-081, CG83-083) and non-megacrystic granitoid rocks (CG83-067, CG83-091B, CG83-099, CG83-101, CG83-104A, CG83-146A, CG83-161, CG83-165, CG83-175, SG68-023) in thin section (except the recrystallized megacrysts). All contain recrystallized irregularly shaped plagioclase, poorly/untwinned K-feldspar (or microcline in 50% of the samples), irregular quartz, bronzy or orange-brown biotite, hornblende (50% of samples), orthopyroxene (2 samples and pseudomorphed in a third), garnet (all except two samples), an opaque oxide (sulphide in CG83-146B), apatite, zircon, allanite, and secondary allanite, epidote and chlorite are seen in some samples. Scapolite is present in CG83-175. Note that none of the granite samples contain clinopyroxene.

No thin sections were prepared from the alkali-feldspar granite.

11.6.2.4 Mafic Dykes (P_{3C}d)

Mafic dykes within the Double Mer White Hills granulites have only been claimed to be present at three localities (CG83-101, CG83-102, CG83-185). In field notes, they are described as being concordant sheets, up to 30 cm thick, except at CG83-185, where they were noted to be 2- to 20-cm-wide metamorphosed mafic dykes that predate deformation and are intruded by microgranite veins. Given the pervasive mylonitic state of their host rocks and the prevalence of mafic dykes in similar rocks elsewhere in eastern Labrador, it is suspected that their apparent sparseness is simply the result of having been 'smeared out' by severe strain.

A thin section prepared from the best-established dyke (CG83-185B) proved to be atypical of P_{3C}d mafic dykes, in that it is ultramafic rather than mafic, consisting mostly of mafic metamorphic/secondary minerals, namely pale-green hornblende, opaque oxides, titanite, epidote, chlorite, and very minor heavily sericitized plagioclase.