CHAPTER 14

EARLY MESOPROTEROZOIC (M_1 1600–1350 Ma)

14.1 PINWARE–MEALY MOUNTAINS TERRANE BOUNDARY MAFIC ROCKS

In this section, the connecting thesis governing the grouping of the rocks is that they comprise a series of gabbronoritic (locally ultramafic) to anorthositic, partly layered intrusions that occupy a specific tectonic position close to the boundary between the Mealy Mountains and Pinware terranes (Figure 14.1). As the terrane boundary is, at least partly, a Grenvillian feature, implied is some sort of pre-existing interface that influenced the emplacement location of the mafic–anorthositic rocks.

If the rocks are genetically related, one would expect the gabbronorite–anorthosite intrusions to have a common age. The only directly applicable geochronological data is from a gabbroic pegmatite within melanocratic metagabbro from the No-Name Lake mafic intrusion (Figure 14.1). Four single zircon fractions and one fraction of three fragments were analyzed from sample CG98-302B. Two fractions were near-concordant at the upper intercept; two were near-concordant at the lower intercept; and one was mid-chord and slightly off the mixing line. Excluding the off-line point, the upper and lower intercepts of 1473 ± 19 and 993 ± 25 Ma were interpreted as dating emplacement and metamorphism, respectively (Gower *et al.*, 2008b). The only other geochronological data available of potential relevance is from the Upper Paradise River monzogranitic suite (*see* Section 14.2.1). Concordant zircon ages of 1501 ± 9 and 1495 ± 7 Ma were obtained by Wasteneys *et al.* (1997) from alkali-feldspar granite and granite, respectively. Given the spatial association of the Upper Paradise River monzogranitic and gabbronoritic–anorthositic rocks, it is not unreasonable to anticipate that they are related and similar in

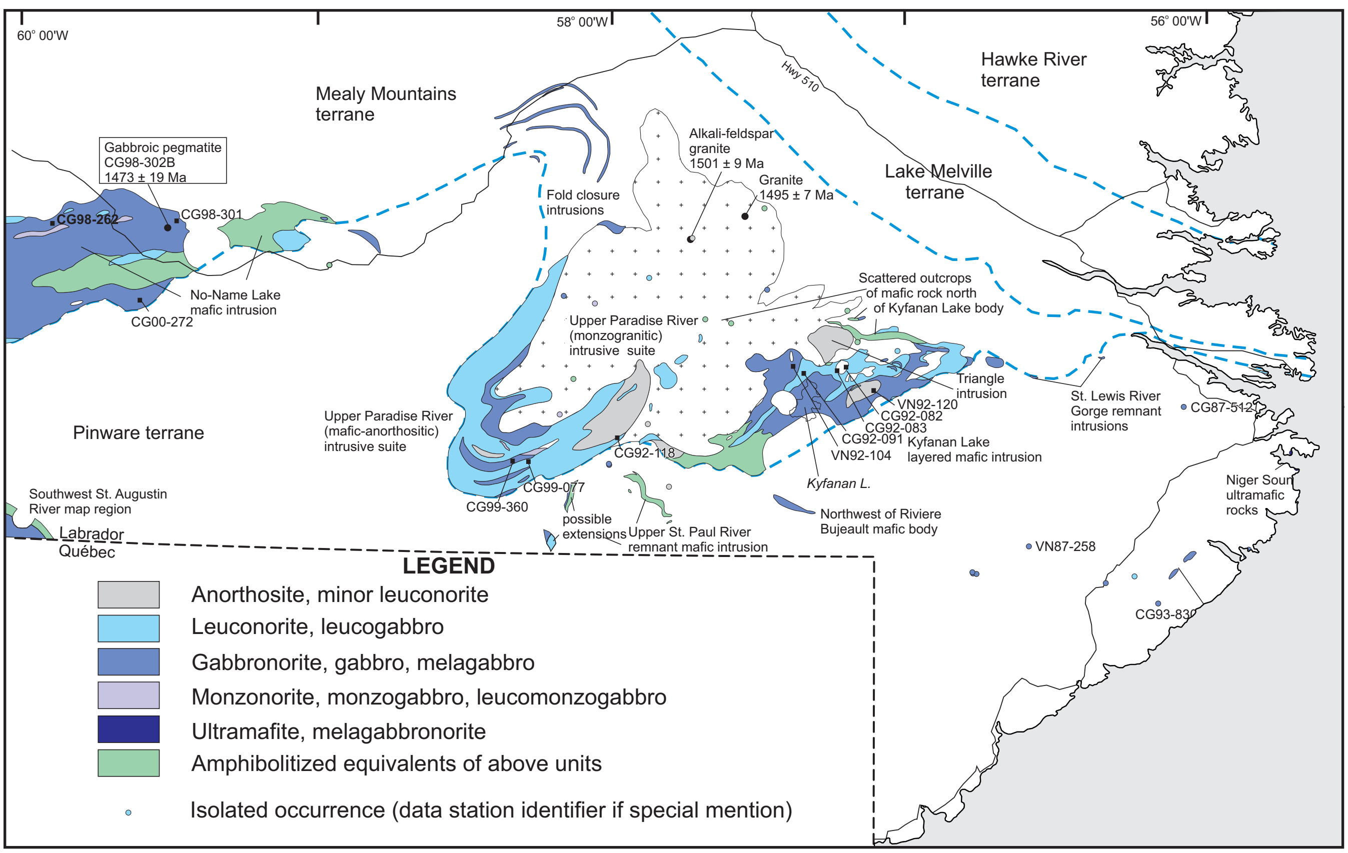


Figure 14.1. Distribution of Unit M_1 ultramafic, mafic and anorthositic rocks at the Pinware–Mealy Mountains terrane boundary.

age. Wasteneys *et al.* (1997) also processed a leucogabbronorite from the Kyfanan Lake intrusion, but no dateable material was retrieved.

Details of the individual gabbronoritic–anorthositic intrusions follow, from west to east. The descriptions tend to be somewhat repetitive, but the reader is cautioned that it has yet to be demonstrated that all the intrusions are collectively related, so greater generalization is premature.

Representative stained slabs are presented in Appendix 2, Slabs 14.1 (ultramafic to anorthositic rocks) and Slabs 14.2 (felsic rocks).

14.1.1 NO-NAME LAKE MAFIC INTRUSION

Part of the No-Name Lake mafic intrusion was first mapped by Gower (1999), although a small isolated area of gabbro within its presently defined extent is shown on the map of Eade (1962). Continuation of the body in the Upper St. Augustin River map region to the south (*see* Figure 14.1, but map regions indicated in Figure 13.12) was mapped by Gower (2001), and in the Kenamu River map region to the west by James and Lawlor (1999).

The name 'No-Name Lake mafic intrusion' was first used by Gower (2012). Rock types present within it are here classified into five types: i) olivine gabbro/melagabbro grading into ultramafic rocks, ii) gabbro and leucogabbro, iii) amphibolite, iv) monzogabbro to leucomonzogabbro, and v) diorite to monzodiorite. Igneous names have been retained because vestiges of igneous textures remain, but most rocks have been partially transformed to metamorphic assemblages. The main transformations are recrystallization of both mafic and felsic minerals, and hydration of mafic minerals to amphibole and, less commonly, phyllosilicate minerals. In all rock types, pegmatite and microgranite dykes/veins are common and late-stage shearing is apparent, accompanied by greenschist alteration. Potassium metasomatism has affected mafic rocks adjacent to some granitic intrusions. Note that, due to emplacement of late- to post-Grenvillian granite, the No-Name Lake body is divided into two main segments (Figure 14.1).

14.1.1.1 Olivine Gabbro/Melagabbro, Grading into Ultramafic Rocks (M_1um)

The rocks weather black, grey, brown or green, are medium to coarse grained and are weakly to moderately recrystallized. Primary rock types were gabbro, melagabbro and pyroxenite (Plate 14.1A). Some evidence remains of igneous layering, both in mafic minerals and plagioclase. In this unit, plagioclase-rich layers are thin (less than 10 cm wide) and sparse (but *see* leucogabbro unit described in the next section). Cumulate and ophitic textures can be commonly identified, although both are modified by metamorphic overprinting. More extensive metamorphic effects include the development of plagioclase-rich segregations, felsic veinlets and minor shearing. Foliation evident in some outcrops is mostly attributable to deformation, but, in a few cases, may reflect primary igneous mineral alignment.

The mineral assemblage is dominated by clinopyroxene and plagioclase (commonly in the 5–15% range), olivine, primary amphibole and opaque minerals (thin sections CG98-125, CG98-165, CG98-262 and CG98-302A) (Photomicrograph 14.1A). The olivine is rounded to subhedral and mostly fresh, except for Fe-oxide and minor serpentinization along fractures within the mineral. One of these rocks lacks olivine (CG98-302A) but contains orthopyroxene–opaque oxide symplectic intergrowths that were derived from olivine. Clinopyroxene crystallized after olivine and shows ophitic relationship with plagioclase. The clinopyroxene is colourless to pale-brown, has high relief and characteristically contains exsolved Fe-oxide needles. The primary amphibole is late stage, enveloping both olivine and clinopyroxene as large, pale-brown, poikilitic crystals. Opaque minerals include both oxide (*cf.* magnetite) and sulphide (pyrite or, less commonly pyrrhotite). Hercynite is also a common primary accessory mineral and orange-brown biotite is seen as a primary mineral in one thin section (CG98-165). Spinel(?)–amphibole sympletites between olivine and plagioclase occur in three thin sections (CG98-125, CG98-165 and CG98-302A), but they are absent from CG98-262. In the latter sample, most of the olivine is armoured by primary amphibole, but, even where olivine is seen in direct contact with plagioclase, no coronas are evident.

One other outcrop, from which samples were examined in thin section, can be included in this group. It is data station CG98-256, which has also been designated as a magnetite + minor pyrite mineral occurrence. Two thin sections (CG98-256A, CG98-256B) were examined and contain almost identical mineral assemblages, comprising high-relief, colourless clinopyroxene (40–55%), plagioclase (15–20%), pale-brown primary amphibole (10–20%), opaque minerals (15–25%; mostly magnetite, but very minor sulphide) and hercynite (5%).

The gabbro at station CG98-302 is intruded by a mafic pegmatite from which the 1473 ± 19 Ma age was obtained. It consists mostly of primary plagioclase and hornblende, but with both minerals showing extensive alteration (thin section CG98-302B). Much of the plagioclase is now a mosaic of white mica with some epidote/clinozoisite. The primary equant form of the hornblende has been corroded by secondary orange-brown biotite, epidote, chlorite and granular-looking, high relief material that is probably a mixture of titanite and epidote.

14.1.1.2 Gabbro and Leucogabbro (M_1rg, M_1ln)

There is a continuum between gabbro and leucogabbro within the mafic intrusion. On the basis of proportions seen in outcrop, leucogabbroic rocks probably form less than 15% of the body. The rocks are white-, buff-, or creamy-brown-weathering, fine to medium grained, recrystallized, and weak to moderately foliated. Relict igneous textures are partially preserved in some of the samples, although a few are thoroughly recrystallized. Primary igneous layering or lamination was observed in two outcrops (Plate 14.1B), sup-

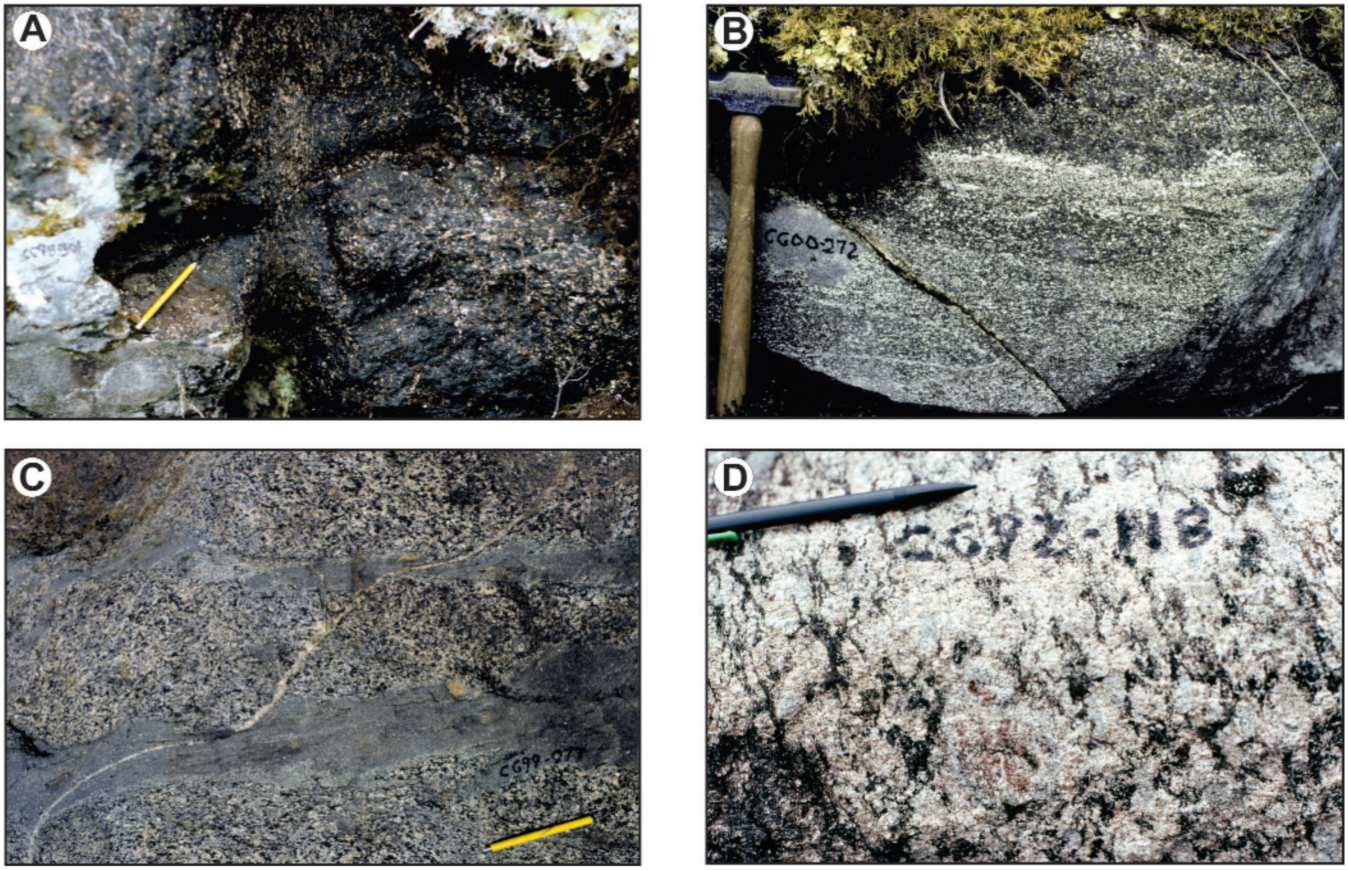


Plate 14.1. *Pinware–Mealy Mountains terrane boundary mafic rocks. No-Name Lake mafic intrusion (A, B) and Upper Paradise River suite (C, D). A. Metamorphosed melagabbro from No-Name Lake mafic intrusion (CG98-301), B. Foliated and compositionally banded (reflecting primary layering?) mafic rock from No-Name Lake mafic intrusion (CG00-272), C. Metagabbro hosting finer-grained mafic rock (residual magma?). Intruded by felsic vein, more strained in fine grained mafic rock (CG99-077), D. Meta-leucogabbro/anorthosite displaying relict garnet. Outline of former garnet defined by slightly greyer plagioclase (CG92-118).*

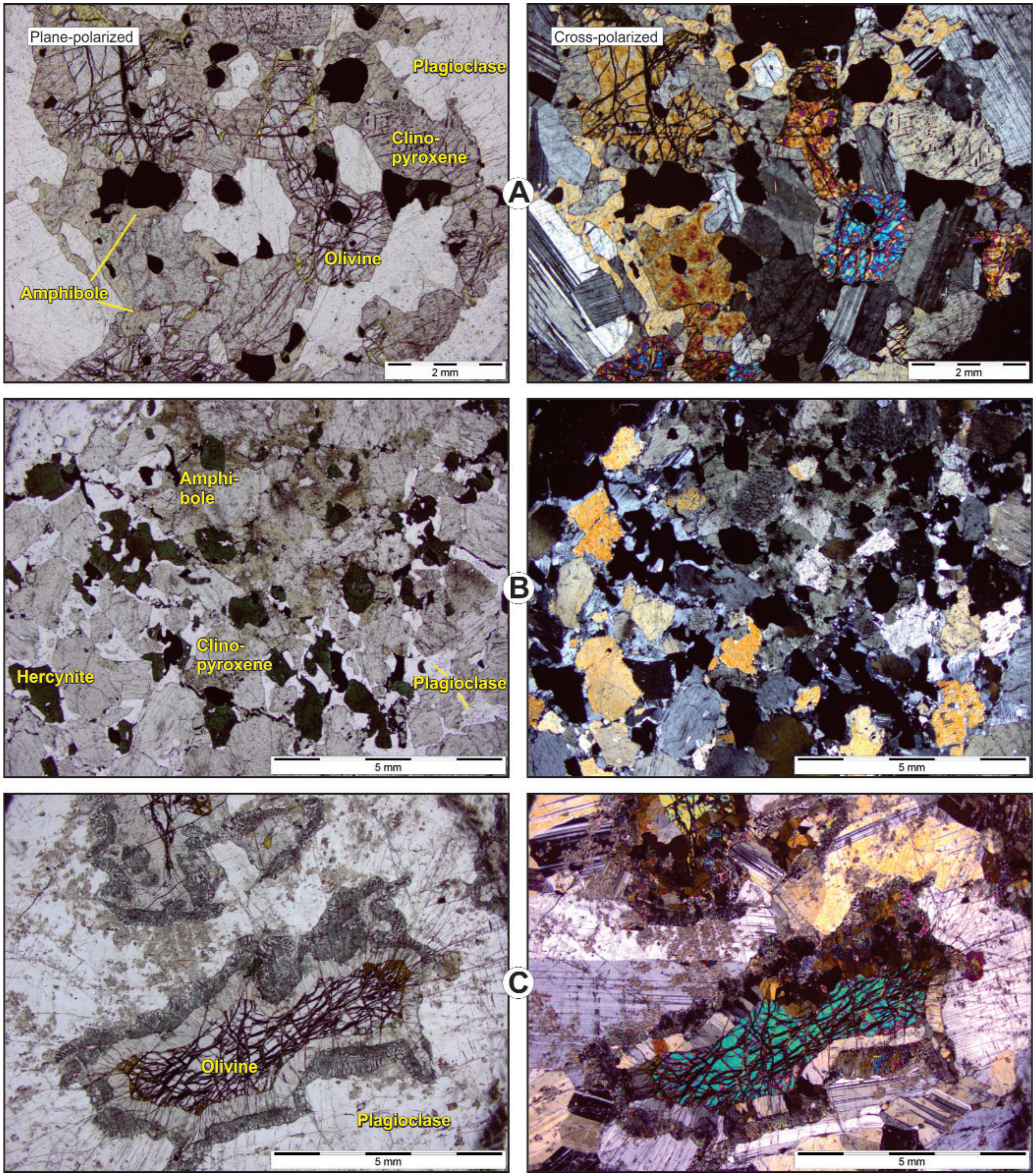
porting previous statements that the body is a layered mafic intrusion (Gower, 1999; James and Nadeau, 2000).

Thin sections examined from the main body (CG00-014, CG00-271, CG98-254, CG98-257, CG98-259, CG98-270, CG98-272, CG98-288, CG98-294) consist of primary plagioclase, clinopyroxene, apatite and opaque minerals (mostly oxide but minor sulphide), and secondary amphibole, biotite, epidote, titanite, and, locally, chlorite and carbonate. Clinopyroxene is present in three sections (CG98-270, CG98-272, CG98-294) existing as ragged cores to secondary mafic mineral mosaics. In the remaining samples, the former presence of clinopyroxene can be inferred from the outline of the mafic mineral clusters. Plagioclase is thoroughly recrystallized in all samples, except in CG98-294, where subhedral-to-euhedral, zoned, primary laths show subophitic relationship with clinopyroxene and its secondary products. The distinctiveness of the plagioclase in CG98-294, especially zoning, leads to the speculation that this sample might be genetically distinct – perhaps a later dyke? The only other sample to show comparable textures is CG98-254 (also a dyke?), but severe retrogression during later brittle faulting has obscured primary features in this rock. Narrow (<2 mm wide) seams of prehnite are present in CG00-014 and CG00-271.

14.1.1.3 Amphibolite (M_1am)

Rocks forming this unit weather green, grey or black, are generally medium grained and are moderately to strongly foliated. Although segregation into plagioclase-rich leucosome and hornblende-rich melanosome is evident locally, most outcrops are fairly homogeneous. One strongly foliated variety exposed on the Joir River verges on gneiss and displays plagioclase porphyroclasts, suggesting significant ductile deformation in the vicinity. There is a gradation from amphibolite to metagabbro and, from a genetic perspective there seems little justification in differentiating between them.

The mineral assemblage in five thin sections examined (CG98-123A, CG98-202, CG98-219, CG98-292, CG98-282) includes amphibole, plagioclase, epidote, biotite, K-feldspar, titanite, apatite, clinopyroxene, white mica, chlorite and opaque minerals. Of these only clinopyroxene (present in only one thin section – CG98-282) can be regarded as an essential primary mineral, and, even in this case, exists only as a relict core enveloped in secondary mafic min-



Photomicrograph 14.1. *Examples of Pinware–Mealy Mountains terane boundary mafic rocks. A. No-Name Lake olivine gabbro (CG98-262), B. Hercynite-rich websterite in Upper Paradise River mafic–anorthositic unit (CG99-360), C. Coronitic texture mantling olivine in Kyfanan Lake mafic intrusion (CG92-082).*

erals. The plagioclase is thoroughly recrystallized and commonly is also severely sericitized and saussuritized. A mixture of amphiboles is present. Much is a ragged, acicular blue-green actinolitic hornblende, but some colourless aggregates in the cores of the mafic clusters are probably closer to tremolite. Olive-green biotite, granular epidote, anhedral titanite, and chlorite are present as retrograde derivative products of pyroxene and amphibole breakdown. The opaque minerals include both oxide and sulphide; sulphide is unusually common in CG98-202 and CG98-282.

14.1.1.4 Monzogabbro to Leucomonzogabbro (M_1mn)

Monzogabbro to leucomonzogabbro within the mafic intrusion is dark-weathering, medium to coarse grained and recrystallized. It is not an especially distinctive unit and is gradational into leucogabbroic rocks.

Essential minerals in six thin sections examined (CG00-001, CG00-092, CG98-265, CG98-274, CG98-275, CG98-290) are plagioclase, clinopyroxene, biotite and K-feldspar, with secondary amphibole, biotite, epidote, chlorite and titanite, and accessory apatite, quartz (rare) and opaque minerals (mostly oxide, but minor sulphide). Primary and recrystallized plagioclase are both present. Clinopyroxene (only seen in two thin sections; CG98-274 and CG98-290) forms relict grains in the cores of clusters of polysynthetically twinned amphibole (tremolite–actinolite and actinolitic hornblende), epidote, titanite, chlorite and secondary biotite. Primary biotite (orange-brown) was only seen in one thin section (CG98-265). Most of the K-feldspar is anhedral, untwinned and interstitial, and comprises both perthite and microcline.

14.1.1.5 Diorite to Monzodiorite (M_1ln/M_1mz)

In the eastern segment of the body, metamorphosed diorite to monzodiorite was found. It is not shown separately on Figure 14.1. It is compiled into the 1:100 000-scale map for the area as unit M_1ln/M_1mz, but it is distinct from the leucogabbronorite unit seen elsewhere. It is also distinct from adjacent amphibolite to the north and west, and the orthogneiss to the south. There is no compelling reason to link these dioritic rocks with the mafic intrusion, other than by spatial association. The rocks are creamy-, grey- or green-weathering, coarse grained, foliated and homogeneous. The ratio between K-feldspar and plagioclase varies significantly (hence the rock name range), but the rocks share textural similarity, taken to imply a common origin. Monzodiorite at one locality is intruded by undeformed pegmatite.

In one thin section examined (CG98-171), the minerals include partly recrystallized plagioclase, K-feldspar, relict clinopyroxene, hornblende, apatite and opaque minerals (mostly oxide, but minor sulphide), and secondary tremolite–actinolite, biotite, titanite, chlorite and quartz. Very little clinopyroxene is preserved, having been mostly replaced by secondary mafic silicates.

14.1.2 FOLD CLOSURE INTRUSIONS (M_1rg)

With the aid of well-defined aeromagnetic patterns, scattered outcrops of metamorphosed and recrystallized metagabbro/diabase have been interpreted as sill-like mafic bodies, emplaced into the enveloping granitic gneisses. The rocks were originally mapped by Gower (1998), but are newly named here. They are black-weathering, fine- to coarse-grained, generally weakly foliated or massive gabbro. Leucocratic variants are also present and suggestions of layering imply emplacement as subhorizontal sheets. The fine-grained varieties, despite recrystallization, still preserve ophitic textures, including evidence of quenched plagioclase. Such rocks may represent chilled margins of the intrusions. The coarser grained rocks are generally more recrystallized, but also show relict ophitic textures.

All of the five samples examined in thin section (CG97-045, CG97-056, CG97-062, CG97-133B, CG97-289) are somewhat texturally distinct from each other, but the contrasts are not drastic enough to make genetic linkage unlikely. Mineral assemblages are largely metamorphic, but relict well-twined laths of igneous plagioclase (clouded with opaque inclusions in part) are preserved in two thin sections and poikilophitic igneous clinopyroxene in three. Recrystallization of plagioclase varies from merely crystal boundary effects (shown by wavy, irregular grain margins divided by small, scattered, polygonal plagioclase crystals) to thoroughly recrystallized pervasive mosaics. Relict clinopyroxene is so heavily charged with exsolved opaque inclusions that it appears almost black in places. Pseudomorphs of olivine were tentatively identified in slabs, but were not seen in thin section. Nevertheless, olivine is suspected to have been once present and a reaction between olivine and plagioclase to have produced necklaces and stubby rods of garnet (characteristically flanked by inclusion-free plagioclase) and aggregates of equant, polygonal orthopyroxene. Other minerals include an oxide opaque mineral, orange-brown biotite (typically forming aggregates surrounding the opaque mineral), apatite and metamorphic amphibole. The habit of the amphibole varies. In samples CG97-045 and CG97-289, it occurs as large poikilitic grains enclosing relict primary plagioclase, and also as extensively recrystallized blue-green amphibole or tremolite–actinolite patches. These samples lack garnet, but retrogressed garnet pseudomorphs were suspected in outcrop at CG97-045. In CG97-133B and CG97-289, the transition from clinopyroxene to amphibole is evident. In contrast, in sample CG97-062, amphibole is dull-green and only encloses opaque-cored biotite clusters. Many of the mineral relationships described here are typical of higher grade coronitic reactions in tholeiitic mafic rocks.

14.1.3 UPPER PARADISE RIVER INTRUSIVE SUITE (MAFIC–ANORTHOSITIC)

The Upper Paradise River intrusive suite can be divided into two groups, namely: i) mafic to anorthositic rocks and ii) monzonitic to granitic units. It was previously termed the Upper Paradise River pluton by van Nostrand (1992) and van Nostrand *et al.* (1992), who mapped part of the granitoid northeastern quadrant of the body. The southeastern and western parts were mapped by Gower *et al.* (1993), Gower (1998, 1999). The modification of name to 'intrusive suite' is made here to emphasize the diversity of rock types found in the body. The mafic to anorthositic rocks, addressed here, form a 5- to 15-km-wide envelop around the south, southwest and west flanks of the monzonitic to granitic core. The spatial association between the two groups of rocks is taken as grounds for inferring a genetic link and for making the assumption that the mafic–anorthositic rocks have an age similar to monzonitic to granite units, which are dated to be 1495 ± 7 and 1501 ± 9 Ma (Wasteneys *et al.*, 1997).

Relationships with the surrounding rocks are poorly known. Based on ductile structures along the southeastern flank of the body, it seems likely that that part of the contact is a thrust. On the western flank, two outcrops displaying complex mixtures of amphibolitic, leucoamphibolitic and granitic rocks may be a remnant of a hybridized border between the mafic–anorthositic rocks and the surrounding granitoid units. The mafic component occurs as irregular masses of recrystallized and migmatitic material, enveloped in inhomogeneous white to creamy granitoid material. The outcrops are isolated from both granitoid rocks to the west and mafic–anorthositic rocks to the east, so relationships to either remain undetermined.

The mafic to anorthositic rocks are divided into the following units: i) gabbronorite to ultramafic rocks, ii) leucogabbronorite, iii) anorthosite, and iv) monzogabbronorite. Of these, the leucogabbronorite and anorthosite units are the most abundant. Depicting gabbronorite as crescent-shaped areas (convex to the southwest) within the leucogabbronorite is undoubtedly highly oversimplified. It is based on aeromagnetic patterns and on forcing boundaries to conform with the overall margins of the mafic to anorthositic unit – all within the context of limited outcrop control. Along the St. Paul River, where outcrop is better, only one gabbronorite to ultramafic layer was mapped and this is merely about 30 m thick, so the mafic layers in the forested areas might be equally thin (but preferentially exposed?).

14.1.3.1 Gabbronorite to Ultramafic Rocks (M_1um)

Within the gabbronorite to ultramafic rocks unit, strictly ultramafic rocks are uncommon (about 5–10% of collected samples of this unit, including borderline cases), and no sample is completely devoid of plagioclase. Gabbronorite grading into leucogabbronorite (including their metamorphic amphibole-rich derivatives) is most usual. The rocks weather black, grey, brown, green, or, rarely, ocherous. They are mostly medium to coarse grained, but fine-grained variants are found. Where primary textures are evident, the original igneous grain size is about 0.5 cm. Typically, the rocks have been moderately to completely recrystallized, although the polygonized outline of former larger primary grains can commonly be discerned. Fabric ranges from weakly foliated, homogeneous, igneous-looking rocks (Plate 14.1C) to strongly foliated equivalents, and even well-banded mafic gneiss. Weakly to moderately foliated rocks are most common. In the gneissic variants, banding is defined by melanocratic veneers/lenses and leucocratic layers, streaks and segregations. The melanocratic veneers tend to be made up mostly of hornblende, and the leucocratic segregations to consist of plagioclase, sporadically accompanied by quartz and K-feldspar. Lenses and blocks of mafic material, contrasting in either composition or texture, are present locally, and may be entrapped representatives of earlier magmatic pulses. Vague primary layering was noted at one locality, but variations in composition and texture from one outcrop to the next suggest that layering may be more widespread than poor exposure indicates. Gneissosity may also have preferentially developed in rocks already possessing primary layering. A few microgranite or pegmatitic veins intrude the mafic rocks, both concordantly and discordantly to the host-rock fabric. One outcrop within the body is entirely granite pegmatite, except for a 3-m-long, 40-cm-wide enclave of metamorphosed melagabbro in it. The enclave is the only rock in the mafic–anorthositic unit containing noteworthy sulphide (mostly pyrite, but possibly minor chalcopyrite).

From petrographic study, four groups are distinguished, namely: i) websterite, ii) olivine websterite to olivine gabbronorite, iii) gabbronorite, and iv) amphibolitized metagabbronorite. Only one thin section (CG99-360) is assigned to the websterite group. It is a cumulate rock consisting mostly of clinopyroxene, which forms anhedral to locally subhedral, colourless to pale-brown crystals, with intercumulus amphibole, orthopyroxene and plagioclase. The amphibole is a distinctive yellow-green and poikilitically encloses clinopyroxene. Other minerals are hercynite and opaque minerals (an oxide phase and two sulphides – reflected light examination suggests pyrite and pyrrhotite). The hercynite is distinctive in being unusually large (up to about 1 mm in diameter) and abundant (about 10%) (Photomicrograph 14.1B).

Three thin sections are included in the websterite to olivine gabbronorite group (CG99-078, CG99-096, CG99-109) and all contain olivine, clinopyroxene, orthopyroxene, plagioclase, amphibole, hercynite and an opaque mineral. Olivine shows a complete range from fresh grains to serpentinized pseudomorphs, and is surrounded, or completely replaced, by double coronas. As is typical, the inner corona consists of radial fibrous to scaly orthopyroxene and the outer corona is made up of clinopyroxene (or amphibole) plus spinel. The coronas are severely modified as a result of recrystallization, especially in CG99-078 and CG99-096. Orthopyroxene also forms a primary mineral in CG99-078 and clinopyroxene is a primary mineral in all three samples. Amphibole is a pale-yellow-green-brown late-stage primary phase pokilitically enclosing the other mafic minerals. Plagioclase forms well-twinned, unzoned, unaltered grains that are somewhat turbid due to colourless (spinel/corundum?) inclusions. Hercynite is a common accessory phase, occurring as vermiform inclusions in the outer parts of coronas and as small anhedral grains elsewhere. An opaque mineral is only significant in CG99-109 and is mostly sulphide (its colour suggests pyrrhotite).

Six samples belonging to the third group (gabbronorite) (CG99-062, CG99-066, CG99-069, CG99-105, CG99-106, CG99-130) all contain plagioclase, clinopyroxene, orthopyroxene, an opaque mineral and apatite (no apatite seen in CG99-062), plus hydrous mafic silicates. Plagioclase is anhedral, well twinned, and shows marked grain-size variation due to variable recrystallization. Clinopyroxene and orthopyroxene both form polygonal clusters of equant grains. The opaque mineral is mostly oxide but minor sulphide is present in

CG99-062, CG99-105 and CG99-130. Samples CG99-062, CG99-066 and CG99-069 contain common red-brown biotite, in contrast to samples CG99-105, CG99-106 and CG99-130 (from farther west) that lack biotite, but contain late-stage primary hornblende and/or early secondary hornblende.

The fourth group (amphibolitized gabbronorite) is represented by five samples (CG99-064, CG99-082, CG99-116A, CG99-165, CG99-341A), which contain plagioclase, hornblende, clinopyroxene (except CG99-082, CG99-341A), an oxide and/or sulphide opaque mineral, apatite and red-brown biotite. In addition, sample CG99-116A contains titanite and sample CG99-082 has titanite, chlorite and prehnite(?). Variation in the size and appearance of both felsic and mafic minerals attests to extensive recrystallization. Plagioclase ranges from fairly large, well-twinned grains to poorly twinned, polygonal, tiny-grain aggregates. Clinopyroxene forms pale green clusters of polygonal, equant, relict primary grains, having been replaced by hornblende, which, in turn, exhibits recrystallized borders. The samples generally show a well-defined preferred mineral orientation.

One closely associated rock examined in thin section that cannot be assigned to any of the above groups is sample CG99-340, which comes from a thin meta-anorthosite layer within a metagabbronorite. It consists mostly of polygonized plagioclase, with biotite, opaque minerals (oxide and sulphide), titanite and apatite localized at feldspar grain boundaries. Prehnite and chlorite are present as fracture-fill minerals.

14.1.3.2 Leucogabbronorite (M_1ln)

The leucogabbronoritic rocks weather white, grey, brown, buff, creamy and, rarely, pale-pink, are medium to coarse grained, generally homogeneous, moderately to completely recrystallized, and have variable fabrics. A few are massive, but weakly to moderately foliated rocks are most typical, and strongly foliated, gneissic and mylonitic variants are also present. Textural variation includes rare occurrences of very coarse-grained rocks, in which plagioclase crystals exceed 10 cm long, and porphyroclastic rocks that contain primary plagioclase ovoids in a fine-grained, recrystallized matrix. A few of the more metamorphosed rocks could be referred to as foliated diorite, but the collective lithological assemblage makes this name inappropriate. At a few sites, indistinct layering was seen, expressed more by differences in grain size than by compositional contrasts, although the latter do occur. Mafic enclaves, typically fine-grained amphibolite, are found sporadically, the largest being about 3 m long and 20 cm wide, but most are less than a few centimetres. A few quartzofeldspathic stringers and pink microgranite dykes, locally *en échelon*, intrude leucogabbronorite in places.

The mafic minerals are mostly pyroxene, accompanied by hornblende and lesser biotite in the strongly foliated and gneissic rocks. Plagioclase is typically the sole felsic mineral, but is accompanied by traces of K-feldspar (evident in stained slabs) in clusters of small, interstitial grains in some rocks. In hand sample, K-feldspar-bearing leuconorite can be mistaken for monzonite, as there is little mineralogical difference, beyond K-feldspar proportions. Partially retrograded garnet is present within leucogabbronoritic or anorthositic rocks in eastern areas of leucogabbronorite (Gower *et al.*, 1993).

Two subgroups are distinguished petrographically on the basis of the presence or absence of pyroxene. Samples belonging to the pyroxene-present group (CG99-007, CG99-044, CG99-086, CG99-115, CG99-118, CG99-120, CG99-136) all contain both clinopyroxene and orthopyroxene, except CG99-086, which lacks orthopyroxene. Other minerals in common are plagioclase, orange-brown biotite, an opaque oxide and apatite. Plagioclase twins are characteristically bent or broken, providing clear indication of the extensive deformation that these rocks have experienced. Evidence of deformation is also given by equant, polygonal pyroxene clusters that commonly have ragged grain boundaries and bent cleavage surfaces. Amphibole forms a secondary, ragged product, in consort with biotite. Other minerals are K-feldspar, quartz (both in CG99-044, CG99-115, CG99-120), epidote (CG99-007, CG99-118), chlorite (CG99-118) and zircon (CG99-120).

The pyroxene-absent group (CG99-008, CG99-094, CG99-103, CG99-339A, CG99-347) probably represents little other than a more deformed and metamorphosed equivalent of the previous group, in which pyroxenes have been modified to hydrous mafic equivalents, especially hornblende and biotite. Both of these are characteristic mafic minerals in all five samples, although their habit varies from ragged to equant, depending on stage of recrystallization. All samples contain sulphide and an oxide opaque mineral. Retrogression to greenschist-facies minerals (actinolite, carbonate, white mica, chlorite and epidote), is evident to varying extent in all thin sections.

Several small bodies of anorthositic gabbro or leucogabbronorite, within syenite to monzonite, were mapped northeast of the eastern flank of the leucogabbronorite envelop of the Upper Paradise River intrusive suite. Given poor outcrop control, it might be legitimate to map these as part of the anorthosite to the southwest, rather than depicting them as isolated intrusions. Some details are as follows:

i) A single outcrop (JA92-073) of recrystallized leucogabbro in one body most closely resembles rocks seen in the large anorthositic intrusion to the west. The mineral assemblage is plagioclase, clinopyroxene, brown-green amphibole, red-grown biotite and traces of apatite and an opaque mineral.

ii) Two ovoid bodies east of the northeast tip of the anorthosite intrusion contain rocks that weather to honey-brown characteristic of the surrounding monzonite and syenite, but stained slabs deny that they contain K-feldspar or quartz. Rather, the rocks are anorthositic gabbro, leucogabbro and leucogabbronorite, with minor amphibolite. Well-developed coronas of amphibole around primary pyroxene are common.

From the western ovoid body, two anorthosites (JA92-061, VN92-108) were examined in thin section. Both rocks contain over 97% plagioclase, which appears to be primary. Clinopyroxene makes up almost all of the remainder of the rocks and is relegated to interstitial beads at plagioclase grain boundaries. A ubiquitous acicular mineral throughout the plagioclase may be rutile. A coronitic rock (HP92-076) contains primary plagioclase, olivine and orthopyroxene, together with minor clinopyroxene and an opaque phase. The coronas are made up of vermiform intergrowths of green spinel and clinopyroxene. The remaining rock examined from this body (JA92-067) contrasts from the other three in being a completely recrystallized two-pyroxene granulite, also containing, in equilibrium, pale-brown amphibole, green spinel and a few grains of an opaque phase. The relationship of this rock to the other three is not known, but clearly, although the body is represented as a single unit on the map, it is not a straightforward, simple intrusion. The only sample (CG92-064) seen in thin section from the eastern ovoid body has a plagioclase–orthopyroxene–clinopyroxene–opaque mineral equilibrium mineral assemblage with minor secondary biotite. It is partially recrystallized and could be termed a medium-grained gabbronorite or a two-pyroxene granulite.

14.1.3.3 Anorthosite (M_1an)

Anorthosite in the Upper Paradise River intrusive suite is manifest as a leucocratic variation of the leucogabbronorite, rather than being an obviously separate unit. It is quite well exposed, although outcrops are isolated and unevenly distributed. The rock varies considerably in field appearance. It is dominantly pale-grey to white-weathering, but may be locally pinkish, creamy, dark grey or even black. Some outcrops are completely homogeneous, and massive or weakly foliated; elsewhere an indistinct layering (interpreted as primary) is present, or the rock may exhibit a moderate to strong foliation due to subsequent deformation. Grain size varies from medium to very coarse grained, partly being linked to intensity of recrystallization, which varies from slight to extensive. In general, there seems to be an increase in deformation and recrystallization from north to south across the body. The anorthosite is noteworthy in its lack of crosscutting minor intrusions. At one locality, some fine-grained enclaves were seen. As these have the same composition as the host rock, they may be cognate.

Primary plagioclase is present at many localities. In many places it is preserved as relict cores in which multiple twinning is clearly evident. Primary orthopyroxene and clinopyroxene, both up to 2 cm long, were also observed in outcrop. Commonly the grains are mantled by amphibole coronas. In the rocks thin sectioned, however, pyroxene is not a common phase, having been mostly reacted to form amphibole. Some clusters of mafic minerals have orange brown cores, probably representing serpentine alteration after orthopyroxene.

The dominant mafic silicates seen both in the field and in thin section are metamorphic amphibole and biotite, but, in the southern part of the body, retrograded former garnets were also observed in the field. Only 1- to 2-mm-diameter garnet kernels remain in the cores of crystals originally up to 2 cm in diameter (Plate 14.1D). Also evident from thin section are mantles of colourless, multiple-twinned ortho-amphibole (CG92-110), rare interstitial recrystallized quartz, traces of apatite and opaque minerals, suspected to be Fe(Ti) oxide and pyrrhotite.

14.1.3.4 Monzogabbronorite (M_1mn)

Monzogabbronorite associated with mafic–anorthositic rocks of the Upper Paradise River intrusive suite is rare. It is grey-brown- or buff-weathering, medium to coarse grained, homogeneous, and weakly foliated. It differs from the K-feldspar-bearing leucogabbronorite in having a higher colour index, more K-feldspar, and perhaps higher hydrous mafic mineral content. Two outcrops, consisting mostly of K-feldspar-rich mafic gneissic rocks having relatively high colour indices, have also been equivocally grouped with this unit, but the K-feldspar content in these examples is more likely the result of K-rich fluid introduction during deformation, rather than reflecting original igneous crystallization.

An excellent exposure of this unit is situated at CG99-079. The monzogabbronorite consists of anhedral, well-twinned, zoned plagioclase, poorly exsolved bead perthite, pale-green clinopyroxene, relict, ragged orthopyroxene, orange-brown biotite, minor fibrous amphibole fringing clinopyroxene, an opaque oxide, traces of sulphide and apatite. The outcrop is intruded by mafic and pegmatitic dykes (trending at 050 and 090, respectively), with the latter offset by minor apparent-dextral faults.

14.1.4 KYFANAN LAKE LAYERED MAFIC–ANORTHOSITIC INTRUSION

The Kyfanan Lake layered mafic–anorthositic intrusion was mapped and named by Gower *et al.* (1993). It is an east-northeast-trending body that underlies much of the Kyfanan Lake 1:100 000-scale map region. Prior to mapping in 1992, it was unknown, although a single outcrop of gabbro within the presently defined area of the intrusion is shown on the map of Eade (1962). Rocks that are its eastward continuation had been earlier mapped in the St. Lewis River map region (Gower *et al.*, 1988), but their significance as part of the much larger body to the west was unrecognized at the time. Including the St. Lewis River region rocks, the body has a length of about 80 km and a width of up to 15 km.

The intrusion comprises five main rock groups. These are: i) ultramafic rocks, ii) troctolite, norite and gabbro, iii) leucocratic equivalents of troctolite, norite and gabbro, iv) anorthosite and anorthositic gabbro, and v) metamorphic derivatives of the previous four units.

14.1.4.1 Ultramafic Rocks (M_1um)

These rocks vary from having almost entirely primary igneous mineral assemblages and textures, to being completely metamorphic (Plate 14.2A).

A noteworthy example of a rock having primary minerals and texture is a dark-brown-weathering lherzolite to olivine websterite exposed 13 km west-southwest of Kyfanan Lake (CG92-175). The overall rock is layered, defined by fracture parting coupled with mineralogical contrasts, which are better seen on weathered than fresh surfaces. Within individual layers, the rock is homogeneous and massive.

Olivine is present as stubby, euhedral cumulate grains in a matrix consisting mainly of orthopyroxene with some clinopyroxene, brown amphibole, hercynite, an opaque mineral and traces of red-brown biotite. Another ultramafic rock, consisting largely of primary minerals, was sampled 8 km west of Kyfanan Lake (CG92-029). The mineral assemblage is the same, although proportions differ, and the rock can be termed either olivine websterite or olivine clinopyroxenite.

One primary-textured ultramafic rock belonging to the Kyfanan Lake intrusion was found within the St. Lewis map region.

A sample examined petrographically (VN87-037) is a cumulate wehrlite containing a primary igneous mineral assemblage. Subhedral to euhedral primary olivine makes up about 50–60% of the rock, and is associated with clinopyroxene containing abundant opaque mineral inclusions, colourless to pale-brown amphibole that poikilitically encloses olivine and clinopyroxene, pale-orange (phologopitic) biotite, and an opaque oxide. The rock lacks felsic minerals.

The mineralogically modified equivalent rocks are black-, green-, or brown-weathering, medium grained, weakly to strongly foliated, recrystallized and, in places, slightly schistose (*e.g.*, VN92-109). They are now largely

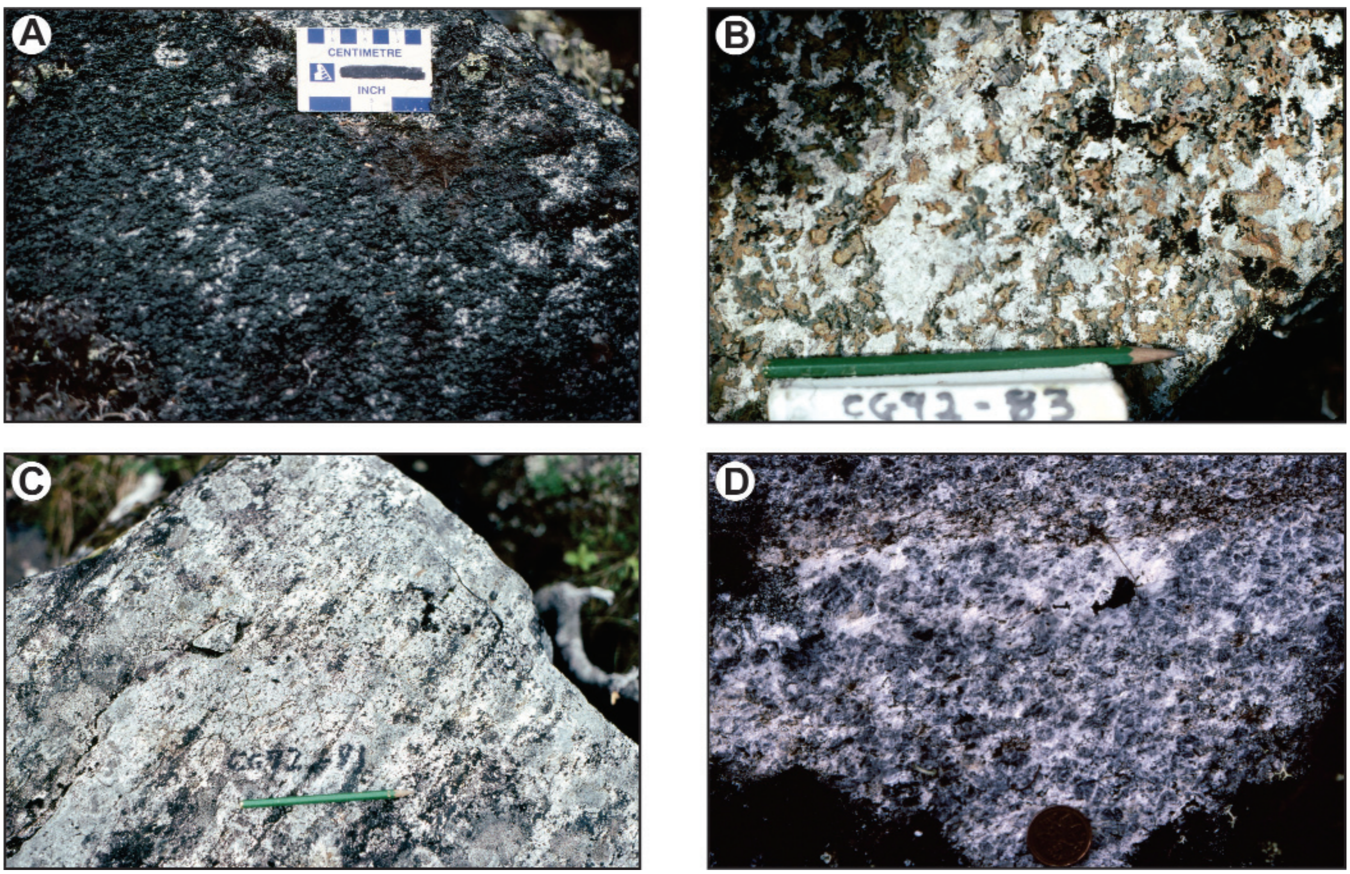


Plate 14.2. *Pinware–Mealy Mountains terrane boundary mafic rocks; Kyfanan Lake layered mafic–anorthositic intrusion. A. Metamorphosed ultramafite/melagabbro from Kyfanan Lake layered intrusion (VN92-104), B. Detail of troctolite from Kyfanan Lake layered intrusion showing coronitic texture (orange olivine cores and green rims) (CG92-083), C. Anorthositic gabbro from Kyfanan Lake layered intrusion showing primary igneous layering (CG92-091), D. Anorthosite from Kyfanan Lake layered intrusion. Primary plagioclase is grey; recrystallized plagioclase is white (VN92-120).*

composed of amphibole, commonly with some clinopyroxene, minor interstitial plagioclase and an opaque mineral. Minor secondary biotite and apatite are present.

14.1.4.2 Troctolite, Norite and Gabbro (M_1rg)

This unit weathers dark-green, brown, purple or grey, is medium to coarse grained and massive to moderately foliated. Layering was observed in many outcrops. Subophitic textures are commonly preserved. Plagioclase crystals may be equant to extremely acicular. Primary olivine, orthopyroxene and clinopyroxene occur as orange or brown grain cores mantled by green amphibole (Plate 14.2B). A composite petrographic description for both this unit and the following one is given in the next section.

14.1.4.3 Leucocratic Equivalents of Troctolite, Norite and Gabbro (M_1ln)

Similar overall to the previous unit, these rocks tend to be lighter weathering (white, dark grey or brown) and to exhibit greater variation in appearance, including more evidence of primary layering (Plate 14.2C). One such variation is a mottled texture, interpreted as due to recrystallization of large primary pyroxene grains to anhedral clusters of amphibole, in an originally more leucocratic matrix.

In thin section, the above two units define a bimodal spectrum from rocks having nearly pristine igneous textures and mineral assemblages to those that are essentially two-pyroxene granulites. For petrographic descriptive purposes, the samples have been classified into two groups, namely: i) coronitic primary-textured rocks, and ii) granulite-textured rocks. The two groups do not have a simple pattern of distribution, although most of the granulite-textured samples are from east of Kyfanan Lake. Petrographically, it is fairly easy to divide the rocks into the two groups, but it is difficult to apply such a classification in the field. The mineral proportions and grain size of the rocks vary considerably, reflecting their igneous protolith, and these features remain the criteria by which the rocks were mapped.

The coronitic, primary-textured samples examined in thin section (CG92-022, CG92-030, CG92-082, CG92-127, HP92-045, VN87-077, VN92-028, VN92-091, VN92-092, VN92-096A) contain anhedral to subhedral, equant to elongate plagioclase; partially serpentinized anhedral olivine; large, anhedral, late-crystallizing clinopyroxene; and brown amphibole as primary minerals. The coronas mantling olivine consist of an inner orthopyroxene corona (locally radiating fibrous orthopyroxene, but commonly more uniform in appearance), and an outer corona of symplectic clinopyroxene and vermiform green spinel (Photomicrograph 14.1C). In places, brown amphibole has replaced clinopyroxene and is also riddled with spinel. Isolated primary opaque grains also occur, but are not common. Most of the opaque minerals are secondary from alteration of olivine.

The granulite-textured rocks examined in thin section (CG87-018, CG92-076, CG92-078, CG92-084, CG92-088, CG92-089, CG92-097, CG92-131, HP92-050, JA92-020, JA92-036, VN87-038) contain plagioclase (generally anhedral, straight-sided grains, but some larger possibly relict primary crystals); anhedral, equant orthopyroxene and clinopyroxene; anhedral amphibole, an opaque mineral, biotite and traces of apatite. Both the clinopyroxene and amphibole are dusted with exsolved opaque inclusions and the amphibole is fringed with a secondary opaque mineral associated with a granular ferromagnesian phase, possibly orthopyroxene. Both biotite and the equilibrium opaque phase are much more abundant than in the corona-textured rocks. Green spinel is absent.

Some samples having a gabbroic or leucogabbroic protolith from the eastern end of the Kyfanan Lake body (St. Lewis River map region) do not readily fit into the two groups outlined above in that they are neither coronitic (an exception is VN87-077 included above), nor are they granulite textured. They are more extensively recrystallized and have amphibolite-facies metamorphic mineral assemblages, having only relict primary plagioclase and clinopyroxene sporadically preserved. Two gabbroic-protolith samples (CG87-018, VN87-038) and four leucogabbroic samples (CG87-371, JS87-070, JS87-073, VN87-076) were examined petrographically. Sample VN87-038 is of interest, in that, despite its thoroughly metamorphic mineral assemblage, it is less than 200 m from a near-pristine ultramafic rock described earlier (VN87-037). One cannot help but suspect a significant fault between the two outcrops (but for which neither aerial photographs of the area nor potential-field data offer any persuasive indication).

14.1.4.4 Anorthosite and Anorthositic Gabbro (M_1an)

The anorthosite unit simply represents the end member of the lithological progression (Plate 14.2D). Two areas have been separately distinguished on the map (near the western extremity of the body, and east of Kyfanan Lake), but anorthositic layers are locally associated with the more melanocratic units elsewhere. The anorthosite is white-, or grey-weathering, medium, coarse or very coarse grained, partially recrystallized and locally moderately to strongly foliated (VN92-118, VN92-120). Fabric is defined by narrow mafic-mineral-rich zones, or aligned amphibole aggregates, within the overall plagioclase-dominant rock.

The anorthosite near the western end of the Kyfanan Lake layered mafic intrusion is known only from three outcrops. As there is a large gap between these outcrops and the mafic rocks farther east, it can be questioned as to whether these anorthositic rocks really belong to the intrusion, or whether they should be grouped with anorthosite of the Upper Paradise River intrusive suite. The linkage adopted here is based on the author's interpretation of aeromagnetic patterns. The rocks are white- to grey-weathering, homogeneous, massive to foliated, completely recrystallized anorthosite to leucogabbro.

One sample examined in thin section (CG92-135) consists of plagioclase, clinopyroxene, amphibole and biotite, apparently in equilibrium, together with minor apatite and an opaque mineral. All the major silicates show granulation at grain boundaries and evidence of deformation within grains is common (*e.g.*, bent twin lamellae). One outcrop is slightly different, having a mottled appearance due to clustering of recrystallized amphibole and plagioclase (replacing former large grains of pyroxene?) within a more leucocratic medium-grained matrix of similar minerals.

Some anorthosite east of Kyfanan Lake could be alternatively termed very leucocratic amphibolite, but an anorthositic protolith can be fairly confidently inferred, despite the mineral assemblage. In these rocks, the amphibole is relict, having been extensively altered – mainly to chlorite, epidote, titanite and an opaque mineral (thin sections VN92-032, VN92-069, VN92-117).

14.1.4.5 Metamorphic Derivatives of the Previous Four Units

Some parts of the Kyfanan Lake body are so modified that it is no longer reasonable even to attempt to map the rocks by protolith. All are amphibolite of one sort or another, including leucocratic and melanocratic variants. The rocks are white-, dark–grey-, black-, orange-grey- or rusty-brown-weathering, homogeneous, recrystallized, weakly to markedly foliated, and fine to medium grained. A fine-grained 10-cm-wide amphibolite that could be a mafic dyke occurs within one coarser grained amphibolite.

The dominant minerals are amphibole and plagioclase, but metamorphic clinopyroxene and an opaque mineral, and a retrograde assemblage of chlorite, epidote, white mica, biotite, allanite, titanite and an opaque mineral are sporadically present (thin sections EA61-052A, CG92-252, HP92-044, JA92-017, JA92-040, VN92-104).

14.1.4.6 Regional Variation in Mineral Assemblages

The Kyfanan Lake layered mafic intrusion shows an interesting pattern of mineral assemblage variation. The following features are pertinent: i) a zone of ultramafic rocks appears to be present on the northwest flank of the body, although some are also present on the southeast side, east of the Upper St. Lewis River (west) granite, ii) all coronitic olivine gabbro, except for one example on the southeast side, are confined to the northwest part of the body, iii) rocks lacking olivine and characterized by orthopyroxene and clinopyroxene, are found southeast of the main zone of coronitic rocks (on the basis of textures in stained slabs, some of these rocks can be termed gabbronorite, whereas others are two-pyroxene granulite), iv) some amphibolite-facies rocks are present; they appear to be distributed mostly, but not exclusively, close to the margins of the body, and v) mafic–anorthositic rocks altered to greenschist-facies assemblages occupy a well-defined circular area in the southeast part of the body.

The most straightforward explanation for most of the mineralogical variations is that the ultramafic rocks – olivine gabbro – gabbronorite distribution is due to primary layering in a mostly southeast-facing body that might also be partially synformal (to account for the ultramafic and coronitic outcrops on the southeast side). This explanation is not entirely satisfactory, however, as many of the non-coronitic orthopyroxene- and clinopyroxene-bearing rocks are, textually, granulite. It would seem, therefore, that there is a metamorphic control as well.

The area of greenschist-facies retrogression is probably independent of the other mineralogical spatial variations. Some rocks found in the area are brecciated and crosscut by veins of granitoid material (VN92-117, 118) and it is possible that a late- to post-Grenvillian pluton lurks not far below. Rocks forming the Upper St. Lewis River (north) pluton are finer grained than is typical of late- to post-Grenvillian plutons, and they may represent the roof of a pluton.

14.1.5 SCATTERED OUTCROPS NORTH OF THE KYFANAN LAKE LAYERED INTRUSION (M_1dr, M_1am, M_1rg)

Scattered outcrops of mafic rock north of the Kyfanan Lake body mapped by Gower *et al.* (1993) show a similar diversity of rock types to those within it, and it is possible that these rocks are tectonically dismembered outliers of that intrusion. The rocks are white-, brown-, buff-, grey-, green-, black- and rusty-weathering, homogeneous, medium to coarse grained and moderately foliated (locally massive or strongly foliated). Rock types include recrystallized metagabbro, leucogabbro, anorthositic gabbro, ultramafic rocks, meladiorite and amphibolite. The rocks lack minor intrusions or enclaves. Mineral assemblages include plagioclase, clinopyroxene, orthopyroxene, serpentinized olivine, amphibole, biotite, an opaque mineral, and rare accessory apatite. The metagabbroic rocks are typically equigranular and show relict ophitic texture. Some of the leucogabbroic to anorthositic rocks exhibit euhedral cumulate laths of plagioclase associated with interstitial pyroxene. The ultramafic rocks contain relict olivine or orthopyroxene, mostly pseudomorphed to amphibole with minor interstitial plagioclase. Some rocks resemble diorite in the field, but are most likely metamorphic derivatives of leucogabbronorite.

The plagioclase is generally polygonal and typically shows some grain boundary granulation. Polygonization of the mafic minerals is also evident locally. Partially retrograded garnet was observed in one amphibolite in outcrop (CG92-001). Samples examined in thin section are HP92-012, HP92-020, HP92-121, JA92-025, JA92-086, JA92-102, VN92-008, VN92-037, VN92-050.

14.1.6 TRIANGLE INTRUSION (M_1an)

A roughly triangular-shaped area on the north side of the Kyfanan Lake body is underlain by anorthosite and leucogabbro (Gower *et al.*, 1993). It could be linked with either the Upper Paradise River intrusive suite or the Kyfanan Lake layered mafic intrusion, but, other than by spatial association, there are no compelling reasons to consider linkage with either. Possibly, it is less deformed and less recrystallized than those potential correlatives, but, as strain varies considerably in the region, such features need not imply that it is necessarily younger.

The rocks are brown-, mauve-, white- or grey-weathering, homogeneous, medium to coarse grained, massive to weakly (locally moderately) foliated, and lightly to moderately recrystallized.

In the six samples examined in thin section (JA92-013, HP92-016, HP92-017, HP92-039, VN92-042, VN92-059), the mafic mineral content varies from about 1 to 20% and consists mostly of hornblende and biotite. Some of the biotite has clearly replaced amphibole. In the field, minor pyroxene was thought to be present in the cores of some mafic silicate mineral clusters, but was not seen in any of the thin sections. Of the felsic minerals, noteworthy features are that the plagioclase is commonly mauve, and rounded blebs of quartz (about 0.5 cm in diameter) occur in the western part of the intrusion. The plagioclase is mostly primary, but grain boundaries in most samples are recrystallized seams of polygonal aggregates. Quartz content is locally up to nearly 10%; hence the field name leuco quartz diorite could apply. Other minerals include opaque minerals (*cf.* ilmenomagnetite), traces of titanite and apatite and secondary chlorite.

14.1.7 ST. LEWIS RIVER GORGE REMNANT INTRUSIONS (M_1um, M_1rg/M_1am)

Lensoid remnants of extensively deformed and metamorphosed ultramafic, gabbroic leucogabbronoritic and 'dioritic' rocks (the latter probably derived from leucogabbronorite) occur as strike-slip-fault- and/or thrust-bound tectonized slivers in the St. Lewis River gorge area, mostly too small to show on Figure 14.1. The author interprets them as the eastward attenuated extension of the Kyfanan Lake layered mafic intrusion. This concept received some support during 2007 field work (data stations CG07-062 to CG07-068) when gabbroic intrusive rocks were found in an intervening area between the eastern end of the Kyfanan Lake body and the tectonized slivers. No outcrop was located in this area during 1:100 000-scale mapping in 1987 and the new exposures are the result of the later extension of a wood-harvesting road.

An ultramafic rock examined petrographically (CG87-267) contains colourless, high-relief clinopyroxene largely pseudomorphed by pale-green amphibole, minor interstitial altered plagioclase, an opaque sulphide (probably pyrrhotite) and interstitial carbonate. A metagabbro in a similar structural position 10 km east-northeast (CG87-308) retains vestiges of a medium- to coarse-grained igneous texture, despite extensive recrystallization. Its mineral assemblage comprises plagioclase, leaf-green hornblende, orange-brown biotite, opaque minerals (both oxide and sulphide), apatite, titanite, and very minor secondary white mica and chlorite.

Other rocks within the St. Lewis River gorge structural melange could also be correlative remnants (*e.g.*, JS87-065, VN87-367) even though they have been assigned an early Labradorian age on 1:100 000-scale geological maps of Gower (2010a).

14.1.8 LONG HARBOUR MAFIC ROCKS (on map as PMrg, PMln, PMam)

North of Long Harbour, underlying an area roughly 5 km long and up to 0.6 km wide, mafic rocks were mapped by Gower *et al.* (1988). Together with a sliver of ultramafic rocks 5 km west of the Long Harbour outcrops (CG87-618), these could be interpreted as being regionally on strike with mafic rocks exposed in the gorge of St. Lewis River, with which they have some textural similarities. Note that these occurrences were given, on the 1:100 000-scale map of Gower (2010a; St. Lewis River map region), the unit designators PMrg, PMln and/or PMam, which remain a valid alternative. Also to be noted on the 1:100 000-scale map is that the polygon for the ultramafic sliver at CG87-618 is labelled as PMum, which is not a unit included in the legend (M_1um would have been better).

Two samples (VN87-497B, VN87-500) were examined in thin section. Both contain relict igneous plagioclase and clinopyroxene. The clinopyroxene is heavily dusted with exsolved opaque inclusions. Amphibole is the main mafic silicate in both rocks, being either a blue-green hornblende or colourless to pale-green tremolite/actinolite. In association with metamorphic quartz, it mantles and replaces clinopyroxene and clearly formed during retrograde metamorphism of the rocks. Both rocks contain garnet, biotite, apatite and opaque minerals (oxide and sulphide). Despite the extensive retrogression, there are hints that olivine, mantled by double coronas, might have once existed in sample VN87-500.

The gabbroic rocks north of Long Harbour are intruded by very fine-grained mafic dykes oriented parallel to the regional strike.

One, exhibiting 20-cm-wide chilled margins, was examined petrographically (VN87-499). Like its host rock, it is thoroughly recrystallized, and is extensively retrograded from its former high-grade metamorphic state. Nevertheless, it still retains vestiges of its igneous diabasic texture and igneous mineral assemblage. Relict igneous plagioclase and clinopyroxene are dusted with opaque oxides and occur in a sea of polygonal metamorphic plagioclase, pale-green amphibole and minor opaque oxide. The author regards the dyke as near contemporaneous with, and genetically related to its host.

14.2 PINWARE–MEALY MOUNTAINS TERRANE BOUNDARY FELSIC ROCKS

14.2.1 UPPER PARADISE RIVER INTRUSIVE SUITE (MONZONITE–GRANITE)

In the previous section, attention was drawn to the potential correlation between the various mafic to anorthositic rocks along the length of the Mealy Mountains–Pinware terrane boundary. In this section the felsic rocks of the Upper Paradise River intrusive suite are addressed, which, equally, are considered here to be part of these intrusive bodies. Note that, although the monzogranitic rocks are all grouped as part of the Upper Paradise River intrusive suite, it is to be kept in mind that some could be affiliated with the Kyfanan Lake layered mafic intrusion (if, indeed, any real distinction exists between the two bodies).

As noted in the previous section, the name Upper Paradise River pluton was previously applied to the northeast section of the presently defined body by van Nostrand (1992) and van Nostrand *et al.* (1992). They subdivided it into four units, namely monzonite, K-feldspar megacrystic monzonite to quartz monzonite, syenite to quartz syenite, and K-feldspar megacrystic syenite to quartz syenite (Figure 14.2). On the basis of further study of the area mapped by van Nostrand (1992) and van Nostrand *et al.* (1992), and integration with information gathered from mapping the continuation of the body to the south and west (Gower *et al.*, 1993; Gower, 1997, 2000), the following revised classification has been adopted: i) monzonite to monzodiorite, ii) quartz monzonite to monzonite, iii) quartz syenite, syenite, minor alkali-feldspar granite, and iv) granite, alkali-feldspar granite, minor quartz monzonite (although each group is gradational into, and may contain the other rock types). Distinction between megacrystic and non-megacrystic textures has been dropped due to difficulties in applying it consistently (but not denying the presence of megacrysts).

14.2.1.1 Monzonite to Monzodiorite (M_1mz)

The monzonite unit weathers buff, honey, orange, pink, grey, creamy, or white. It is characteristically severely weathered and very crumbly, and appears rusty on 'fresh' surfaces. The rocks are remarkably homogeneous, medium to coarse grained, and vary from massive to weakly or moderately foliated (rarely mylonitic). They lack minor granitic intrusions, but some fine-grained monzonite is present locally, possibly forming dykes and/or cognate enclaves. Apart from the fine-grained monzonite, the only significant atypical features are: i) a locally gneissic fabric near the southern margin, implying that the boundary with the adjacent leucogabbronorite may be a zone of ductile deformation, and ii) a suggestion that the monzonite in the northwest part of the unit is more melanocratic.

The monzonite is partly recrystallized, commonly resulting in a fine-grained, recrystallized feldspar matrix enveloping euhedral to ovoid remnants of primary feldspar. K-feldspar forms primary grey or purplish primary grains

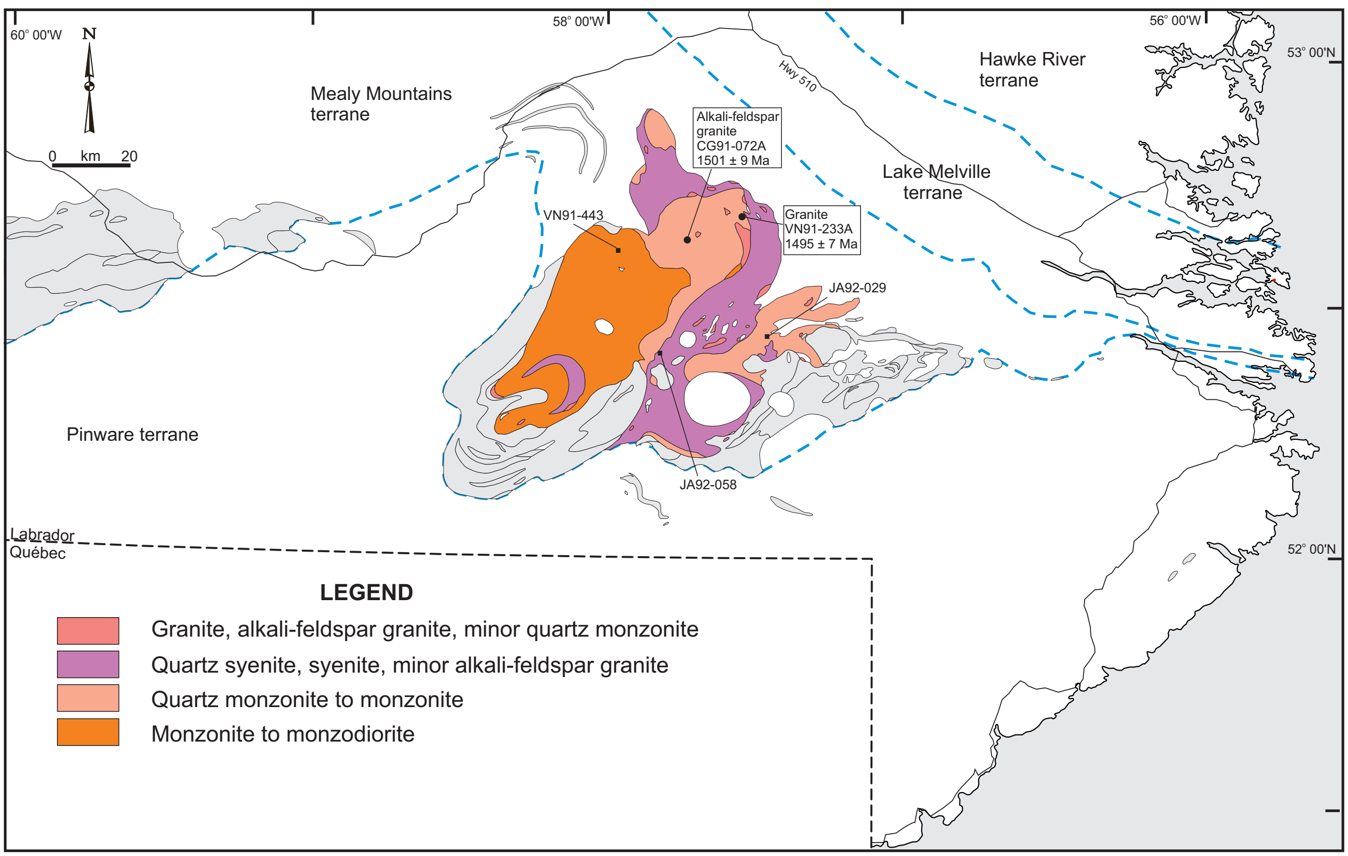


Figure 14.2. *Upper Paradise intrusive suite (monzonite–granite). Potentially related mafic to anorthositic rocks shown in grey.*

mantled by recrystallized aggregates. In the more deformed rocks, plagioclase is ovoid and K-feldspar occurs as elliptical aggregates containing dispersed flecks of plagioclase. Grains of K-feldspar tend to be larger than other minerals, giving the rocks a seriate to megacrystic appearance (Plate 14.3A). Primary plagioclase is much less abundant and is mantled by recrystallized K-feldspar aggregates. Recrystallized sodic plagioclase is common in most rocks. Mantled-feldspar textures are common. The simplest and most common mantling scheme is a subhedral to locally euhedral plagioclase core and a K-feldspar rim (p–k), but a K-feldspar core, surrounded by plagioclase shell and an outer K-feldspar rim is also common (k–p–k), and even more complex patterns are found (p–k–p–k and k–p–k–p–k). In most of the rocks, quartz is minor and interstitial. Mafic minerals occur in granular, interstitial clusters and comprise orthopyroxene, clinopyroxene, amphibole and biotite. The orthopyroxene and clinopyroxene are commonly intergrown, and amphibole typically mantles clinopyroxene cores. The opaque mineral is invariably magnetite.

All samples of monzonite examined in thin section (CG92-036, CG92-042, CG97-197, CG99-012, CG99-016, CG99-032, CG99-037, CG99-054, CG99-058, CG99-088, CG99-104, DE91-028B, DE91-030, DE91-032, VN91-024, VN91-444, VN91-446) are very similar, differing only in mineral proportions of major minerals and the presence/absence of some accessory phases. Plagioclase is anhedral to locally subhedral, poor to well twinned. It typically shows zoning, which is quite marked in some samples. Characteristically, K-feldspar forms bead or stringlet perthite, although is poorly or finely exsolved in some cases. Crystals of both plagioclase and perthite are commonly bounded by polygonal necklaces or mosaics of recrystallized, fine-grained aggregates. Quartz is an accessory mineral, partly interstitial or forming clusters of recrystallized or fractured grains. Both clinopyroxene and orthopyroxene are ubiquitously present and typically occur as fresh to altered, ragged, anhedral crystals or clusters of grains. Pigeonitic exsolution textures are common in CG99-012 and CG99-037. Clinopyroxene is pale-green and has high relief, suggesting it to be Fe-rich. Alteration of clinopyroxene to dark-green amphibole (*i.e.*, probably Fe-rich) containing vermiform quartz inclusions is seen locally. Orthopyroxene is also partially altered, mostly to orange-brown biotite plus quartz, but locally to bastite. Amphibole also occurs as rims mantling an opaque mineral. From field tests, the opaque mineral is identified as magnetite, but minor secondary hematite and rare sulphide are seen sporadically. Other minerals include apatite (common and fairly large), zircon (usually common, large and locally with rims – but not seen in CG99-088 or CG99-104), allanite (small, orange-brown, metamict grains) and, in CG99-058, titanite (mantling an opaque oxide).

Samples DE91-028A, DE91-030, DE91-032 are rather more variable than is typical for Upper Paradise River mon-

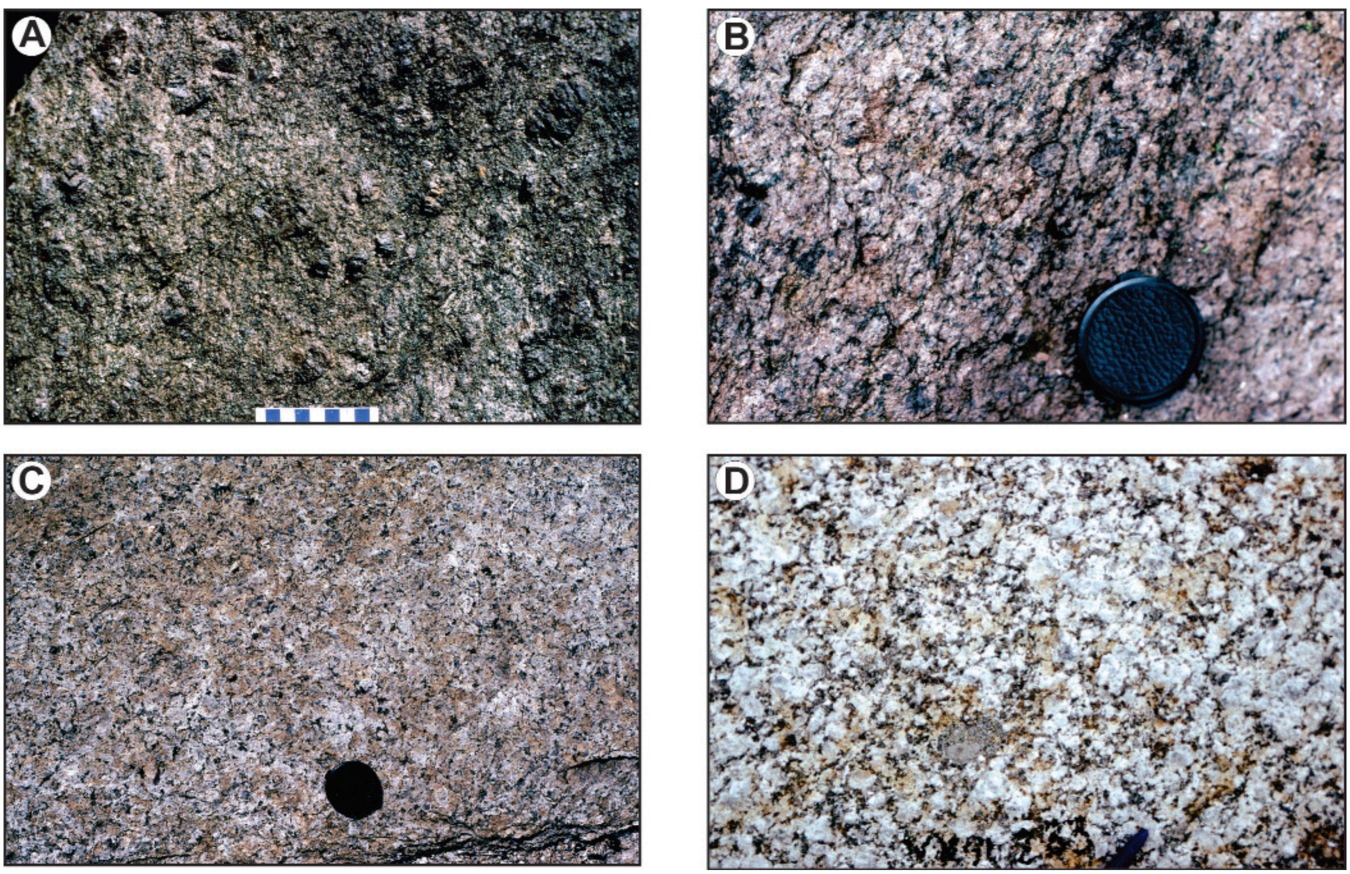


Plate 14.3. *Upper Paradise River intrusive suite (monzonite-granite). A. Monzonite containing K-feldspar megacrysts (VN91-443), B. Quartz monzonite to monzonite (JA92-029), C. Syenite (JA92-058), D. Granite dated to be 1495 ± 7 Ma (VN91-233).*

zonite. They come from an area mapped as a tongue of monzonite interfingering with early Labradorian granitoid rocks, especially K-feldspar megacrystic granodiorite. It is possible that these rocks have been incorrectly assigned and are Labradorian.

Three additional thin sections are CG97-191B, CG99-044 and CG99-101. Sample CG97-191B is from a grey-weathering, fine to medium grained, rather lensy-textured, foliated rock within coarse-grained monzonite. It contains patches and spindles of K-feldspar- and quartz-rich material in a granulitic matrix of orthopyroxene, clinopyroxene, plagioclase, hornblende, biotite, with accessory apatite and zircon. Clinopyroxene is clearly a reactant in a retrogressive reaction producing ragged, green amphibole, deep orange-brown biotite, quartz and an opaque oxide. The rock is interpreted to be an enclave of retrogressed mafic to intermediate granulite containing melt segregations, but field relationships to monzonite at the same outcrop were not seen.

Thin sections CG99-044 and CG99-101 demonstrate that the boundary between the mafic–anorthositic and monzogranitic units is not abrupt as map patterns suggest, thus providing an indication that the two rock groups are related. Sample CG99-044 is a leucogabbronorite within the main area of monzonite, whereas CG99-101 is a monzonite within a larger body of leucogabbronorite. Both rocks have similar mineral assemblages (plagioclase, perthite, quartz, pale-green clinopyroxene, partially altered orthopyroxene, secondary amphibole (in CG99-044) and biotite, and accessory opaque minerals and apatite), but mineral proportions and textures are dissimilar.

14.2.1.2 Quartz Monzonite to Monzonite (M_1mq)

Quartz monzonite occurs in two main areas, namely: i) northeast of the previously described monzonite, and ii) farther east, on the north side of the Kyfanan Lake layered mafic intrusion. With respect to the quartz monzonite northeast of the monzonite, the boundaries shown on the map differ considerably from those depicted by van Nostrand (1992). This is partly the result of no longer attempting to discriminate between megacrystic and non-megacrystic textures, but also due to reassessment of rock types present based on further examination of thin sections and stained slabs. In truth, given the gradational nature of the lithological boundaries and poor exposure, it is likely that neither depiction is correct. Nevertheless, a key point is that both representations imply that the rocks become progressively more felsic in a northeast direction. Quartz monzonite on the north side of the Kyfanan Lake layered mafic intrusion is more texturally diverse, and its assignation as part of the Upper Paradise River intrusive suite may mean some unrelated rocks have been included. Smaller areas of quartz monzonite are also found elsewhere in the intrusion, most commonly associated with the syenitic rocks.

The two dates available for the Upper Paradise River intrusive suite are both from the quartz monzonite unit, although one sample (CG91-072A) is alkali-feldspar granite and the other (VN91-233A) is granite (the unit *vs.* sample–name inconsistency is an illustration of the variability of the granitoid rocks in the suite and generalizations made during map compilation). Sample CG91-072A yielded a near-concordant age of 1501 ± 9 Ma based on two single zircon grains and a small multigrain fraction. Sample VN91-233A gave a very slightly discordant age of 1495 ± 7 Ma based on five zircon fractions. Both regressions were anchored by a 960 ± 34 Ma lower intercept.

Field characteristics of the quartz monzonite (colour, grain size, fabric, associated minor rock types) are much the same as for the monzonite, except for having higher quartz and K-feldspar content and less, or absence of, orthopyroxene (Plate 14.3B). K-feldspar megacrysts were described by van Nostrand (1992) as euhedral to subhedral, comprising 10 to 50% of the total rock, and ranging from 1 to 4 cm in length. They vary from relatively fresh and unrecrystallized, but typically display very thin (0.5 to 1 mm-wide) recrystallized rims. Locally, a weakly developed fabric is defined by preferred alignment of K-feldspar megacrysts. In rare cases, mafic phases are also aligned. Clinopyroxene is commonly present, but orthopyroxene less so, except close to the previously described monzonite unit.

Thin sections available are as follows:
i) Northeast of monzonite: CG91-072A, CG91-077, EA61-045, HP92-62, JA92-054, VN91-240, VN91-353C, VN92-124, VN91-233A, VN91-233C, VN91-408,
ii) North of Kyfanan Lake: CG92-101, HP92-023, JA92-023A, VN91-166, VN92-038, VN92-084, VN92-095, VN92-097, VN91-380,
iii) Within syenite: CG92-008, JA92-089B, JA92-095, and
iv) South of syenite, north side of Kyfanan Lake body: HP92-81.

14.2.1.3 Quartz Syenite, Syenite, Minor Alkali-feldspar Granite (M_1yq)

Although individual exposures of syenitic rock are generally homogeneous, a wide range of textural types exists between outcrops. Compositions grade from monzonite, through syenite, to quartz syenite, but minor granite and alkali-feldspar granite may also be present. Some of the syenitic rocks are similar to monzonite and quartz monzonite, but are more leucocratic (having less than 2% mafic and opaque minerals) and very potassic (being completely devoid of plagioclase, and lacking, or having only minor quartz). Commonly, a particular textural variety is found in only one or two outcrops, hence providing inadequate information to map out specific units. The syenitic rocks adjacent to the monzonite are similar to it, suggesting a gradational and genetic link between the two units. Syenite is depicted as forming a crescent-shaped area within monzonite in the southwest part of the Upper Paradise River intrusive suite. The form is conjectural, but derives support from an arcuate foliation trend, the area's magnetic signature, and reciprocation of the arcuate shape at the monzonite and mafic–

anorthositic unit boundary. The pattern is interpreted to mean that the core of the body has been folded into a northeast-plunging complex synform.

The rocks are white-, pink-, pale–pink-, orange-, buff-, or rusty-brown-weathering, fine to coarse grained, and moderately to strongly foliated (locally mylonitic, Plate 14.3C). Many were originally coarse grained, but crystals have now been recrystallized to fine-grained aggregates. Relict large K-feldspar crystals give some of the rocks a pseudomegacrystic appearance, but it is possible that some of the rocks were also originally megacrystic, as described by van Nostrand (1992). Mantled feldspars are present locally (*e.g.*, sample HP92-074; k–p–k pattern). Trains of fine-grained aggregates of contrasting composition define the foliation. The rocks are almost totally devoid of minor granitoid intrusions or mafic enclaves, except for very rare biotite-rich patches. One exception is a mafic enclave at data station CG99-040.

Kernels of relict primary K-feldspar (stringlet and bead perthite) are surrounded by fine-grained, recrystallized feldspar aggregates. In stained slabs, the outlines of recrystallized former large K-feldspar grains can be identified by seams of green-black mafic mineral aggregates in quartz-poor syenite, and by sugary, white, fine-grained mosaics of quartz and sodic feldspar in quartz-rich syenite. With increasing recrystallization and reduction in proportion of quartz and mafic minerals, there is a progression to rocks that consist of little more than a mosaic of fine-grained recrystallized K-feldspar, in some cases with opaque grains. A distinctive texture is developed especially in the very K-feldspar-rich rocks that resembles miniature crazy paving (*cf.* Section 13.3.2 for explanation). Large primary grains of plagioclase, or recrystallized aggregates outlining former grains of plagioclase, occur sporadically, but are rare. Quartz occurs locally as phenocrysts up to 2 cm long and 0.5 cm wide. A very minor, but distinctive, rock type is characterized by a quartz 'eye' fabric (van Nostrand, 1992). Mafic minerals form interstitial, recrystallized clusters and include pale- to mid-green clinopyroxene; high-relief, moderately pleochroic orthopyroxene; dark-green amphibole; and orange-brown biotite.

In many thin sections, the rthopyroxene is relict, having been partially replaced by amphibole, biotite and an opaque mineral. A sporadic brown mineral that stains to bright orange-brown in slabs may be bastite and/or oxidized biotite. Accessory minerals include an opaque mineral, apatite and zircon (very common and locally with cores), but lack of titanite and allanite. Allanite and titanite are only present (albeit sparsely) in a northeast-trending zone in the north-central part of the Upper Paradise River intrusive suite. Garnet, elsewhere lacking, is also sparsely present. Garnet appears to have formed according to the reaction (*e.g.*, thin section JA92-052):

Plagioclase + Pyroxene = Garnet + Amphibole + Quartz + Opaque mineral

Thin sections examined are CG91-026, CG91-031, CG91-058, CG91-067A, CG92-56, CG92-124, CG92-177, CG99-053, DE91-105, DE91-158, HP92-060, HP92-072, HP92-074, HP92-107B, HP92-109, HP92-111B, HP92-113, HP92-125A, JA92-011, JA92-052, JA92-101, JA92-107, VN91-204, VN91-205, VN91-207, VN91-242C and VN92-132.

14.2.1.4 Granite, Alkali-feldspar Granite, Minor Quartz Monzonite (M_1gr)

A few small areas of granite and alkali-feldspar granite are shown scattered throughout the Upper Paradise River intrusive suite, intermixed with monzonite and syenite. Apart from higher quartz content, the rocks differ little in composition from their quartz syenite neighbours, and need only be regarded as slightly more fractionated variants.The mineral assemblage of these is simple, comprising stringlet perthite (locally partially inverted to microcline), quartz, an opaque mineral, zircon and traces of biotite, apatite, amphibole and plagioclase. The colour index of all samples is very low, certainly less than 2 (Plate 14.3D).

All samples examined in thin section show evidence of extensive grain size reduction through recrystallization. The effects of recrystallization vary from being confined to grain boundaries to almost completely pervasive throughout the rock, except for residual islands of larger perthite grains. Plagioclase is ragged, moderately twinned and zoned, and antiperthitic locally. K-feldspar is untwinned and poorly exsolved, having most exsolution restricted to small beads in grain cores. Quartz forms anhedral, sutured aggregates. Although recrystallization is most obvious in quartz, it is also evident in feldspar, especially in the form of seams of recrystallized granules at grain boundaries. Dark-orange-brown biotite is the sole mafic silicate. Accessory minerals are an opaque oxide, minor sulphide, apatite and zircon (thin sections CG92-002, CG92-012, CG92-059, CG99-090, DD91-090, HP92-100, HP92-120, HP92-135).

14.2.2 PINWARE–MEALY MOUNTAINS TERRANE BORDER MAFIC–FELSIC WHOLE-ROCK CHEMISTRY

The Pinware–Mealy Mountains terrane border mafic and felsic rocks are not well represented by whole-rock geochemical data. Only 29 analyses are available, 11 from the Upper Paradise River intrusive suite (8 of which are monzogranitic rocks), 7 from the Kyfanan Lake layered mafic intrusion, 5 from the No-Name Lake mafic intrusion, and 6 from other bodies. A wide range of rock types and individual intrusions are represented, so it is not surprising that the data are rather scattered. Nevertheless, a few comments are pertinent. Overall, the rocks are alkalic to alkali-calcic and have indications of an arc-related signature. That they form a geochemically coherent group is suggested by similar-sloping REE patterns (LREE 50–250 times chondrite; HREE 20–30 times chondrite). The single exception is CG07-058, which has a slightly steeper pattern. This sample is also enriched in F, P_2O_5, and TiO_2 relative to the other samples. Given that is comes from a possibly isolated body (east of the Kyfanan Lake layered mafic intrusion), it may well be unrelated.

Features of individual bodies noted are as follows: i) the No-Name Lake mafic intrusion whole-rock samples are enriched in Cu – which is consistent with indications of Cu mineralization seen within the intrusion, and ii) the Kyfanan Lake layered mafic intrusion is enriched in Ni, Cr and (locally) Cu in samples collected northwest of Kyfanan Lake (in the same area as lake-sediment anomalies in Ni, Co and V). Both mafic bodies have received some attention from explorationists, but, in the author's opinion, neither has been thoroughly investigated and both deserve more detailed exploration.

14.3 PINWARIAN ACTIVITY ELSEWHERE IN EASTERN LABRADOR

Pinwarian activity addressed here refers to that north of the Pinware–Mealy Mountains terrane border region in eastern Labrador (Figure 14.3). All evidence comes from U–Pb geochronological data, which can be divided into: i) minor granitoid intrusions, ii) metamorphic overprinting, and iii) two results for which a Pinwarian age has been challenged. The key conclusion to be taken from the dating detailed below is that, although ubiquitous, in contrast to areas farther south, Pinwarian magmatism in this region was very minor and Pinwarian metamorphism was moderate.

14.3.1 MINOR GRANITOID INTRUSIONS

Evidence of Pinwarian magmatic activity in the northern part of the Grenville Province in eastern Labrador is based on dates from two minor granitoid intrusions. The first date comes from a pegmatite on Double Island, north of Cartwright (Plate 10.2A). The pegmatite is 2 m wide, pink-weathering, coarse grained, and contains biotite and garnet. From three zircon fractions, an age of 1499 +8/–7 Ma was obtained. The pegmatite discordantly intrudes quartz dioritic to granodioritic gneiss dated to be 1658 ± 5 and 1654 ± 5 Ma, and is, itself, discordantly intruded by Michael gabbro (Chapter 15) dated to be 1426 ± 6 Ma (Schärer *et al.*, 1986; all dates from the same locality; CG84-172). The second date is from a 20-m-wide pink, fine- to medium-grained, equigranular leucogranite near Rigolet, termed Wolfrey granite by Corrigan *et al.* (2000; sample 2). On the basis of four multigrain zircon-fraction analyses and one single zircon-tip analysis, Corrigan *et al.* determined an age of 1474 +10/–7 Ma (one off-discordia analysis excluded). As pointed out by Gower and Krogh (2002), a worrisome feature of the regression is an apparent lack of Grenvillian Pb-loss (lower intercept is 353 +130/–126 Ma) in an area where other geochronological data indicate that such effects are severe.

14.3.2 METAMORPHIC OVERPRINTING

Pinwarian metamorphic overprinting probably affected all parts of the Grenville Province in eastern Labrador. The northernmost indication, albeit rather tenuous, is from near the Grenville front, at Mundy Island, in the Smokey archipelago. At this locality (CG92-065), a pegmatite discordantly intrudes buff-grey aplite, which has been dated as having an emplacement age of 1647 +7/–5 Ma (Kamo *et al.*, 1996), but is itself strongly deformed and boudinaged. Based on two titanite analyses, upper and lower intercepts of 1500 ± 270 and 1030 ± 10 Ma were obtained. The large upper intercept error would seem to preclude meaningful interpretation as Pinwarian, but, in its support, Owen *et al.* (1988) obtained an Ar–Ar total-gas biotite date of 1507 ± 2 Ma from a granitoid rock 15 km to the north.

More conclusively Pinwarian are two results from the southeastern part of the Hawke River terrane. One is from an amphibolite at Shoal Bay (CG85-654), where two near-concordant titanite analyses indicate a date of *ca.* 1490 Ma (Kamo *et al.*, 1996). The other is from the border of a Labradorian mafic volcanic rock (CG86-528), from which a concordant titanite gave an age of 1474 ± 41 Ma.

Three remaining metamorphic overprinting results are from the Mealy Mountains terrane. Two are from a single outcrop. Data from a pre-Labradorian quartzofeldspathic gneiss (CG95-341A) included a 1% discordant monazite $^{207}Pb/^{206}Pb$ age of 1469 ± 3 Ma, and pegmatitic infill (CG95-341D) between boudinaged segments of an amphibolite dyke intruding the quartzofeldspathic gneiss gave an age of 1496 ± 10 Ma based on two zircon tips (Gower *et al.*, 2008b). The third result is from a granulite-facies meta-leuconorite (CG97-080), which gave a Labradorian age for high-grade metamorphism (1662 ± 19 Ma) based on three single zircons, and an imprecise lower intercept of 1500 ± 340 Ma dating a subsequent thermal event (Gower *et al.*, 2008b).

14.3.3 RESULTS CHALLENGED

Two other, nominally Pinwarian, dates have been reported, both of which have been challenged. The first is the Rigolet quartz diorite, for which Corrigan *et al.* (2000; sample 1 / RIG95-025) reported a date of 1489 +2/–8 Ma. Gower and Krogh (2002) noted that the result is based on one concordant fraction that anchored the lower intercept of a poorly correlated line that included two of the other four fractions. The line projects to an upper intercept of 2653 ±

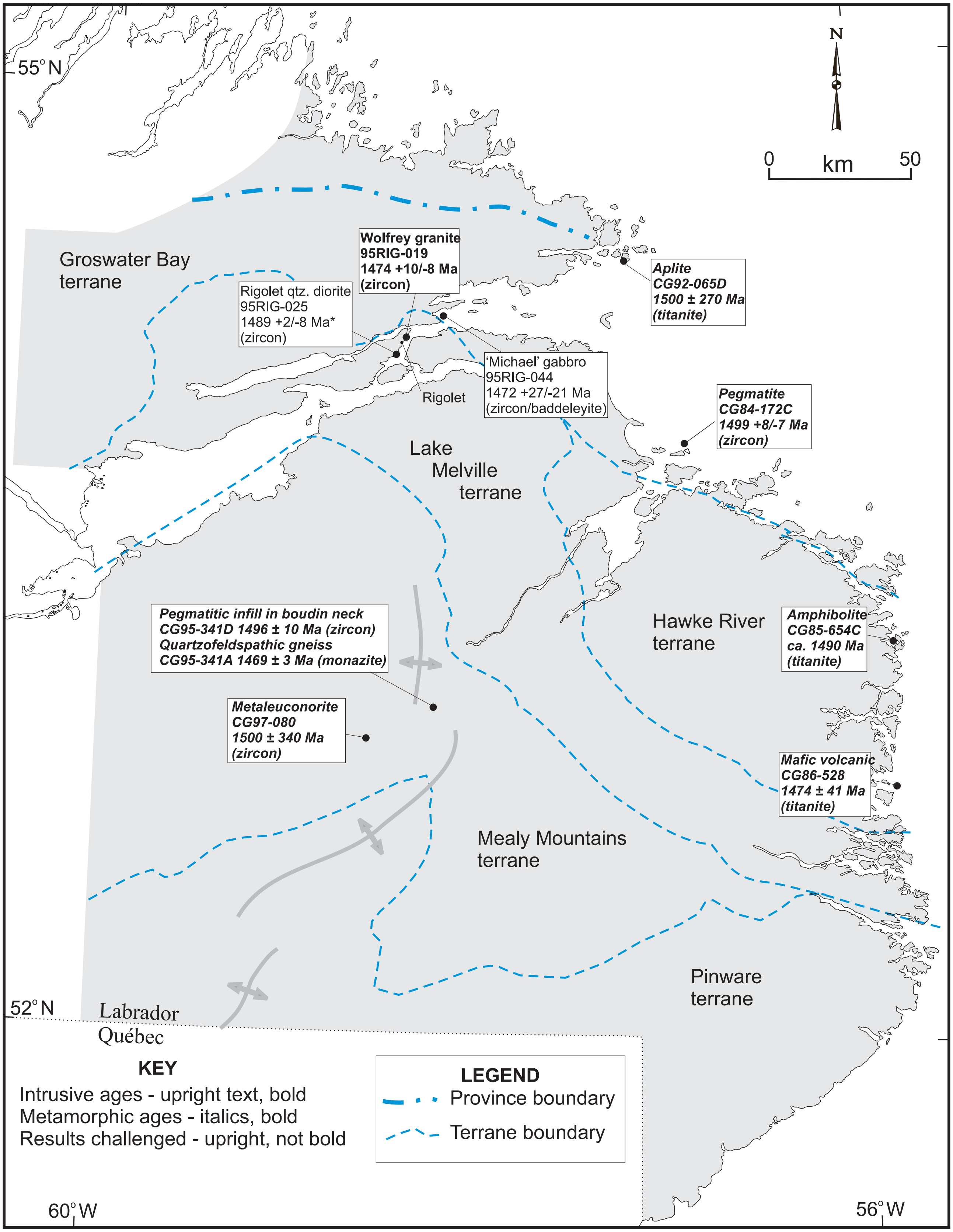


Figure 14.3. *Pinwarian activity north of Pinware terrane identified by U–Pb geochronological data.*

37 Ma, which is unique in intrusive rocks in the eastern Grenville Province. An alternative explanation was suggested by Gower and Krogh (*op. cit.*), involving pre-Labradorian inheritance, Labradorian emplacement, and/or Labradorian, Pinwarian and Grenvillian Pb loss. The Rigolet quartz diorite is morphologically similar to the 1670 Ma Earl Island quartz diorite farther southeast.

The second result is for a gabbro, also near Rigolet. For this sample, Corrigan *et al.* (2000, sample 3 / RIG95-044) reported a date of 1472 +27/–21 Ma and correlated the rock with the Michael gabbro. The result was questioned by Gower and Krogh (2002), details regarding which are given in the next chapter.