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Field evidence for commingling between ca. 1830 Ma lamprophyric, monzonitic, and monzogranitic magmas, MacQuoid–Gibson lakes area, Nunavut[1]

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Abstract: Although it has been recognized that ca. 1830 Ma, mantle-derived ultrapotassic and mildly alkaline, granitic crustal melts are broadly coeval in the northwest Hearne domain of the western Churchill Province, details of their petrogenetic relationships remain enigmatic. Field observations from a number of localities demonstrate that a range of magmatic compositions coexisted at that time ranging from spessartite lamprophyre and/or phlogopite clinopyroxenite through hornblende+phlogopite gabbro, diorite, and quartz monzonite to biotite granodiorite and biotite+magnetite± fluorite monzogranite. Mutual crosscutting relationships between many of the rock types, typified by irregularly shaped intrusive bodies having diffuse contacts and, scalloped enclaves of lamprophyre and monzonite in monzogranite imply diverse magma commingling, and that the potassic, mantle-derived melts possibly initiated the widespread, ca. 1830 Ma granite bloom in the region.

Résumé : Même si on a reconnu que les bains magmatiques crustaux granitiques, ultrapotassiques et faiblement alcalins d'origine mantellique qui datent d'environ 1 830 Ma sont en gros contemporains dans le nord-ouest du domaine de Hearne, dans la Province de Churchill occidental, les particularités de leurs liens pétrogénétiques demeurent obscures. Des observations sur le terrain à un certain nombre de sites révèlent qu'à l'époque en question, il existait toute une gamme de magmas de compositions différentes, depuis les lamprophyres à spessartine et/ou les clinopyroxénites à phlogopite en passant par les gabbros à hornblende et phlogopite, les diorites et les monzonites quartziques et jusqu'aux granodiorites à biotite et les monzogranites à biotite, magnétite et ± fluorine. Les relations de recoupement entre bon nombre des types lithologiques, caractérisées par des corps intrusifs de forme irrégulière aux contacts diffus et des enclaves festonnées de lamprophyre et de monzonite dans du monzogranite, indiquent qu'il y a eu un mélange de divers magmas et que les bains magmatiques potassiques mantelliques pourraient être à l'origine des nombreux massifs granitiques d'environ 1 830 Ma dans la région.

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[1] Contribution to the Western Churchill NATMAP Project

INTRODUCTION

Magma commingling and mixing, old concepts (see review by Wilcox (1999)) relating the formation of compositionally diverse magmas through physical and chemical interaction, respectively, has more recently been advocated as a major petrogenetic process in both volcanic (Anderson, 1976; Bacon, 1986) and plutonic terrains (Whalen and Currie, 1984; Frost and Mahood, 1987; Babarin, 1988). The role of magma mixing in the evolution of bimodal, granite-potassic mafic rock suites, however, has received relatively minor exposure in the geological literature (Stimac et al., 1995; Carlier et al., 1997).

It has long been recognized that the Archean components of the western Churchill Province are intruded by a diverse assemblage of Proterozoic intrusive rocks, the largest proportion of these comprising a widespread, ca. 1830 Ma 'granite bloom'. In the north-central western Churchill Province (inset Fig. 1), a northeast-trending belt of generally undeformed, orange-pink, biotite+magnetite±fluorite-bearing monzogranite intrusions crosscut much of the structural grain in the region. On this basis, these were originally interpreted as being Hudsonian (Proterozoic)(e.g. Wright, 1967; Eade, 1970; Tella, 1993; A. LeCheminant, pers. comm., 1999) and were therein commonly grouped with what are now known to be slightly younger (ca. 1750 Ma) potassium feldspar megacrystic rapakivi-textured granitic rocks comprising the Nueltin Suite (Peterson and Lee, 1994). Subsequent conventional U-Pb geochronological investigations (Tella, 1993; Tella and Schau, 1994; W.J. Davis, unpub. data, 1999) on zircon and titanite have demonstrated that four of the plutons in the MacQuoid–Gibson lakes and Chesterfield Inlet areas range in age from 1820 to 1830 Ma. Recent SHRIMP U-Pb data from Peterson and van Breemen (1999) overlapped (within error) with these results and provides new data for two additional plutons from the map area.

The apparently coeval Baker Lake Group, representing part of the largest alkaline province on Earth, outcrops to the west of the map area, and is characterized by a basal sequence of channel fill and fault-associated redbed sedimentary rocks, and finer grained playa and aeolian deposits (Blake, 1980; LeCheminant et al., 1987; Rainbird et al., 1999). They pass upwards into voluminous pyroclastic flows and lavas of the ultrapotassic Christopher Island Formation, consisting of thick sequences of tuffs, agglomerates, epiclastic tuffs, and lavas, all of which contain phenocrystic phlogopite and have minette-like compositions. Thinner units of mudstone associated with the lower, and possibly more distal parts of the Christopher Island Formation also have minette-like compositions (Cousens, 1999). Associated with the Christopher Island Formation is a suite of tan-brown minette dykes (Digel, 1986; Peterson et al., 1994; Beaudoin, 1998) that crosscut all Archean and many Proterozoic rocks of the central and northern Hearne domain of the western Churchill Province. The age of these ultrapotassic rocks is presently poorly constrained. A U-Pb zircon age of 1850+30/-20 Ma was determined for a quartz syenite associated with minette dykes exposed near Amer lake, comparable to a K-Ar age on hornblende of 1833 ± 32 Ma from the same intrusion (Tella et al., 1985). Similarly, a ^{40}Ar-^{39}Ar analysis on hornblende from a Martell syenite, the presumed intrusive equivalent of the Christopher Island Formation, yielded an age of 1825 ± 12 Ma (Roddick and Miller, 1994). The diamondiferous Akluliak minette dyke (MacRae et al., 1996) yielded a U-Pb monazite+apatite age of 1832 ± 28 Ma. Not only are each of these ages imprecise, but overall they imply at least a 25 Ma time interval for much of the ultrapotassic magmatism associated with development of the Baker Lake Group.

This report presents the preliminary results of follow-up field studies on a number of the ca. 1830 Ma plutons, a study prompted by recognition during the 1998 field season of possible lamprophyre-monzogranite commingling textures in the MacQuoid–Gibson lakes area.

FIELD OBSERVATIONS

Although many of the features and rock types described below were observed in the majority of the ca. 1830 Ma plutons investigated during the 1998 and 1999 field seasons, herein we discuss four of the more noteworthy localities. These are all characterized by a diverse assemblage of weakly foliated to undeformed intrusive rock types of inferred Proterozoic age that, on a broad-scale, exhibit a progressive change in composition from mafic to felsic with age of the rocks. The rocks under investigation are everywhere observed to crosscut more intensely deformed granitoid and gneissic rocks of presumed Archean age. Nomenclature is based on simple field names for the majority of the rocks (i.e. phlogopite gabbro or phlogopite clinopyroxenite) but more precise names such as biotite+magnetite+fluorite monzogranite or spessartite lamprophyre have been confirmed through petrographic and qualitative electron microprobe studies. Lamprophyre nomenclature follows that of Rock (1984). For reference, spessartite is a calc-alkaline lamprophyre containing hornblende>phlogopite phenocrysts, and plagioclase>potassium feldspar in the matrix.

"Squiggly lake"

In the central western parts of the 1998 map area (Hanmer et al., 1999; Fig. 1), an approximately 20 km^2 body of predominantly biotite monzogranite crosscuts gneissose tonalite and diorite of the Cross Bay intrusive complex. This pluton was recognized to 'stitch' the western segment of the Big lake shear zone (Hanmer et al., 1999) and was observed to contain features suggestive of magma commingling. Therefore, examination of its relationships with the country rocks, in particular along its western margin, was undertaken in greater detail in 1999 (Fig. 2). The parts of the pluton lying west of the long northwest-trending lake, informally named "Squiggly lake", comprise a complex series of small (≤ 100 m^2) irregular intrusive bodies consisting of hornblende+phlogopite gabbro (Fig. 3a) to biotite monzogranite (Fig. 3b) exhibiting complex, irregular contacts with each other and their host rocks. The country rock contacts are everywhere typified by moderate hematitization of the wall rocks and the intrusive units, thereby obscuring many of the complex petrological

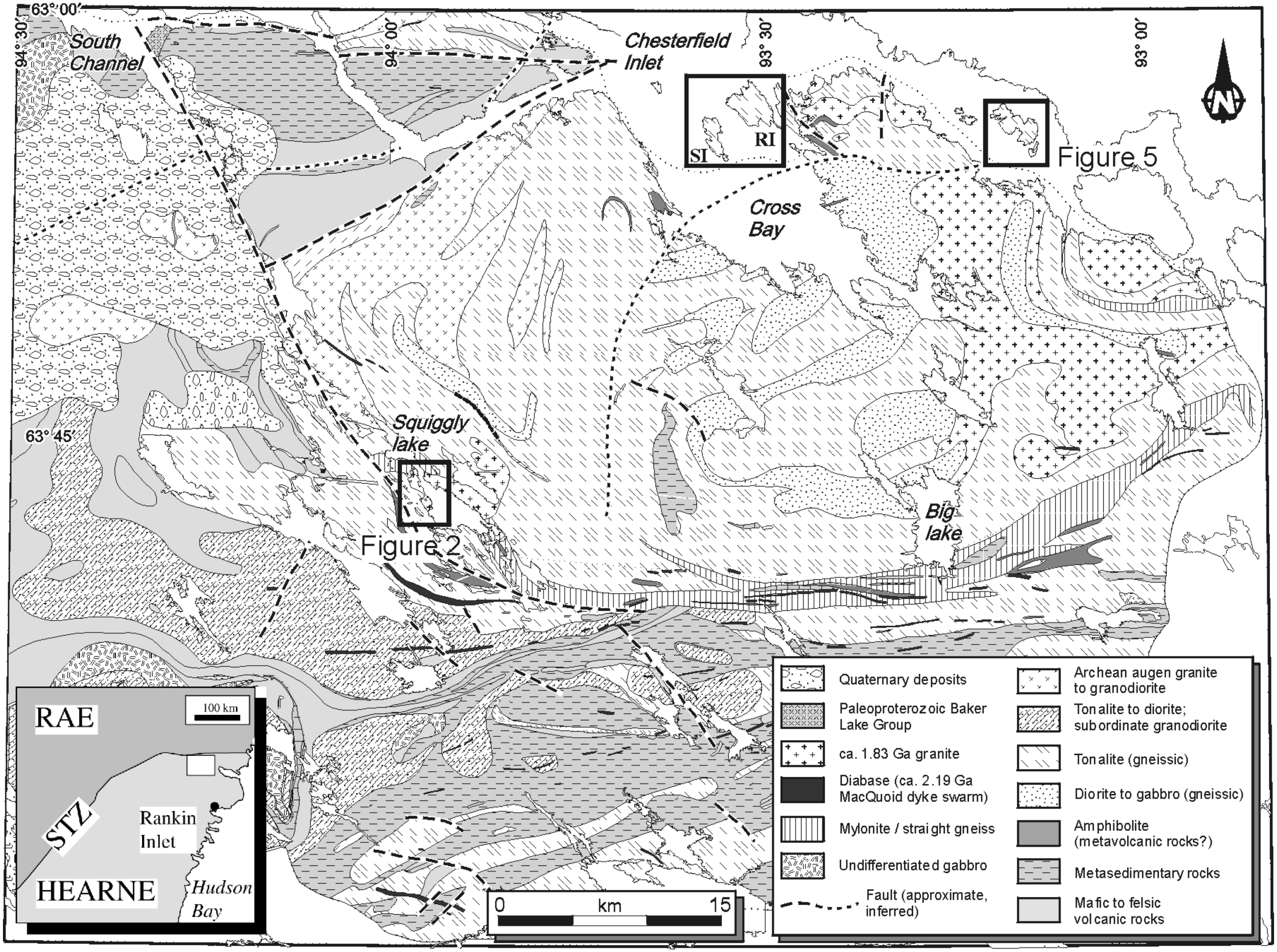


Figure 1. *Simplified geological map of the MacQuoid–Gibson lakes area indicating the location of the subsequent figures and localities described in the text; SI=Strivewell Island, RI=Round Island, STZ= Snowbird Tectonic Zone.*

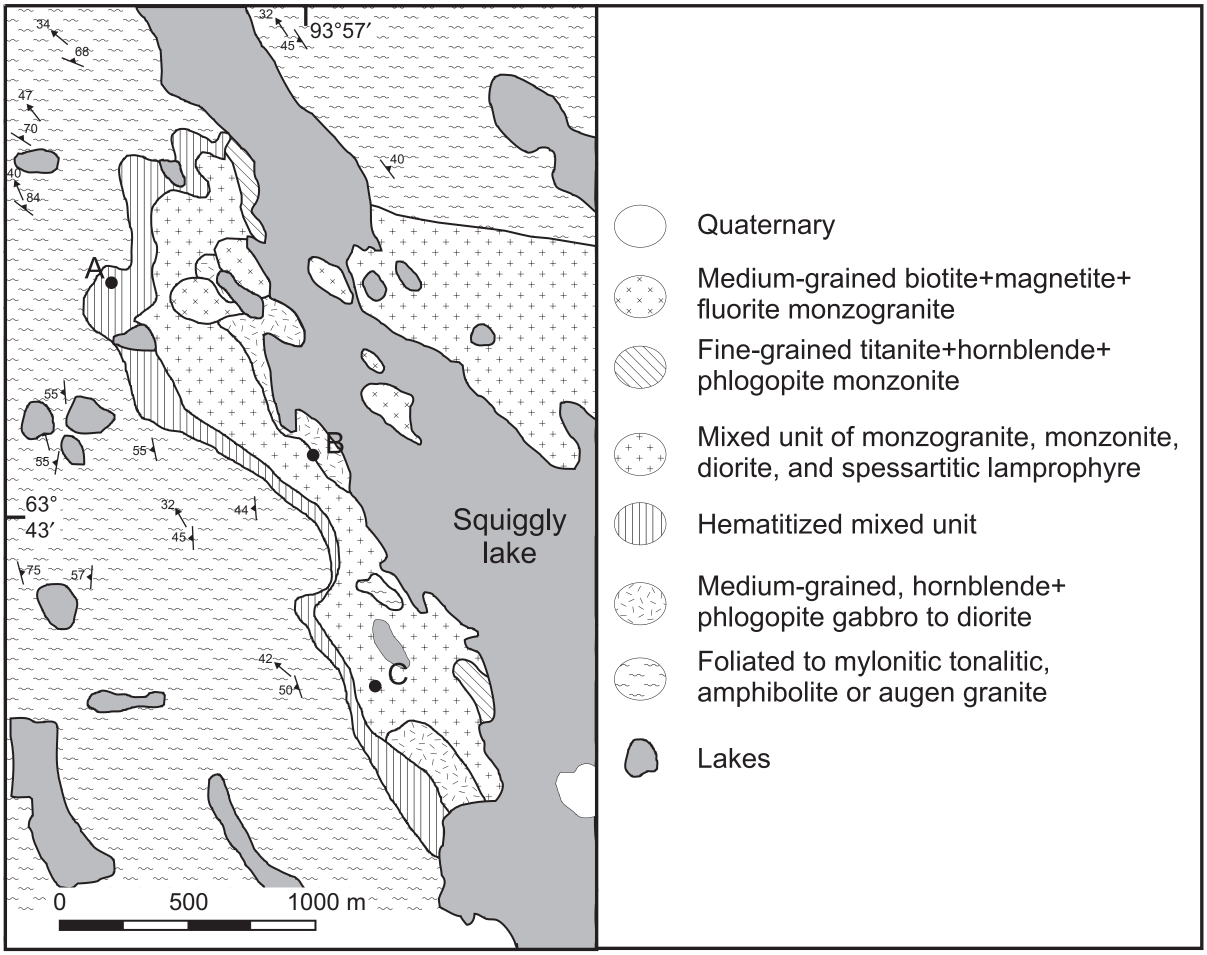


Figure 2. *Geological sketch map of the area in and around the western margin of "Squiggly lake".*

relationships. In Figure 2, large outcrops consisting of one distinct rock type are shown, whereas a majority of the exposures, comprising complex, irregular intrusive bodies and numerous examples of commingled magmatic assemblages are combined as a 'mixed' single map unit.

Along the northwestern margin of the pluton, fine- to medium-grained monzonitic rocks, typified by hematitization and locally epidotization, are locally intruded by irregular dykes of biotite monzogranite. One of these dykes of monzogranite (99TXJ215: location A, Fig. 2) has been dated by U-Pb TIMS analysis of zircon, yielding an age of ca.1830 Ma (W.J. Davis, pers. comm., 1999). The monzonite bodies at this locality commonly contain angular inclusions of a green, dense, amphibole-rich rock interpreted as having originally been clinopyroxenite (Fig. 3c) and remarkably similar to the phlogopite clinopyroxenite units described below. These monzonite units also contain abundant polycrystalline grains of quartz that have notable hornblende± phlogopite coronas, a texture characteristic of either magma commingling or accidental inclusion of country rock in a silica-undersaturated magma.

Near the lake shore to the south, an irregular body of medium-grained hornblende+phlogopite gabbro has poorly defined, diffuse contacts with the adjacent composite unit (locality B, Fig. 2). Locally, the grain size of the gabbro body decreases and grades into diorite then monzonite and or granodiorite. These last two can be observed to intrude a finer grained variety of the gabbro and contain rounded, lobate enclaves of hornblende glomerophyric gabbroic material that resemble spessartite lamprophyre that is commonly observed as dykes throughout the region (Fig. 3d). The gabbro also locally includes rounded enclaves and blebs of the granodiorite. These features imply that the two distinct magmas coexisted and intruded one another.

Locality C (Fig. 2) provides the most spectacular outcrop of commingling features wherein biotite+magnetite+fluorite monzogranite is crosscut by an irregular dyke of spessartite lamprophyre (Fig. 3e). The monzogranite in the area contains dispersed lobate and rounded enclaves of spessartite that increase in abundance near the dyke (Fig. 3f). These locally vary significantly in colour index implying that a wide range of bulk compositions is represented. The monzogranite is also characterized by a 'spotted texture' (hornblende+ phlogopite glomerocrysts) resulting from numerous

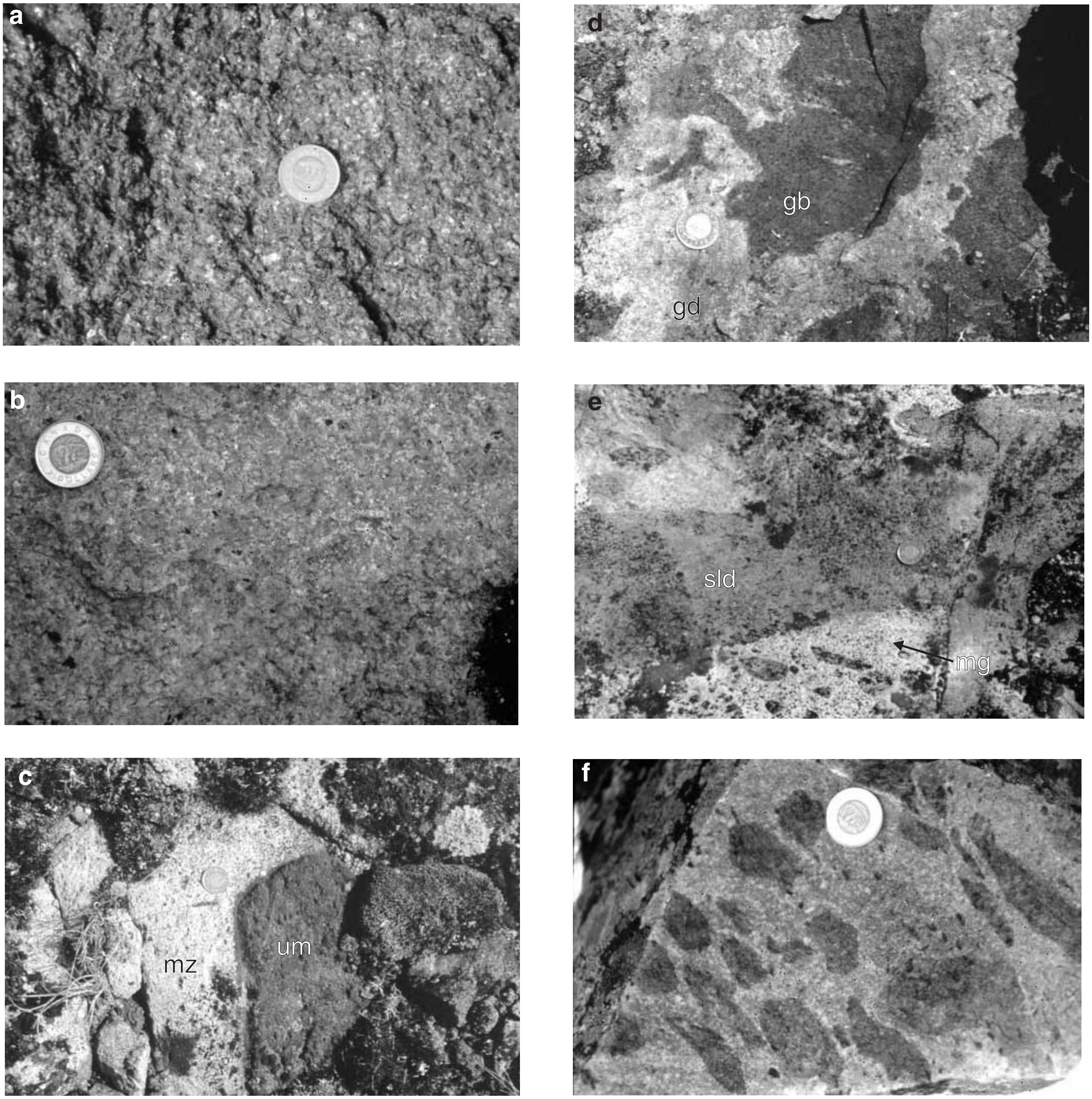
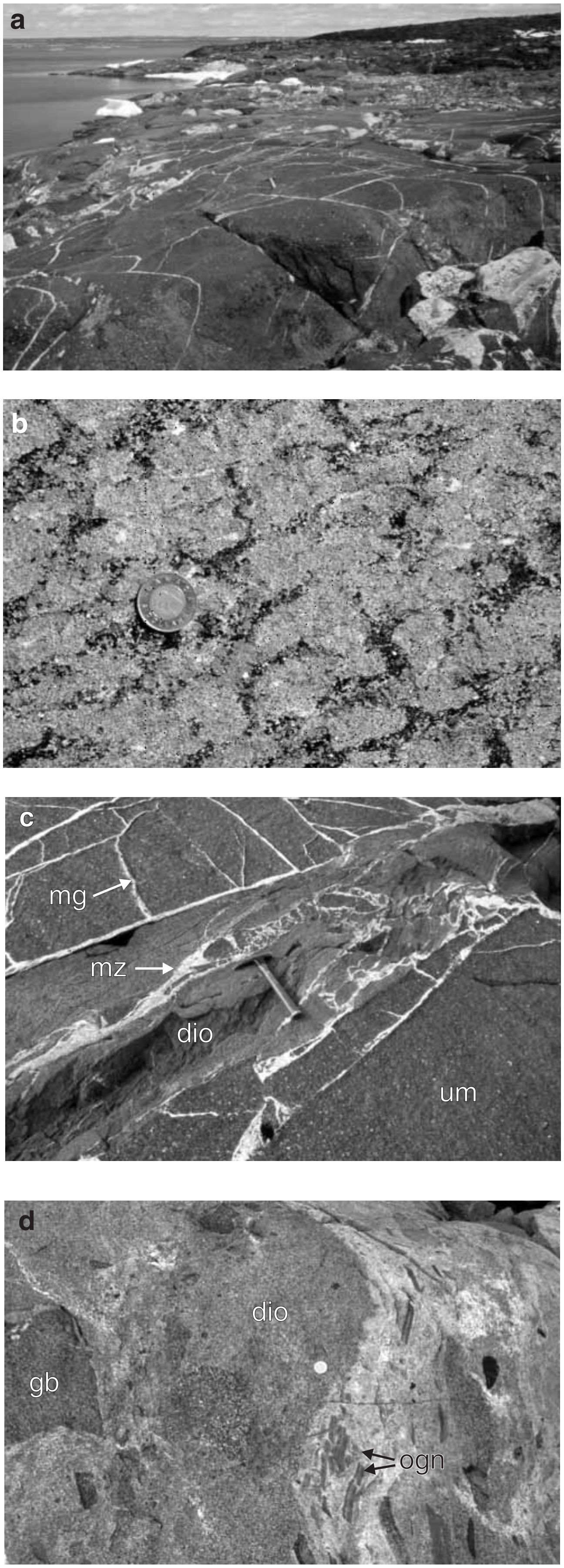


Figure 3. *Selected geological field photographs of the rocks outcropping on the western shore of Squiggly lake. A two-dollar coin is used as a scale (28 mm) in all of the plates except where otherwise noted.* ***a****) A representative, medium-grained hornblende+phlogopite gabbro from location B of Figure 2.* ***b****) A representative medium-grained biotite monzogranite from the exposure immediately north of location B of Figure 2.* ***c****) Green amphibole-rich ultramafic inclusion (um) in monzonite (mz) from the northern intrusive contact (locality A of Fig. 2).* ***d****) Lobate inclusions and irregular intrusions of fine- to medium-grained spotty-textured hornblende+phlogopite gabbro (gb) in granodiorite (gd). Note that the two rock types are mutually crosscutting. Photograph taken near locality B, Figure 2.* ***e****) An irregular dyke of spessartite lamprophyre (sld) with marginal zones rich in enclaves cuts fine-grained biotite monzogranite (mg) at locality C of Figure 2. f) Biotite monzogranite containing numerous rounded inclusions of spessartite lamprophyre as well as polycrystalline clots of hornblende. Note the variable colour indices of the inclusions (locality C, Fig. 2).*

dispersed, polycrystalline aggregates of hornblende± phlogopite derived from the spessartite units. These observations lend strong support to the proposal of magma commingling between monzogranite and spessartite lamprophyre.

Strivewell and Round islands

Strivewell and Round islands of Cross Bay (Fig. 1) comprise predominantly well foliated, dioritic to tonalitic orthogneiss units of the Cross Bay intrusive complex that exhibit a strong north-south mineral stretching lineation (Tella et al., 2000). These orthogneiss units are intruded by a series of nonfoliated to weakly foliated, northeast-trending, irregular dykes and sheets of biotite+magnetite monzogranite, hornblende+ phlogopite gabbro, hornblende+phlogopite diorite, hornblende monzonite, and less common phlogopite clinopyroxenite (now predominantly altered to hornblende+ phlogopite± clinopyroxene).



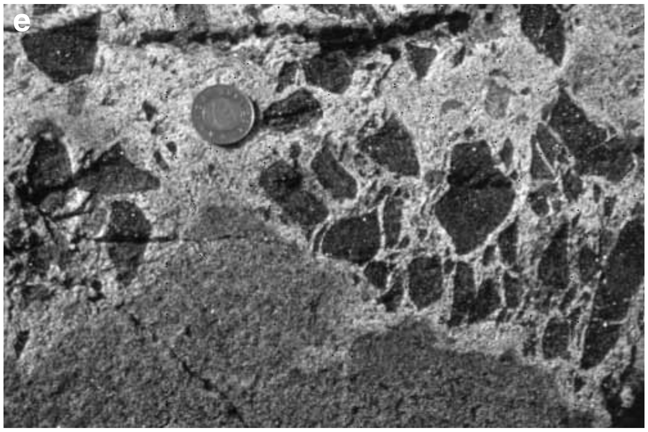


Figure 4. *Field photographs of the rocks outcropping on Round and Strivewell islands of Cross Bay (Fig. 1). Coin in 4b) and 4e) is 28 mm.* ***a****) On the north end of Round Island, coarse-grained phlogopite+hornblende clinopyroxenite is net veined by fine-grained biotite monzogranite. Geological hammer in the centre of the photograph is 50 cm long.* ***b****) 'Blebby texture' in hornblende+phlogopite gabbro to diorite exposed on northwestern Round Island.* ***c****) A 60 cm wide dyke of hornblende+phlogopite diorite (dio) crosscuts phlogopite+hornblende clinopyroxenite (um) on the north end of Round Island. The dyke contains marginal veins and stringers of monzonite (mz) distinct in composition from other crosscutting monzogranite veins (mg). The geological hammer is 30 cm long.* ***d****) A composite, multiphase intrusion containing rounded enclaves of hornblende+phlogopite gabbro (gb) and diorite (dio) in a predominantly monzonitic host magma exposed on the western shore of Strivewell Island. Angular xenoliths of dioritic to tonalitic orthogneiss (ogn) are also common.* ***e****) Intrusion breccia of ultramafic, hornblende+phlogopite clinopyroxenite inclusions with hornblende-rich margins, in a granodioritic host. Note the*

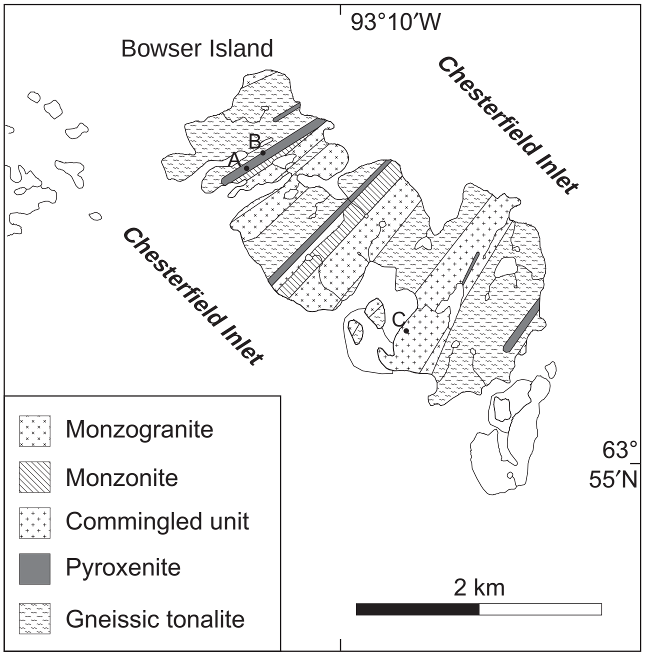


Figure 5. *Schematic geological map of Bowser Island (Fig. 1). The island can be divided into three distinct morphological and geological lobes, each of which comprises a wide range of rocks types, many similar to those described from Squiggly lake and Round and Strivewell islands.*

On the northwestern end of Round Island (Fig. 1), an approximately 0.3 km^2 exposure of coarse-grained (≤ 1 cm) phlogopite clinopyroxenite (strongly replaced by hornblende; Fig. 4a) is mantled by hornblende+phlogopite gabbro and hornblende+ phlogopite diorite. The last two exhibit a variety of conspicuous ‘blebby textures’ characterized by either hornblende+phlogopite-rich domains surrounded by red feldspar-rich mantles or the reverse (Fig. 4b). These features are interpreted to represent commingled assemblages of feldspar-rich and feldspar-poor monzonite clan magmas. All of these units are crosscut by rare dykes of grey monzonite and hornblende+phlogopite diorite and abundant veins and sheets of fine- to medium-grained biotite monzogranite (Fig. 4c).

On the north and northwestern end of Strivewell Island (Fig. 1), dykes and irregular small composite intrusions of hornblende+phlogopite gabbro to monzonite, as well as fine- to medium-grained biotite monzogranite, crosscut well foliated tonalitic and dioritic orthogneiss. The composite intrusions are typified by lateral gradations in composition (5–10 cm), and more notably by diffuse rounded enclaves of hornblende+phlogopite gabbro and hornblende+phlogopite diorite in a predominantly monzonitic and locally granodioritic host (Fig. 4d). Angular inclusions (xenoliths) of well foliated country rock are also common. Beach exposures on the western shore of the island are characterized by abundant intrusion breccia (Fig. 4e). These have compositionally diverse matrices consisting of hornblende+phlogopite gabbro through to monzogranite and the breccia fragments typically comprise ultramafic, hornblende (cpx)+phlogopite assemblages. The fragments exhibit a mineralogical zonation, varying from margins that are hornblende-rich, through to cores that are clinopyroxene-rich. This phenomenon is interpreted as reflecting strong hydration of the breccia fragments accompanying intrusion of the host magma.

Bowser Island

Bowser Island, located in Chesterfield Inlet (NTS 55 N/14; Fig. 1) is host to a diverse range of rock types, all of which exhibit a weakly to moderately developed foliation. The island can be divided into three morphological and geological lobes (Fig. 5). The northwest lobe is characterized by moderately deformed tonalitic orthogneiss that is intruded by a series of compositionally similar, yet temporally distinct, phases of granodiorite to monzogranite. In the central part of the northwest lobe, an approximately 10 m wide northeast-trending dyke-like intrusion of coarse-grained (≤ 1.5 cm) hornblende+phlogopite clinopyroxenite is net-veined by biotite monzogranite (Fig. 6a). One xenolith of well foliated tonalitic orthogneiss wall rock in the dyke was observed to contain a crosscutting vein of unfoliated biotite monzogranite similar in composition to those seen cutting the dyke elsewhere. The granite vein is absent, however, in the engulfing hornblende+phlogopite clinopyroxenite, implying it predated this dyke, and that the monzogranite and hornblende+ phlogopite clinopyroxenite are mutually crosscutting (Fig. 6b). Marginal to this dyke are a series of sheets of compositionally diverse rocks ranging from hornblende+ phlogopite gabbro to monzogranite. The observed mutual crosscutting relationships, as well as rare lobate contacts (Fig. 6c) between monzogranite and hornblende+phlogopite clinopyroxenite, in conjunction with the irregular morphology of the various intrusive sheets and dykes, clearly imply that a number of compositionally distinct magmas coexisted.

The central lobe of Bowser Island exhibits not only the best exposed, but the most complex rock relationships. Similar to the northwest lobe, a central dyke-like body of generally fine- to medium-grained clinopyroxenite is mantled to the northwest, and in particular to the southeast, by numerous sheets of monzogranite, granodiorite, monzonite, and hornblende+phlogopite diorite. These have gradational, irregular lobate contacts, commonly characterized by hydration zones exhibiting replacement of anhydrous mafic silicate minerals by hornblende and by a gradation in the modes of the mafic silicate minerals. Contacts between quartz-saturated and undersaturated rock types exhibit thin (≤ 50 cm) zones having dispersed rounded quartz xenocrysts with hornblende rims. Field observations and follow-up petrographic studies indicate that much of the central part of the ultramafic dyke is characterized by less abundant phlogopite than the margins and its northeast extension, and moreover, by abundant, fresh clinopyroxene (Fig. 6d). Generally, however, much of the clinopyroxene has been overgrown by hornblende, a reaction inferred from abundant remnant clinopyroxene in the cores of large hornblende crystals (Fig. 6e).

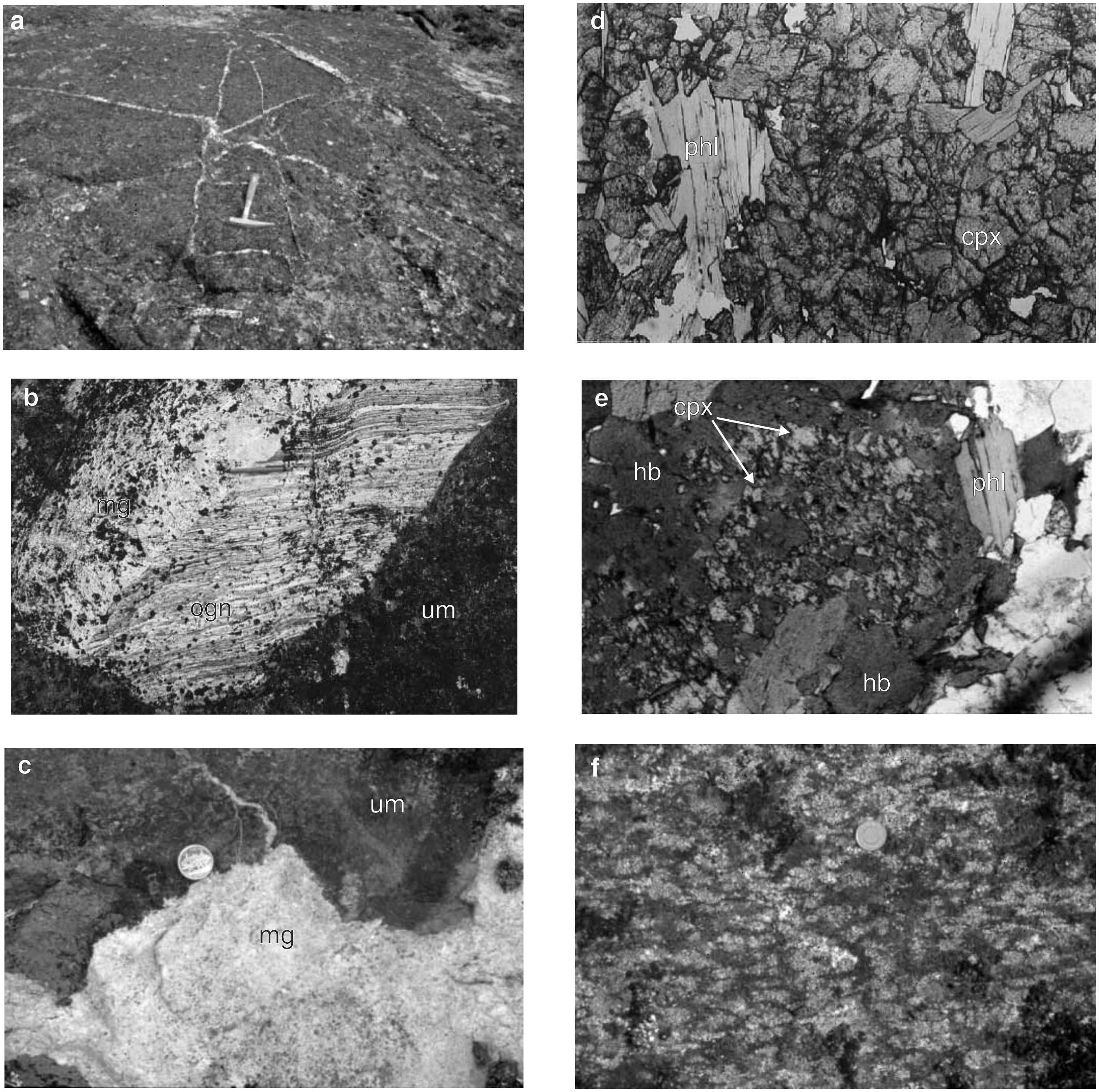


Figure 6. *Field photographs of representative rocks outcropping on Bowser Island.* ***a****) Coarse-grained hornblende+phlogopite clinopyroxenite from the centre of the northwest-trending dyke that is net-veined by biotite monzogranite. Geological hammer is 30 cm long.* ***b****) At locality A in Figure 5, a vein of unfoliated monzogranite (mg) crosscuts a xenolith of foliated tonalitic orthogneiss (ogn) in hornblende+phlogopite clinopyroxenite (um). Note that the monzogranite vein does not continue into the host clinopyroxenite. Pencil is 14 cm in length.* ***c****) An irregular, lobate contact between hornblende+phlogopite clinopyroxenite (um) and monzogranite (mg) implying coexisting magmas (locality B); coin= 28 mm.* ***d****) Photomicrograph of fresh clinopyroxenite from the core of the central ultramafic dyke; phl=phlogopite, cpx=clinopyroxene. Field of view is 2 mm.* ***e****) Photomicrograph of hornblende+phlogopite clinopyroxenite, from the central ultramafic dyke, with hornblende replacing clinopyroxene. Note the remnant clinopyroxene (cpx) in the core of the hornblende grain (hb); phl=phlogopite. Field of view is 2 mm.* ***f****) 'Blebby texture' in diorite exposed on the southeast lobe of the island at locality C; coin= 28 mm.*

The southeastern lobe of Bowser Island contains only minor phlogopite clinopyroxenite (on the north end), but coarse-grained, blebby-textured hornblende+phlogopite gabbro and diorite (Fig. 6f) is significantly more abundant than in the other lobes. These rocks are mantled by irregular sheets and dykes of hornblende+phlogopite diorite, monzonite, and by less common monzogranite. Gradational changes in the rock types from hornblende+phlogopite gabbro to hornblende+phlogopite diorite and monzonite are common. The biotite monzogranite typically crosscuts all other rock types.

RELATIONSHIPS WITH ULTRAPOTASSIC ROCKS OF THE CHRISTOPHER ISLAND FORMATION

Although no ultrapotassic volcanic rocks occur in the study area, probably owing to the deeper level of exposure, lamprophyre dykes are widespread. The lamprophyre dykes are diverse and can be divided into three compositional groups (Armitage, 1998). By far the most abundant in the study area are east- to northeast-trending, grey, hornblende+phlogopite glomerophyric spessartite dykes; less common, east- southeast-trending, tan to brown, phlogopite-rich minette units comparable in composition to the bulk of the Christopher Island Formation (Peterson et al., 1994; Armitage, 1998; Beaudoin, 1998); and rare, north-northwest- trending, black minette-(?lamproite) dykes comparable in composition to the diamondiferous Akluliak dyke (MacRae et al., 1996; Armitage, 1998).

As described above, spessartite lamprophyres are spatially and temporally associated with the granitoid rocks described herein and have been locally observed to crosscut other, presumably ca. 1830 Ma biotite+magnetite+fluorite plutons exposed in the region. To our knowledge, these dykes have not been described in areas where the ca. 1830 Ma monzogranite plutons are absent. The regionally more abundant brown minette dykes, however, are less common in the study area and were rarely observed to crosscut the ca. 1830 Ma granitic rocks. These observations suggest that the diverse compositions represented by the lamprophyres may reflect a number of discrete pulses of compositionally distinct ultrapotassic melts generated in the lithospheric mantle. Moreover, these distinct magma batches may characterize separate, possibly overlapping geographic zones marginal to the locus of ultrapotassic magmatism in the Baker Lake Basin. The relative timing of these magma batches, however, is not known, but further U-Pb geochronology on both hornblende+phlogopite diorite from the study area and a series of rocks from the type section of the Christopher Island Formation (R. Rainbird, pers. comm., 1999) may help constrain the sequence of magmatic events characterizing this large alkaline province.

CONCLUSIONS

In the MacQuoid–Gibson lakes map area, a clear spatial and temporal relationship exists between the widespread suite of ca. 1830 Ma biotite monzogranite and a broad range of quartz-poor to undersaturated rocks including phlogopite clinopyroxenite, hornblende+phlogopite gabbro, hornblende+ phlogopite diorite, monzonite, and spessartitic lamprophyre. Unequivocal field observations such as mutual crosscutting relationships, as well as diffuse, rounded enclaves of spessartite lamprophyre and hornblende+phlogopite gabbro in both monzonitic and monzogranitic magmas, imply that magmatic commingling occurred. Other features such as rounded and resorbed coronitic quartz grains in diorite, lamprophyre, and monzonite, and gradational contacts between the irregular sheet-like and dyke-like intrusions of diverse composition all support the hypothesis of coexisting magmas.

The close spatial and temporal association of these diverse magmatic rock types, in particular the mafic to ultramafic spessartitic lamprophyre, clinopyroxenite, and hornblende+phlogopite gabbro units with the ca. 1830 Ma biotite monzogranite units suggests that much of the late Paleoproterozoic granite bloom, at least in the study area, resulted from intrusion of mafic, silica-poor to silica-undersaturated magmas into the lower crust. Further petrological investigations will help to clarify the compositional diversity of these rocks, elucidate the relative roles of partial melting, fractional crystallization, and magma commingling, and define the characteristics of their mantle and crustal sources. These investigations may provide critical data to aid in understanding the processes of mechanical weakening of western Churchill Province crust that have permitted this region to have been extensively reworked in the Proterozoic.

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