Insights into the origin of calc-alkaline lamprophyres (minettes, spessartites, pyroxene-hornblende syenites) via an oblique Paleoproterozoic crustal section through the northern Hearne Province, Nunavut

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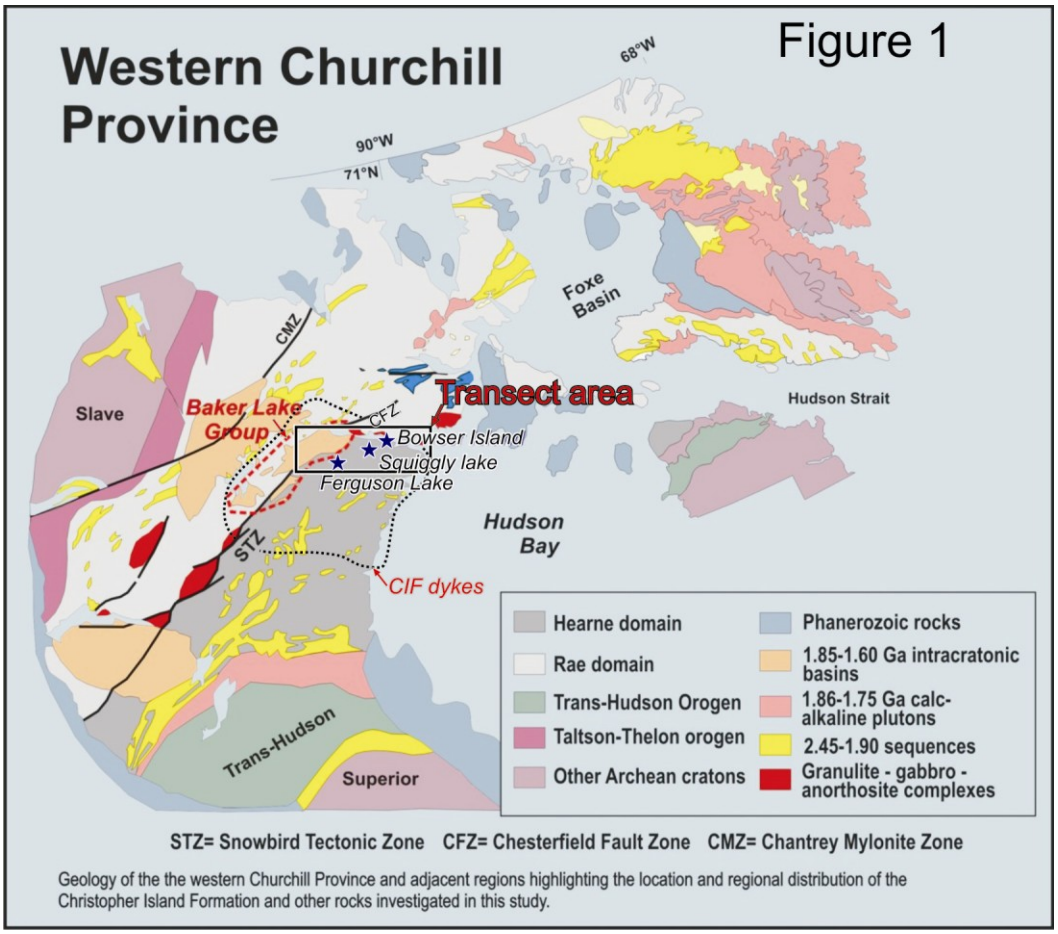
Introduction

The western Churchill Province is host to a diverse assemblage of Paleoproterozoic (1840-1790 Ma) alkaline mafic to felsic igneous rocks including transitional minette-lamproites, minettes, spessartites (calc-alkaline lamprophyres: Rock, 1984, 1991) and, a voluminous suite of infracrustal granitoids (*s.l.*). A transect from west to east through the northern latitudes of the Hearne Province in Nunavut affords a unique opportunity to investigate the relationships between these contemporaneous rocks and to evaluate their petrogeneses. Our observations have significant implications for the genesis of such rock-types, and moreover, help elucidate their mutual genetic relationships.

Background and field observations

From west to east, the transect (Figure 1) preserves volcanic units erupted into the Baker Lake Basin through epizonal intrusive temporal and petrogenetic, equivalents at Ferguson Lake, into contemporaneous, heteromorphic, mid-crustal equivalents near Chesterfield Inlet at Bowser Island. The transect therefore preserves, across an inclined, ca. 1800 Ma crustal section, paleosurface emplacement of the minette lavas of the Christopher Island Formation (LeCheminant, 1987; Cousens et al., 2001), but with deeper crustal exposures, metamorphic grade increases eastward through greenschist facies assemblages and culminate in upper amphibolite facies to granulite facies conditions near Chesterfield Inlet. Although the area is likely disrupted by late Trans-Hudson (ca. 1800-1700 Ma) brittle faults, the oblique crustal section preserves Paleoproterozoic rocks in both the volcanic, near surface and meso –to-epizonal plutonic environments. Earlier investigations focused on the volcanic, and hypabyssal intrusive *minette* suite of the Christopher Island Formation and, although a range of petrologically diverse potassic intrusive rocks have locally been described (Blake, 1980; Smith et al., 1980; Tella et al., 1985; LeCheminant, 1987; Sandeman et al., 2000), their petrogenetic relationships with the Christopher Island Formation were not elucidated and they have unfortunately remained obscurities in the literature. Thus, all of these rocks, whether volcanic epizonal or plutonic have invariably been assigned to the CIF, although coarse-grained syenitic intrusive rocks have also locally been termed Martell Syenites (MS). On the basis of the compositional diversity of these igneous rocks, their contemporaneity, intimate spatial associations' and, their petrochemical variations Sandeman and Hadlari (2007) proposed a revised lithostratigraphic and lithodemic nomenclature nomenclature that included all of the diverse units and, moreover emphasized their petrogenetic affiliations.

Rocks exposed in the surface and near surface environments in the western portion of the transect comprise minette, fractionated minette, felsite, minette plugs and ovoid, domal monzonite-syenite laccolithic or sill-like intrusions. Christopher Island Formation lavas are



Geology of the the western Churchill Province and adjacent regions highlighting the location and regional distribution of the Christopher Island Formation and other rocks investigated in this study.

confined to a number of large depocentres along the western edge of the Hearne Province, but metre-scale, Christopher Island Formation dykes extend over a much broader area including parts of the southern Rae and much of the Central Hearne Provinces. In the eastern parts of the transect near Chesterfield Inlet, however, minettes are rare but spessartites are abundant. The spessartites are contemporaneous and cospatial with a wide-range of small intrusions including: phlogopite clinopyroxenite, two-pyroxene phlogopite gabbro and, clinopyroxene-hornblende-phlogopite monzodiorite to monzonite sills and sheets. All of these minor intrusions accompany and typically crop out along the margins of a widespread series of mid-crustal (ca. 0.45 GPa, 550°C) granite (*s.l.*) plutons (Hudson monzogranites: Peterson et al., 2002). The intervening area is characterized by small granitic or syenitic cupolas and cross-cutting dykes of both minette and spessartite.

Lithogeochemical data

We explore the mineralogical, lithogeochemical, Nd isotopic compositions and mineralogical variations of Christopher Island Formation lavas and dykes and compare these to a number of meso –to– epizonal occurrences of holocrystalline, heteromorphic equivalents exposed in the Ferguson Lake, MacQuoid Lake and Chesterfield Inlet areas. Examination of the database suggests that spessartitic lamprophyres and hornblende-phlogopite±clinopyroxene monzodiorites to monzonites are heteromorphic equivalents of the minettes, although the minettes are generally typified by slightly lower SiO_2, TiO_2 and Al_2O_3 concentrations but systematically strongly elevated CO_2 abundances. Collectively, incompatible element

concentrations are similar but are very variable and thus make modeling of the lithogeochemical data difficult. $\varepsilon Nd_{(t=1830\ Ma)}$ values for the minettes, spessartites and hornblende-phlogopite±clinopyroxene monzodiorites to monzonites are strongly negative (-6.2 –to– -11.0) and the mean for the minettes overlaps with that for the spessartites and syenitic rocks. Model T_{DM} ages (DePaolo, 1981) range from 2546-3452 Ma indicating their derivation from: either a significantly older, metasomatically enriched lithospheric mantle source or, that their parental magmas extensively interacted with crustal granitoids or crustally derived granitoid magmas. Observations derived from field, petrographic and lithogeochemical data indicate, that the latter is viable and that many of the hornblende-bearing rock-types are likely mixtures of minette and/or its derivatives with subsolvus, near minimum melt Hudson monzogranitic magmas (Peterson et al., 2002). The strongly negative εNd values for very primitive (high Mg#, Cr and Ni) end-members, however, predicates a mantle source that experienced an ancient metasomatic enrichment event. Although commingling and mixing were observed at a number of localities, we infer that more extensive mixing and homogenization between these disparate magmas probably occurred at a crustal exposure level deeper than that presently exposed.

Conclusions

Detailed and regional field observations indicate that above the ca. 1830 Ma minimum melt granite bathograd (ca. 0.4 GPa), and in the absence or near absence of granitic magma (i.e., west of Squiggly lake), minette magmas were commonly transported directly to surface but locally stalled in the upper crust and produced small plugs and kilometre-scale, sill-like laccolithic intrusions. Fractionation of these minette magmas subsequently yielded clinopyroxene-phlogopite±hornblende – bearing syenitic derivatives (MSS *s.s*). Near the greenschist-amphibolite transition, small cupolas of contemporaneous, subsolvus, metaluminous biotite-magnetite-titanite-fluorite - bearing Hudsonian monzogranite and syenogranite are cross-cut by both minette and spessartite dykes. This crustal exposure level represents the upper limit of Hudsonian granite magma emplacement during crustal anatexis; volcanic equivalents of these granitoids are absent. Slightly deeper levels of exposure (middle amphibolite facies) are characterized by domal, 2-25 km –wide, sheet-like intrusions (laccoliths) of predominant biotite-magnetite-titanite±fluorite - bearing monzogranite commonly having marginal phases ranging from hornblende+phlogopite±clinopyroxene pyroxenite through hornblende-phlogopite-titanite monzodiorite, hornblende-biotite-titanite monzonite and rare hornblende-biotite-titanite syenite. Mutual cross-cutting and gradational relationships between these are typical. Spessartite dykes that are mineralogically and geochemically identical to hornblende-phlogopite-titanite monzodiorites are observed to both cross-cut and commingle with monzogranite and monzonite.

Our observations have important implications for the present chaotic nomenclature and disputed interrelationships between two mineralogically distinct types of calc-alkaline lamprophyre, namely minette and spessartite as defined by Rock (1984). Spessartite and its intrusive equivalents likely represent the products of deep crustal magmatic commingling and mixing between primitive minette and contemporaneous granitic magmas (*s.l.).* Moreover, both the primitive minettes and the hybridized spessartitic magmas locally undergo crystal-liquid fractionation to produce more silicic and aluminous differentiates as well as cumulate-facies residues in middle –to– deep crustal plutonic settings. Thus, the observations presented here demonstrate that, like “normal” calc-alkaline or tholeiitic volcanic-plutonic rock series, calc-alkaline lamprophyres are also represented by mineralogically and chemically equivalent epizonal, mesozonal and, likely, hypozonal plutonic equivalents. These potassic –to– ultrapotassic minettes and spessartites do not only form epizonal dyke swarms and less common lavas, but also comprise sills, laccolithic-lopolithic intrusions, and occur as marginal phases to larger, homogeneous, contemporaneous and commonly consanguineous granitoid (*s.l.*) plutons. The localities discussed herein, their exposed rock-types and the observed diverse interrelationships indicate that the western Churchill calc-alkaline lamprophyres

encompass two of the three petrological associations of Rock (1984) namely: (A) those associated with granitoid plutons and; (C) those associated with appinite–breccia-pipe complexes. Our observations therefore indicate that, in any single calc-alkaline lamprophyre district, more than one association may occur and apparent restriction to a single association is largely controlled by the local crustal exposure level.

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