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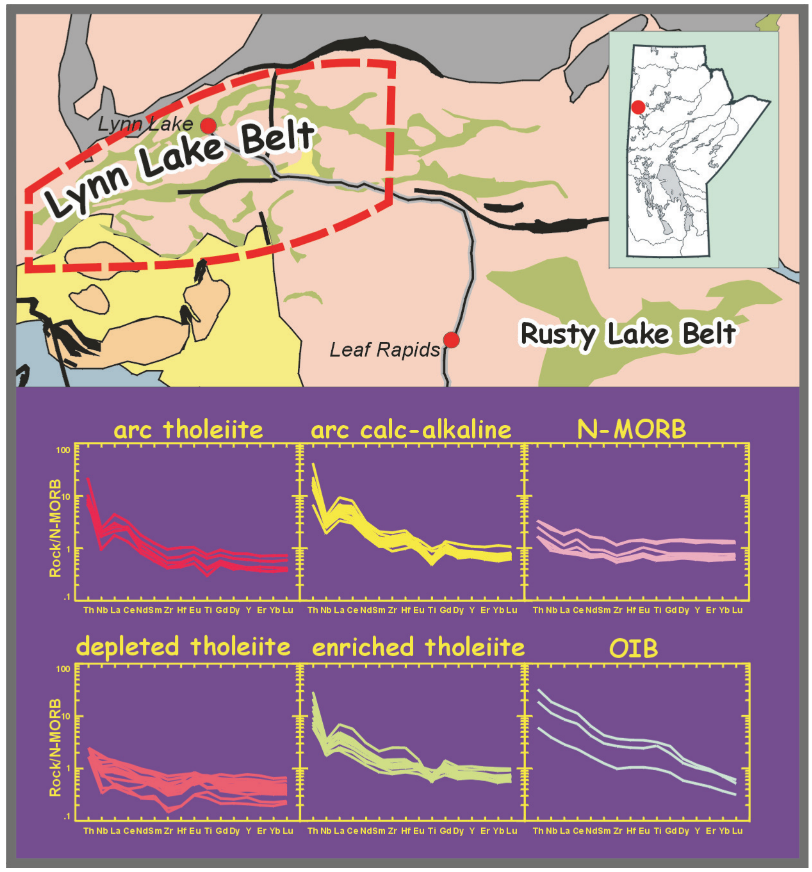
Updated Trace Element Geochemistry of ca. 1.9 Ga Metavolcanic Rocks in the Paleoproterozoic Lynn Lake Belt



By
H.V. Zwanzig, E.C. Syme
and H.P. Gilbert

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by H.V. Zwanzig, E.C. Syme and H.P. Gilbert
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INTRODUCTION

The Paleoproterozoic Lynn Lake greenstone belt (Lynn Lake Belt) occurs in the interior, juvenile portion (Reindeer Zone) of the Trans-Hudson Orogen (Fig. 1). Metavolcanic rocks in the Lynn Lake Belt are ca. 1.9 Ga (Baldwin et al., 1987), the same age as metavolcanic rocks in the Flin Flon Belt (NATMAP Shield Margin Working Group, 1998, and references therein). The Lynn Lake Belt is flanked by metasedimentary gneisses to the south (Kisseynew Domain) and to the north (Southern Indian Domain; Fig. 2).

The metavolcanic rocks in the Lynn Lake Belt have historically been termed 'Wasekwan Group' (Gilbert et al., 1980, and references therein). Regional mapping (Gilbert et al., 1980) and follow-up geochemistry (Syme, 1985) provided a gross stratigraphy for the Wasekwan Group, from the Saskatchewan border to Hughes Lake, and this scheme has proved to be relatively robust in light of the new trace element geochemistry reported here. The tectonic framework for the stratigraphic units (Figs. 3.1 to 3.3) has been modified locally to accommodate new structural interpretations (Zwanzig, 1990) and the new geochemical data. The Wasekwan Group is unconformably overlain by fluvial-alluvialarenites of the Sickle Group (Gilbert et al., 1980, and references therein) and these rocks have a largely coeval marine turbidite facies (Burntwood Group) with a depositional age of ca. 1.85-1.84 Ga in the Kisseynew Domain (Machado et al., in press).

The new trace element data has provided unique geochemical patterns for the previously-identified stratigraphic components of the Wasekwan Group. This data demonstrates that the Wasekwan Group is composed of a number of tectonostratigraphic assemblages, including a variety of tholeiitic arc, calc-alkaline arc, MORB-like and OIB-like rocks. Each assemblage represents a distinct package of rocks in terms of its stratigraphy, geochemistry, age and inferred plate tectonic setting. Assemblages were likely structurally juxtaposed early in the evolution of the belt. We suggest here that the term 'Wasekwan Group' be dropped as the means of describing the 1.9 Ga volcanic rocks in the Lynn Lake Belt, because the diverse assemblages defined in this report cannot form a stratigraphic 'group' in the normal sense of the word.

The recognition that the Lynn Lake Belt contains distinct tectono-stratigraphic assemblages has important economic implications. Experience has shown elsewhere that not all assemblages are equally endowed with mineral deposits; for example, all of the mined volcanic-hosted massive sulphide (VMS) base metal deposits in the Flin Flon Belt are associated with the juvenile arc volcanic rocks (Syme and Bailes, 1993). Thus, knowledge of the physical and geochemical characteristics of the assemblages is crucial for effective mineral exploration.

Many of the units in the Lynn Lake Belt have only subtle variations in petrology, field characteristics and major-element geochemistry, but are clearly identified using relatively small trace-element data sets. The critical tools required for this approach are chondrite-normalized plots of REE, MORB-normalized extended element plots, and binary and ternary plots involving high field strength elements (HFSE) and Th.

Analytical procedure

The sample set upon which this report is based was collected and analyzed during regional mapping in the Lynn Lake region (Gilbert et al., 1980; Gilbert, 1993). Samples were selected to most closely characterize the primary, igneous compositions of the diverse stratigraphicunits; alteration, veining and amygdales were avoided. Pulps saved from this early work were re-analyzed by ICP-MS by Activation Laboratories (method Code 4Litho) in 1999. The geochemical data are provided on the accompanying diskette in Excel and ASCII formats (Appendix). These analyses are grouped by belt and stratigraphic unit to mirror the report structure. The original data, including QC information, are available from Syme upon request.

General geology

On a first-order basis, the Lynn Lake Belt can be subdivided in terms of a 'Northern Belt', a 'Southern Belt', as well as several sub-belts (e.g., Miskwa Lake and Keewatin River belts; Fig. 2). These terms had particular stratigraphic significance following the regional mapping (Gilbert et al., 1980) and have been retained in this report.

As discussed above, the early history of the Lynn Lake Belt is dominated by the unrelated 1.91 Ga (Baldwin et al., 1987) volcanic assemblages, which were juxtaposed along early extensional, compressional and possibly transcurrent faults. Subsequent to juxtaposition, the supracrustal rocks in the Lynn Lake Belt were folded and developed an early foliation. The upright folds were intruded by subvertical pipes of Lynn Lake gabbro and the plutons of the 1.876 Ga Pool Lake tonalite (Manitoba Energy and Mines, 1986; Baldwin et al., 1987). These intrusions are 'stitching plutons' in that they are emplaced across and within the boundaries between distinct tectonostratigraphic assemblages, providing a minimum age for the structural juxtaposition and early deformation.

The Northern Belt is a largely homoclinal, north facing succession, unconformably overlain by conglomerate and greywacke of the Southern Indian Lake Belt (Fig. 2). The Southern Belt is dominated by the Cockeram Lake anticline (which predates the Pool Lake tonalite) and Johnson Shear Zone (a long-lived strike fault zone; Beaumont-Smith and Rogge, 1999). At the southwest end of the Southern Belt, an inferred anticline and block faults in volcanic rocks are truncated due to erosion along a regional unconformity; these rocks are overlain by the ca. 1.85-1.84 Ga (Ansdell et al., 1999) Sickle Group.

Volcanic rocks in the Laurie Lake-Granville Lake area adjacent to the north boundary of the Kisseynew Domain are predominantly ocean-floor basalts that were folded and faulted (probably during the pre-1.88Gafolding in the Southern Belt) and subsequently uplifted, erodedandunconformably overlain by the Sickle Group. Stratigraphically similar, highly recrystallized volcanic rocks in Saskatchewan have a minimum age of ca. 1.87 Ga (Corrigan et al., 1999).

After deposition of the Sickle Group, all of the supracrustal and intrusive rocks in the Lynn Lake Belt were metamorphosed to upper greenschist to upper amphibolite facies, and developed regional tectonic foliations and shear zones during polyphase deformation. However, in the interests of brevity the prefix 'meta' has been dropped from rock names in the following discussion.

Report structure

This report retains (except where noted) the stratigraphic nomenclature used in previous publications (primarily Gilbert et al., 1980; Syme, 1985). Note that this report does not replace these earlier publications, but rather compliments them by adding specific geochemical information not available at the time they were written. The unit descriptions and stratigraphy presented in Gilbert et al. (1980) remain as the primary source of information on the field relationships observed during mapping. Major element geochemistry of metavolcanic rocks in the Lynn Lake Belt is discussed satisfactorily in Syme (1985) and is not emphasized in this report.

In the sections that follow, the geochemistry of mafic and intermediate composition rocks are discussed first, subdivided into Southern Belt units, units at the Lynn Lake Belt-Kisseynew Domain margin, and finally Northern Belt units. Felsic rocks (rhyolites, dacites) are then discussed, again organized by where they occur in relation to the defined belts and sub-belts. Mafic intrusions are discussed last, followed by a Discussion and Conclusions. Figures referred to in the text have all been placed at the end of the report so that they may be readily located and compared. Map OF99-13-1 (in back pocket) summarizes the main stratigraphic and geochemical units in the Lynn Lake Belt, and shows the locations of samples analyzed and discussed in this report.

This report is a preliminary examination of the geochemistry of these rocks, published only a few months after the data were received. As a result, only a limited number of geochemical plots are presented that best serve to outline the tectonic affinity of the volcanic rocks. N-MORB-normalized (Sun and McDonough, 1989) extended element plots were chosen to display the relationships between large ion lithophile elements (LILE), high field strength elements (HFSE) and rare earth elements (REE). These diagrams are identical in element order and normalizing factors to those used by Stern et al. (1995a) for rocks in the Flin Flon Belt, to facilitate comparison between these two important Paleoproterozoic greenstone belts.

MAFIC AND INTERMEDIATE VOLCANIC ROCKS

Southern Belt

Cockeram Lake aphyric basalt

Cockeram Lake aphyric basalt is interpreted as an isoclinally folded shield volcano whose present dimensions are 26 km in strike length by at least 2.1 km in thickness. It cores a regional anticline (Cockeram Lake anticline) and thus is structurally the oldest formation in the east-central portion of the Southern Belt (Fig. 3.2). Cockeram Lake basalt is intercalated in the west with McVeigh Lake porphyritic basalt and is in structural contact at Cartwright Lake with calc-alkaline andesites of the Hughes Lake suite (Gilbert et al., 1980; Syme, 1985). Most flows in Cockeram Lake basalt are pillowed.

Cockeram Lake basalt is tholeiitic (Syme, 1985; Fig. 4.1a) and has chondrite-normalized REE patterns ranging from flat to slightly light REE (LREE)-enriched (Fig. 5.1a). On a Th-Zr-Nb discriminant diagram (Fig. 6.1a; Wood, 1980) Cockeram Lake basalt plots, with one exception, in a tight group within the 'arc' field. On a MORB-normalized extended element diagram (Fig. 7.2a) these basalts have prominent negative Nb, Zr and Ti anomalies, and positive Th anomalies, similar to tholeiitic arc basalts in the Flin Flon Belt (Fig. 7.1a). Despite having negative Ti anomalies on the MORB-normalized diagram, TiO_2 contents in Cockeram Lake basalt are nevertheless relatively high (0.76-1.45 wt.%) compared to modern and Paleoproterozoic Flin Flon Belt arc tholeiites (Fig. 8.1a), possibly due to their fractionated or evolved character (MgO contents range from 3.12-6.89 wt.%; Syme, 1985). Nevertheless, Cockeram Lake basalt is, for the Lynn Lake Belt, a prototypical arc tholeiite.

McVeigh Lake porphyritic basalt

McVeigh Lake porphyritic basalt extends 23 km from Cockeram Lake in the east to the Gemmell Lake area in the west; it attains a maximum thickness of 1.5 km in the McVeigh Lake area. It is approximately coeval with Cockeram Lake aphyric basalt, being intercalated with Cockeram Lake basalts on both outcrop and map scales (Gilbert et al., 1980). Massive flows and autoclastic breccia predominate in the unit; pillowed flows are rare.

Major element variation in McVeigh Lake porphyritic basalt indicates that the unit is calc-alkaline in character (Syme, 1985; Fig. 4.1b). The basalts are slightly magnesian (5.88-8.87 wt.% MgO) and have TiO_2 contents ranging from 0.96-1.11 wt.%; they plot above the fields of modern and Flin Flon Belt arc rocks on a TiO_2 vs. MgO diagram (Fig. 8.1b). The basalts are LREE-enriched (Fig. 5.1b) and display positive Th anomalies and negative Nb, Zr and Ti anomalies on MORB-normalized extended element plots (Fig. 7.2b). They plot in the 'arc' field on Th-Zr-Nb discriminant diagrams (Fig. 6.1b). The major and trace element geochemistry of McVeigh Lake porphyritic basalt suggests that, consistent with earlier interpretations (Syme, 1985), the unit is a relatively primitive calc-alkaline arc sequence.

Only one analysis is available of an aphyric basalt intercalated with porphyritic basalt in the McVeigh Lake sequence. This rock is quite distinct from the porphyritic calc-alkaline basalts, having flat REE and MORB-normalized profiles (Figs. 5.3a, 7.3a; note slight Th enrichment). The MORB-normalized pattern of this basalt is also unlike Cockeram Lake aphyric basalt but, despite its similarity to Flin Flon Belt MORB-like back-arc basin basalts (BABB), the paucity of data does not allow further interpretation.

The compositional range exhibited by McVeigh Lake porphyritic basalt is continuous with the more magnesian Fox Lake porphyritic basalt (see below) and the more evolved Hughes Lake calc-alkaline suite (basalt-andesite-dacite-rhyolite; below). These relations suggest that the Fox, McVeigh and Hughes sequences (Figs. 3.1 and 3.2) may be coeval and petrogenetically linked. If so, the calc-alkaline sequences clearly become less magnesian and more evolved eastwards, possibly preserving primary compositional trends in the paleo-Lynn Lake arc.

Fox Lake porphyritic basalt

The Fox Lake porphyritic basalt is a highly mafic unit of flows and breccia that outcrops southeast of the abandoned Fox Lake Mine in the southwestern part of the Lynn Lake Belt. The unit is characterized by its high content of large dark green amphibole (after pyroxene) phenocrysts, and patchy alteration with abundant fine grained, pale green amphibole and diopside. The unit was interpreted to occupy a low stratigraphic position in an anticlinal structure and has a maximum thickness of 1200 m (Gilbert et al., 1980). Although facing directions are known only locally and contacts are not exposed, the Fox Lake porphyritic basalt was interpreted to be stratigraphically overlain by the Snake Lake dacite and the Fox Mine succession (Fig. 3). Nevertheless, faulted contacts between these units cannot be ruled out.

The Fox Lake porphyritic basalt is a calc-alkaline unit that shows no Fe-fractionation trend with increasing SiO_2 (Fig. 4.1b), similar to McVeigh Lake basalt, although the latter has relatively less MgO and more Al_2O_3 (Fig. 9.1a). Both calc-alkaline rock suites are enriched in LREE (5.1c) and have low Zr/Th ratios and high Th/Nb (Fig. 6.1b). They have high MgO contents with uniform TiO_2 contents that are slightly elevated compared to modern arc basalts (Fig. 8.1b). However, their MORB-normalized extended element diagrams have a Th spike and prominent negative Ti, Zr and Nb anomalies (Fig. 7.2c), features that typify arc volcanic rocks.

Laurie Lake assemblage

At the southwest end of the Lynn Lake Belt, highly metamorphosed volcanic rocks occupy a series of narrow fault slices intercalated with sedimentary rocks at the margin of the Kisseynew Domain (Fig. 3.1). The most northwestern of these fault slices (soled by the lower thrust in Fig. 3.1) contains the Laurie Lake assemblage of amphibolite and high-Mg schist. The assemblage is newly named in this report on the basis of geochemistry. Regional stratigraphic relationships of these rocks are unknown because the fault slices were folded into a synform northeast of a complex dome occupied by Kisseynew sedimentary gneisses (Zwanzig, 1990). The Laurie Lake assemblage was originally mapped as the upper part of the Tod Lake aphyric basalt (unit 2e in Gilbert et al., 1980). It was interpreted to stratigraphically overlie the Burntwood Group greywacke-mudstone (unit 1 in Gilbert et al., 1980). However, contacts between the volcanic rocks and the Burntwood Group were subsequently recognized as faults (Zwanzig, 1990).

In the sampling areas (northeast shore of Laurie Lake), amphibolite with locally preserved textures of crystal tuff and lapilli tuff is overlain by high-Mg schist. The assemblage is 10 to 50 m thick and is unconformably overlain by the Sickle Group. In the northern part of Laurie Lake, the assemblage is structurally overlain by sedimentary rocks and volcanic rocks that extend west into the volcanic succession at the Lar VMS deposit and its alteration zone (Ferreira, 1993).

The Laurie Lake assemblage is characterized by low FeO^t/MgO (Fig. 4.1c), similar to Fox Lake porphyritic basalt. This suggests that the Laurie Lake assemblage is also calc-alkaline; the Zr/Th/Nb plot indicates a volcanic arc affinity (Fig. 6.1c). LREE are elevated (Fig. 5.1d) and MORB-normalized extended element diagrams of amphibolite and high-Mg schist have similar profiles to the Fox Lake and McVeigh Lake porphyritic basalts (Fig. 7.2d). The unit has a wide range of MgO and Al_2O_3 contents, similar to Fox Lake porphyritic basalt (Fig. 9.1a).

Fox Mine succession

The volcanic succession that hosted the Fox Lake VMS deposit (past producer) lies northwest of the Fox Lake porphyritic basalt. The Fox Mine succession is a heterogeneous, mafic to intermediate sequence that includes aphyric and porphyritic flows, breccia and minor sedimentary and felsic volcanic rocks. The structural and stratigraphic relationships of the succession are not well understood. The lower (southern) contact was considered to be stratigraphic and northwest facing (Gilbert et al., 1980) but tops at the mine were thought to be south (Sherritt-Gordon Ltd. staff, pers. comm.). Regional mapping suggested that the Fox Mine succession contains large asymmetric S-folds in the area southeast of the abandoned mine site.

The rocks are highly altered south of the mine and only the least altered samples were analyzed for this report. Five of six samples suggest that the Fox Mine succession contains tholeiitic basalt to basaltic andesite. Anomalous samples may be silicified or may represent a calc-alkaline andesite at the base of the succession (Fig. 4.1d). LREE contents and Th/Nb are elevated (Figs. 5.1d, 6.1d), and the MORB-normalized extended element plot has a similar profile to the Fox Lake porphyritic basalt (Figs. 7.2c and e), suggesting a possible transition from calc-alkaline to tholeiitic affinity.

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[1] all major element concentrations recalculated LOI-free

The Fox Mine succession is clearly part of a volcanic arc assemblage with typically low TiO_2 contents (Fig. 8.1c). A distinguishing geochemical feature appears to be that some of the basaltic members have slightly lower total REE and HFSE than arc volcanic units (with equivalent MgO contents) elsewhere in the southwestern part of the Lynn Lake Belt. High-Al basalts (>17% normalized Al_2O_3) occur in outcrops closest to the calc-alkaline Fox Lake porphyritic basalt (Fig. 9.1b). Both the Fox Mine succession and the Fox Lake porphyritic basalt display similar trace element profiles, but are distinguished by different overall trace element contents, consistent with derivation from the same mantle source during arc evolution.

Wilmot Lake and Gemmell-McVeigh Lake volcanic rocks

Gilbert et al. (1980) have interpreted the belt of stratified volcanic and lesser sedimentary rocks between Wilmot Lake and Gemmell Lake to be among the youngest in the Wasekwan Group in the southwestern part of the Lynn Lake Belt. The belt consists mainly of mafic and intermediate volcanic breccia and thin flows; felsic rocks (tuff?) are rare. The succession overlies the southeast-facing Fox Road turbidite. Tops are rare in the volcanic rocks at this locality, but Gilbert et al. (1980) have tentatively identified a northeast-trending syncline truncated to the southeast along the unconformity with the Sickle Group. This interpretation implied a 1 km thick succession, but our reinterpretation here, based on geochemistry, suggests that the stratigraphic or structural pile may be over 3 km thick.

The Gemmell-McVeigh Lake volcanic rocks occupy both the north and south limbs of the west part of the Cockeram Lake anticline (Gilbert et al., 1980). The volcanic rocks in the north limb, at Fraser Lake, occur in a subsidiary syncline, whereas those in the south limb (from Gemmell Lake to Franklin Lake) are separated from the rest of the Southern Belt by the Johnson Shear Zone. Both sections are characterized by relatively thin porphyritic and aphyric mafic volcanic units, subvolcanic intrusions, lens-shaped bodies of sedimentary rocks and local rhyolite.

The rocks near Gemmell Lake and farther northeast were tentatively correlated with those near Wilmot Lake by Gilbert et al. (1980). A comparison of their geochemistry (see below) suggests that the structure and stratigraphy are complex, but south of the Johnson Shear Zone there appears to have been a broadly similar chemical evolution across the belt from northwest to southeast. The belt is most likely a southeast-facing homocline, or consists of several narrow fault slices. However, chemically identical units cannot be traced along the length of the belt.

Plots of Zr/Th/Nb, chondrite-normalized REE and MORB-normalized extended element diagrams discriminate five different volcanic suites that range from modern arc volcanic rock types to E-MORB (Figs. 6.1e and f). Each type is restricted to a certain outcrop area and therefore represents a volcanic body with a distinctive geochemistry. Types that occur near Wilmot Lake are very similar but do not correspond directly to those between Gemmell and McVeigh lakes.

Wilmot Lake volcanic rock

Normal- to high-Mg basalt and andesite have a range of SiO_2 contents with increasing FeO^t/MgO, typical of tholeiitic fractionation (Fig. 4.1e). The more fractionated members have the most Al_2O_3 and contain plagioclase phenocrysts (Fig. 9.1c). The rocks have weakly to moderately negative HFSE anomalies with lower Th/Nb and Th/Zr ratios than most arc volcanic rocks (6.1e), but are slightly enriched in LREE (Fig. 5.1f). At location 142 in the upper part of the section near Wilmot Lake, basalt has a flat REE pattern and a Th spike (Figs. 5.1g, 7.2g).

McVeigh Lake 'high-Al' basalt

High-Al basalt occurs in the western hinge area of the Cockeram Lake anticline (along strike from McVeigh Lake porphyritic basalt) and also occurs as sills and possible thin flows within the overlying greywacke-mudstone in the syncline to the north. The basalt has the same steep REE pattern (Fig. 5.2a) and prominent negative HFSE anomalies (Fig. 7.4a) as the underlying McVeigh Lake calc-alkaline basalt. However, it has a lower MgO content and higher Al_2O_3 content than the McVeigh Lake basalt (Fig. 9.1d). The high-Al basalt plots in the 'arc' field on a Zr/Th/Nb diagram (Fig. 6.1f). The geochemistry and stratigraphic relations of this unit suggest that volcanism continued during sedimentary basin development, but evolved toward higher Al and Fe.

Gemmell-McVeigh Lake basalt (low- to high-Mg)

Gemmell-McVeigh Lake low- to normal-Mg basalts extend from Franklin Lake to Gemmell Lake, south of the Johnson Shear Zone, whereas high-Mg volcanic units, which are interpreted as subvolcanic intrusions, occur throughout a large area from McVeigh Lake to Stear Lake.

The basalts have flat to slightly negatively sloping chondrite-normalized REE patterns (Fig.5.2b and c) and 'normal' Al_2O_3 contents (<17 wt.% Al_2O_3; Fig. 9.1d). The varieties with higher MgO content have the negative slope. Th/Nb ratios in these rocks are equivalent to or slightly lower than those in modem arc basalts (Fig. 6.1f). MORB-normalized trace element patterns display moderate negative Ti anomalies and low Zr and Hf values, consistent with a volcanic arc origin for the whole group (Fig. 7.4b).

Gemmell-McVeigh Lake depleted basalt and andesite

This rock suite is represented by three samples that display a tholeiitic fractionation trend (Fig. 4.1f). Th contents are lower than in most arc volcanic rocks (Fig. 6.1f), and LREE values are weakly depleted (Fig. 5.2d); however, MgO and TiO_2 contents are typical of modern arc volcanic rocks (Fig. 8.1e). The MORB-normalized extended element plot is flat except for slight negative Zr and Hf anomalies, and there is no Ti anomaly in the basalts (only in the andesite; Fig. 7.4c). This pattern is distinctly different from 'typical' arc tholeiites such as those in the Flin Flon Belt (Fig. 7.1a).

These weakly depleted arc volcanic rocks occur southwest of Franklin Lake and are separated from the south margin of the Lynn Lake Belt by the Story Lake pluton. On the basis of their incompatible element profiles, they are tentatively correlated with the top of the Wilmot Lake volcanic rocks at location 142 (ca. 25 km along strike to the southwest; see Map OF99-13-1 in back pocket), which are stratigraphically directly below the Sickle Group unconformity (Fig.7.4c). The single sample of McVeigh Lake aphyric basalt also has a similar geochemistry to the depleted rocks near Franklin Lake (Fig. 7.3a). These 'depleted' volcanic rocks, which are compositionally similar to depleted basalts at the north margin of the Northern Belt (see below), are interpreted as arc tholeiite derived from a relatively refractory mantle source.

Dunphy Lake gabbro

The Dunphy Lake gabbro analyzed herein forms a series of sills in the Fox Road turbidite (Gilbert et al., 1980). In the vicinity of Fox Lake, block-shaped areas of various volcanic rock units are separated by pre-Sickle gabbro intrusions that post-date regional hydrothermal alteration. The location of these gabbroic intrusions is apparently controlled by early block faulting.

The Dunphy Lake gabbro has a flat REE profile (Fig. 5.3e) and a MORB-normalized extended element pattern with prominent negative Zr and Hf anomalies (Fig. 7.4a), patterns that are similar to those of other Southern Belt gabbro intrusions and Gemmell-McVeigh Lake basalts (Fig. 7.4).

Hughes Lake calc-alkaline suite

The Hughes Lake calc-alkaline suite (Gilbert et al., 1980; Syme, 1985) occurs in three geographic segments: 1) Cartwright Lake-Pole Lake, 2) Hughes Lake and 3) Chepil Lake (Map OF99-13-1, in back pocket). Geochemical data are available predominantly from the better exposed Cartwright Lake-Pole Lake and Hughes Lake segments.

The suite is in tectonic contact with Cockeram Lake basalt at Cartwright Lake and is conformably overlain by Hughes Lake olivine-normative, enriched arc tholeiites east of Stan Lake. The true stratigraphic thickness of the calc-alkaline sequence is unknown due to the absence of complete sections through the entire suite; both the Pole Lake and Hughes Lake segments are at least 2.5 km thick. The Cartwright Lake-Pole Lake sequence is predominantly andesitic but progresses to more siliceous rocks (dacites) up-section. Rhyolite flows and tuff are minor components and are scattered throughout the sequence. The sequence at Hughes Lake is dominated by a thick Lower Series of aphyric to porphyritic basalt and basaltic andesite, overlain by an Upper Series of plagioclase phyric and aphyric andesite, local rhyolite, and sedimentary rocks (Syme, 1985).

The Hughes Lake calc-alkaline suite has a typical calc-alkaline trend on AFM and Jensen cation diagrams (Syme, 1985) and displays little or no Fe-enrichment on an FeO^t/MgO vs. SiO_2 plot (Fig. 4.1h). The suite (basalt to dacite) has remarkably consistent REE patterns (Fig. 5.3b), showing no systematic variation of REE with MgO, SiO_2, FeO^t/MgO, etc. The entire suite has smoothly concave-upward patterns that are LREE-enriched. MORB-normalized extended element plots similarly form a tight grouping with characteristic positive Th and negative Nb, Zr and Ti anomalies (Fig. 7.3b). This pattern is typical of calc-alkaline arc rocks in the Flin Flon Belt (Fig. 7.1g) and is consistent with Hughes Lake suite rocks plotting in the 'arc' field on the Th-Zr-Nb discriminant diagram (Fig. 6.2b).

Included in the Hughes Lake suite on Figures 4 to 7 is a fine grained quartz diorite, representative of a suite of small intrusions spatially restricted to the calc-alkaline suite. The geochemical similarity of the quartz diorite and andesites is striking and is consistent with the interpretation that the intrusions are synvolcanic (Gilbert et al., 1980; Syme, 1985).

Hughes Lake basalt

Hughes Lake basalt (1 km thick) overlies the Hughes Lake calc-alkaline suite and is in turn overlain by 200 m of epiclastic sedimentary rocks (Gilbert et al., 1980; Syme, 1985). The contact with the Hughes Lake calc-alkaline suite is stratigraphically and geochemically abrupt (Syme, 1985). Hughes Lake basalt contains normative hypersthene and olivine and has Mg numbers ranging from 48-58 (Syme, 1985). It was termed a "transitional" basalt by Syme (1985) in view of its high P_2O_5, Zr and LREE contents.

New ICP-MS data confirm that Hughes Lake basalt is LREE-enriched (Fig. 5.3c), distinct from, for example, Cockeram Lake tholeiitic basalt (Fig. 5.1a). The REE and MORB-normalized patterns displayed by Hughes Lake basalt are most similar to those displayed by mafic-intermediate volcanic rocks in the Hughes Lake calc-alkaline suite: 1) broadly concave-upward chondrite-normalized REE patterns, and 2) positive Th and negative Nb, Zr and Ti anomalies on a MORB-normalized extended element diagram (Figs. 5.3c, 7.3c). Nevertheless, its abrupt contact with the Hughes Lake suite and the probable tholeiitic character of Hughes Lake basalt (Syme, 1985) suggest that the two are not petrogenetically linked. Hughes Lake basalt has a strong arc geochemical signature (Figs. 6.2d, 8.2b), enriched in LILE, LREE and certain HFSE, and thus is best termed an 'enriched arc tholeiite'.

Keewatin River basalt

The arc-shaped belt of volcanic and related sedimentary rocks exposed east of the Keewatin River, between Sickle and Hughes lakes, is separated from the Southern Belt by the Johnson Shear Zone. The belt comprises three major units: mafic flows and tuff (maximum 2500 m thick), dacite (790 m) and greywacke-siltstone (840 m). Mafic flows and volcaniclastic rocks in the Keewatin River Belt are poorly exposed and commonly epidotized (Gilbert et al., 1980). All of the exposed flows are aphyric and massive; primary structures other than sporadic amygdales have been obliterated during metamorphism and deformation. The wedge-shaped unit of mafic lapilli tuff and plagioclase crystal tuff within Keewatin River basalt is a maximum of 335 m thick (Gilbert et al., 1980); its composition is identical to that of mafic flows which dominate the unit.

Keewatin River basalts (49-55 wt.% SiO_2, 3.9-4.6 wt.% MgO) are tholeiitic, have straight, very slightly LREE-enriched chondrite-normalized REE patterns (Fig. 5.3g), and have MORB-normalized extended element patterns displaying a strong arc signature (positive Th, negative Nb, Zr, Hf and Ti anomalies; Fig. 7.3g). They also plot in the arc field on TiO_2 vs. MgO and Th-Zr-Nb discrimination diagrams (Figs. 8.2c, 6.2f). These basalts have among the highest Th/Nb ratios recorded in the Southern Belt. They contrast sharply with the porphyritic and aphyric mafic flows in the adjacent Miskwa Lake Belt (see below) indicating they represent distinct and unrelated stratigraphic successions.

Miskwa Lake porphyritic basalt

The belt of volcanic and sedimentary rocks extending southeast from Wasekwan Lake is structurally separated from the adjacent Southern Belt (Gilbert et al., 1980) by the Johnson Shear Zone. The belt contains a northwest-trending isoclinal anticline cored by an elongate tonalite pluton. The oldest unit in the belt is aphyric basalt which occurs in the centre of the belt northwest of Miskwa Lake.

Porphyritic basalt occurs along the entire northeastern margin of the belt, between Wasekwan and Sickle lakes. The unit youngs to the northeast and is 460-800 m thick; it includes pyroxene-plagioclase phyric, plagioclase phyric and aphyric mafic flows. Some flows display internal differentiation and settling of phenocryst phases.

Miskwa Lake porphyritic basalts (48-51% wt.% SiO_2, 4.6-5.7 wt.% MgO) are tholeiitic and display flat to slightly concave-downwards chondrite-normalized REE patterns, at about 5-10 times chondritic values (Fig. 5.3e, f). Plagioclase phyric members have small positive Eu anomalies. These rocks display depleted MORB-normalized extended element patterns (Fig. 7.3) characterized by relatively flat profiles, negative Zr and Hf anomalies, and small positive Th anomalies. Notably, they do not show negative Ti anomalies. In these aspects, Miskwa Lake porphyritic basalt most closely resembles the "depleted basalts" (Divisions D and E) in the Northern Belt (Fig. 7.6e). They have among the lowest Th/Nb ratios in the entire Southern Belt but plot in the "arc" field on a TiO_2 vs. MgO diagram (Fig. 8.2d)

Miskwa Lake aphyric basaltic andesite

Aphyric mafic flows in the Miskwa Lake Belt occur in two distinct associations: 1) intercalated with porphyritic basalt, most commonly in that part of the porphyritic basalt unit lying between Miskwa and Wasekwan lakes, and 2) in a distinct unit occurring along the length of the Miskwa Lake Belt, southwest of the porphyritic basalt unit. These stratigraphically distinct aphyric mafic volcanic suites are also geochemically distinct (see below).

Aphyric flows intercalated with porphyritic basalt are massive and commonly amygdaloidal. They are more siliceous (53-57 wt.% SiO_2) and less magnesian (3.1-3.8 wt.% MgO) than Miskwa Lake porphyritic basalt and are best termed basaltic andesites. They have slightly concave-downwards chondrite-normalized REE patterns (Fig. 5.3f) similar in shape and REE abundance to porphyritic basalt. MORB-normalized extended element patterns are flat except for negative excursions at Zr, (Hf) and (Nb), and positive Th anomalies. Negative Ti anomalies are absent. Th/Nb ratios are low and Th contents tend to be as high or higher than porphyritic basalt. In general the trace element profiles of these aphyric basaltic andesites are similar to those of the associated porphyritic basalts, suggesting the units are co-magmatic. The more evolved major element composition of the aphyric basaltic andesite flows suggests that they may be related to the porphyritic basalts by fractional crystallization.

In contrast, a single analysis of the aphyric basaltic andesite (56.7 wt.% SiO_2, 4.4 wt.% MgO) lying in the central portion of the Miskwa Lake Belt is slightly LREE-enriched (Fig. 5.3d) and has a MORB-normalized extended element profile characterized by negative anomalies at Nb, Zr, Ti and Y, and higher Th contents (Fig. 7.3d). This profile is typical of arc rocks. If this analysis is representative of the entire unit then the aphyric mafic unit is unrelated to the aphyric basaltic andesites associated with the porphyritic basalts.

Lynn Lake Belt-Kisseynew Domain margin

Although the volcanic rocks at the southwest end of the Lynn Lake Belt are considered as part of the Southern Belt, they occupy thrust sheets that also extend along the north flank of the Kisseynew Domain, possibly for hundreds of kilometres in the Granville Lake deformation zone (Zwanzig, 1990 and Fig. 2). The volcanic rocks, which are interpreted as ocean-floor types that formed in a marginal basin, are generally overlain, unconformably or disconformably, by continental arenites and conglomerate of the Sickle Group (Fig. 3.1). On the south side of Granville Lake, several thrust sheets of volcanic rocks are structurally underlain by the Burntwood Group greywacke-mudstone turbidites, which are interpreted as deep-water facies equivalents of the Sickle Group. The new geochemical data are consistent with the thrust-sheet model and make the Granville Lake assemblage the largest exposure of ocean-floor basalt, gabbro, cherty sediments and ocean island basalt (see below) in the Trans-Hudson Orogen in Manitoba.

The two main thrust sheets contain superficially identical basaltic flows and gabbro sills, originally called the Tod Lake aphyric basalt (Gilbert et al., 1980). The southeastern (upper) sheet contains well preserved basalt south of Hatchet Lake and on Granville Lake. In this report the term 'Tod Lake basalt' is used for the mafic flows in this (southeastern) thrust sheet. Exposures of the northwestern thrust sheet are restricted to the areas northeast and southwest of Hatchet Lake.

Basalt in the latter sheet is herein renamed 'Hatchet Lake basalt' based on its unique geochemistry. The basaltic thrust sheets were folded both before and after deposition of the Burntwood and Sickle groups.

Tod Lake basalt

Tod Lake basalt comprises units of massive and pillowed flows, locally overlain by pillow breccia and hyaloclastite. Rhyolite dykes or felsic tuff are rare in the basalt. The rock suite extends for 20 km from Hatchet Lake to the south end of Laurie Lake. A narrow, complexly folded belt containing amphibolite that is interpreted as Tod Lake basalt extends over 30 km to the east (Fig. 2). There is also a possible western extension of Tod Lake basalt on Laurie Lake. The greatest apparent thickness (850 m) of the rock suite occurs near its structural contact with the Fox Lake porphyritic basalt.

Up to 350 m of Tod Lake basalt extend for 40 km along peninsulas on the south side of Granville Lake. There, the basalt is intruded by diabase and gabbro, and by pyroxenitic gabbro at the base the section. Commonly, the basalt is structurally intercalated at the base with sedimentary/tectonic breccia, and is structurally underlain by boulder-bearing feldspathic greywacke-turbidite (Granville Lake greywacke) and Burntwood Group greywacke-mudstone turbidite (Zwanzig, 1981). It is stratigraphically interlayered with the transitional to alkaline, mafic-ultramafic, Pickerel Narrows amphibolite. It is conformably overlain by chert, iron formation and fine grained siliciclastic rocks; elsewhere it is unconformably overlain by the Sickle Group (Fig. 3.1).

Tod Lake basalt is tholeiitic (Fig. 4.1g) and contains relatively high TiO_2 contents (Fig. 8.1f), unlike all arc basalts in the Lynn Lake Belt. The most fractionated rocks in the suite are ferrobasalts. Tod Lake basalt is typically high in Th/Nb and Th/Zr (Fig. 6.3a) similar to the arc tholeiites; LREE are slightly enriched except in a sample from the top of the unit (dotted in Fig. 5.4a). There are few HFSE anomalies, but a prominent Th spike exists in MORB-normalized extended element plots (Fig. 7.5a and b).

Tod Lake basalt is interpreted as a contaminated MORB or an arc-rift basalt similar to Scotty Lake basalt in the Flin Flon Belt (Fig. 7.1b, Syme et al., in press). It is also similar to Fish Lake basalt at the east margin of the Kisseynew Domain, adjacent to the Thompson Nickel Belt (Fig. 7.1h, Zwanzig, unpublished data) The more primitive flow near the top of the section at Tod Lake is transitional between typical Tod Lake basalt and Hatchet Lake basalt (see below).

Hatchet Lake basalt

Massive, pillowed and hyaloclastic basalt, similar to Tod Lake basalt but less evolved, is exposed for 20 km from Laurie Lake to the south shore of Dunphy Lakes. Nearly half the exposures in this unit are mafic sills and dykes or thick flows. The unit is up to 500 m thick; its base is reinterpreted here to be a thrust fault, which has Burntwood Group and Granville Lake greywackes and Sickle Group in the footwall (Fig. 3.1).

Hatchet Lake basalt has a uniform tholeiitic composition (e.g. Fig. 4.1g). Flows, breccia and gabbro show slight LREE depletion (Figs. 5.4b, c). Extended element plots have similar profiles to modern N-MORB or BABB, except for slightly elevated Th (Fig. 7.5), a feature also shown by Paleoproterozoic N-MORB or BABB in the Flin Flon Belt (Fig. 7.1e). The presence of Hatchet Lake basalt in the same thrust stack as Tod Lake basalt, and the similar stratigraphy of the two rock suites suggests that they formed in the same marginal ocean basin. A differentiated sill within Hatchet Lake basalt shows low Th values throughout but slight Th contamination in the roof zone (e in Fig. 7.5f). A similar contamination/fractionation process may have affected Tod Lake basalt, which is assumed to be derived from the same magma type as Hatchet Lake basalt.

Pickerel Narrows amphibolite

Fine grained ultramafic to mafic amphibolite is interlayered with the upper part of the Tod Lake basalt on Granville Lake. The amphibolite forms units (up to 35 m thick) of dark green- to grass green-weathering fragmental and massive volcanic rocks. Rocks interpreted as ultramafic to mafic tuff-breccia or reworked tuff contain layers defined by different clast size and phenocryst populations. The matrix contains up to 20% olivine porphyroblasts (<5 mm). Layers containing rounded, ultramafic blocks (up to 20 cm long) and angular slabs (up to 2 m long) may be conglomerate beds or breccia. Uniform schistose amphibolite units are interpreted as flows; partly carbonatized ultramafic pillows occur locally. An uppermost layer of Pickerel Narrows amphibolite is overlain by chert, pelite and siliceous marble; locally it is unconformably overlain by the Sickle Group.

Pickerel Narrows amphibolite displays LREE enrichment and exceptionally steep negative slopes on a chondrite-normalized REE plot (Fig. 5.4d). Nb contents are elevated so that the amphibolite falls into the field of ocean island basalt (OIB) on a tectonic discriminant diagram (Fig. 6.3c). The very high Ti content for a mafic-ultramafic assemblage is also consistent with an affinity for OIB (Fig. 8.2e). The unit has no negative HFSE anomalies on a MORB-normalized diagram (Fig. 7.5g) but shows a slight positive Ti excursion, similar to that in ocean island basalt in the Flin Flon Belt (Fig. 7.1d).

Northern Belt

Introduction

The Northern Belt consists of a volcano-sedimentary assemblage (together with subordinate intrusive rocks) that extends from the vicinity of Lynn Lake northeast to Eagle Lake, and thence east and southeast to Barrington Lake (Map OF99-13-1 in back pocket). Further to the east, the Northern Belt extends to the south shore of MacBride Lake, and is terminated in a series of supracrustal remnants within a granitoid terrane in the Fraser Lake area (NTS area 63B/13; Gilbert, 1993). West of Lynn Lake, the Northern Belt diminishes in thickness toward a drift covered area south of Zed Lake. Mapping indicates the Lynn Lake-Eagle Lake area of the Northern Belt is essentially hom oclinal and northwest- to north-facing; localized reversals of facing direction have been attributed to minor folding (Gilbert et al., 1980). In the Barrington Lake area, the stratigraphic sequence is not clearly defined due to major folding (Gilbert, 1993).

The sequence that is inferred from field data in the Lynn Lake-Eagle Lake area is characterized by a basal felsic volcanic rock suite at the southeast (Lynn Lake rhyolite, ca. 2400 m thick; Division A, Gilbert et al., 1980). The rhyolite is overlain by intermediate to mafic volcanic rocks (Division B), a volcanogenic sedimentary division (C), and predominantly mafic volcanic divisions (D and E) (Fig. 3.3). Northwest of Lynn Lake town, the volcano-sedimentary sequence is topped by an 80 m thick oxide-facies iron formation, whereas west of Lynn Lake, a felsic volcanic lens overlies Division E at a locality north of Motriuk Lake.

Five compositionally distinct, tholeiitic volcanic rock units are defined by geochemical data in the Lynn Lake-Eagle Lake area (Fig. 10). Whereas these geochemical units conform closely to the stratigraphic divisions of Gilbert et al. (1980), equivalent geochemical rock units in the Barrington Lake area cannot be correlated with a stratigraphic order due to structural complexity.

E-MORB-like basalt

A unit of E-MORB-like basalt is the southernmost mafic volcanic component of the Northern Belt in the Lynn Lake-Eagle Lake area; similar basalt occurs further east near Farley Lake, in the Barrington Lake area (Map OF99-13-1 in back pocket). The estimated maximum thickness of the E-MORB-like basalt unit is 200 m. The mafic flows are massive to pillowed, and include both aphyric and porphyritic types, with up to 20% plagioclase phenocrysts and 15% hornblende pseudomorphs after pyroxene.

Northern Belt E-MORB-like basalt is tholeiitic (Fig. 4.2a) and characterized by a slightly inclined REE profile with a smooth negative slope (Fig. 5.5a) similar to the pattern of modern E-MORB. The basalt does not display negative Nb and Ti anomalies (Fig. 7.6a), in contrast to the patterns of arc basalts further north in the volcanic section (Fig. 7.6c to e). The basalt plots in the fields of E-MORB in basalt discrimination diagrams based on Zr/Th/Nb ratios and TiO_2/MgO ratios of modern volcanic rocks (Figs. 6.4a, 8.3a). Northern Belt E-MORB-like basalt is in the normal alumina range (<17wt.% Al_2O_3) in contrast to most other basaltic rocks in the Lynn Lake-Eagle Lake area (Fig. 9.2a), whereas total Fe and TiO_2 are higher than in other mafic volcanic components in the Northern Belt (Fig. 8.3; Table 1).

The incompatible element and REE profiles of Northern Belt E-MORB-like basalt show moderate enrichment of LREE and Th relative to MORB, whereas HFSE contents are similar to MORB values, except for elevated Nb. These patterns are similar to those of modern and Paleoproterozoic E-MORB in extension-related, back-arc basins

(Fig. 7.1f). Such rocks are typically associated with of arc rifting, and are gradational with arc-type mafic volcanic assemblages. Characteristic features of arc-rift basalts are smooth REE profiles that are flat to moderately (negative) sloping, Fe enrichment, lack of HFSE depletion and absence of the negative Nb anomaly typical of subduction-related arc magmas (Fig. 7.1c).

Transitional basalt and andesite

'Transitional' mafic volcanic rocks in the Lynn Lake area are located stratigraphically between E-MORB-like basalt to the southeast and high-LREE basalt to the northwest (within Division B in Gilbert et al., 1980; Fig. 10). The transitional rocks are geochemically intermediate between (and apparently conformable with) flanking E-MORB-like and high-LREE basalts. Transitional basalt also occurs at a locality northeast of Lynn Lake town within Division D, and further east, close to Farley Lake in the Barrington Lake area. The transitional rocks are lithologically akin to arc volcanic rocks, being typically porphyritic and locally associated with fragmental volcanic deposits; one occurrence consists of a boulder in a heterolithologic breccia unit. Plagioclase phenocrysts are abundant (ca. 30%) and locally associated with hornblende pseudomorphs and minor quartz amygdales.

Transitional volcanic rocks are characterized by higher SiO_2 and Al_2O_3 and lower FeO^t than E-MORB-like basalt (Table 1); extended element plots display negative Ti anomalies (Fig. 7.6b) similar to patterns in subduction-related magmas (e.g. Fig. 7.6c), and in contrast to the smooth profiles of E-MORB-like basalt (Fig. 7.6a). Compared to arc basalts, the transitional volcanic rocks contain higher Nb and hence plot in the E-MORB field in the Th-Zr-Nb diagram (Fig. 6.4b). Compared to E-MORB-like basalt, TiO_2 is relatively depleted in the transitional rocks; thus they plot within the field modern arc basalt in the TiO_2 vs. MgO diagram (Fig. 8.3b).

The occurrence of transitional volcanic rocks that are stratigraphically and compositionally intermediate between flanking E-MORB-like and high-LREE basalts in the Lynn Lake area provides evidence for stratigraphic continuity between arc volcanic rocks to the northwest (high-LREE basalt suite) and the E-MORB-like basalt of inferred arc-rift origin at the southeast side of the Northern Belt.

High-LREE basalt

High-LREE basalt (formerly mapped as 'Division B' in Gilbert et al., 1980) is a lithologically diverse geochemical/stratigraphic component that extends northeast through the area between Frances and Sheila lakes (Fig. 10). Compositionally similar rock units occur further northeast, near Minton Lake. Whereas the contact between high-LREE basalt and transitional volcanic rocks to the southeast is apparently conformable, the contact relationship with sedimentary rocks to the northwest is unknown due to lack of exposure. The high-LREE basalt suite, which is approximately 1 km thick, contains mafic to intermediate volcanic and related intrusive rocks, and minor felsic volcanic units. Tuff and coarse heterolithologic breccia of probable mass-flow origin are intercalated with massive and locally brecciated basaltic flows. These rocks are predominantly porphyritic, with abundant plagioclase phenocrysts (up to 35%) and lesser hornblende pseudomorphs after pyroxene; aphyric flows comprise less than 20% of the volcanic rock suite. Vesicles and quartz amygdales occur sporadically in the mafic flows, but pillow structure is rare.

Northern Belt high-LREE basalt is an arc-type suite that is distinguished by high alumina content (average Al_2O_3 = 19.07%; Table 1 and Fig. 9.2c). Minor plagioclase-phyric basalt flows in the 'normal' alumina range (ca. 16% Al_2O_3) are apparently confined to a unit at the southeast margin of the volcanic suite. Al_2O_3 content in high-LREE basalt is not directly proportional to plagioclase phenocryst content (i.e., controlled by plagioclase fractionation), and a "high-alumina" source magma is inferred for this suite; the same inference was made for Northern Belt basalt by Syme (1985), and in the Barrington Lake area by Gilbert (1993). The rocks are characterized by enrichment in LREE and Th, and depletion in HFSE, resulting in high Th/Nb and La/Yb ratios (Table 1); these features are hallmarks of modern subduction-related magmas. High-LREE basalt plots in the volcanic arc fields of discrimination diagrams (Fig. 6.4c, 8.3c). The elevated FeO^t/MgO and SiO_2 contents and distinctive incompatible element profiles in high-LREE basalt compared to the depleted basalt suite indicate the former is relatively more evolved (compare Figs. 4.2c, e and 7.6c, e).

High-Mg basalt

Sporadic occurrences of high-Mg basalt (MgO>10 wt.%) within the central part of the Northern Belt are part of a stratigraphic unit within the "Agassiz Metallotect" (Fedikow, 1983), in part identified as a shear zone (Beaumont-Smith, pers. comm.). They occur at, or a short distance to the northwest of, the significant geochemical break between the high-LREE suite to the southeast and depleted basalt to the northwest (Fig. 10). In the vicinity of the town of Lynn Lake, the high-Mg basalt unit occurs on the south margin of the depleted volcanic rock suite (Division D in Gilbert et al., 1980), approximately 0.5 km northwest of the contact with sedimentary rocks (Division C) that extend through Margaret and Sheila lakes. The width and contact relationships of the high-Mg basalt unit are unknown, because the unit was not delineated during field mapping. Further east in the Barrington Lake area, high-Mg basalt occurs within the Agassiz Metallotect 4 km east of Nickel Lake. The high-Mg rocks, interpreted as volcanic flows, are typically aphyric, homogeneous and devoid of primary volcanic structures.

Northern Belt high-Mg basalt is komatiitic with <0.5 FeO^t/FeO^t+MgO at 11-16 wt.% Al_2O_3. The unit is interpreted as a component of the arc volcanic sequence that was derived from a different source magma from that of the contiguous depleted and high-LREE arc volcanic rocks.

Depleted basalt

Basalt with a distinctive depleted REE pattern is the predominant lithology in a diverse lithostratigraphic assemblage that extends along the northwest flank of the Northern Belt. This assemblage, which contains the same range of lithologic types as the high-LREE volcanic suite, consists of two apparently conformable components: 1) to the southeast, a 2500 m thick section of mafic flows and related breccia with minor tuff and felsic fragmental rocks (Division D in Gilbert et al., 1980) and 2) to the northwest, a 650 m thick sequence of mafic tuff and basalt, with subordinate volcanic breccia and fine grained sedimentary rocks (Division E).

Mafic flows consist of moderately to densely porphyritic basalt (with 10-40% plagioclase and up to 25% altered pyroxene phenocrysts) interlayered with subordinate aphyric units. Mafic to intermediate, heterolithologic breccia of debris-flow origin is a minor component of the section, in contrast to the high-LREE suite where mass flows are more prominent. The northwest flank of the depleted basalt suite consists mainly of moderately- to well-sorted mafic tuff and crystal (± lapilli) tuff; local graded bedding, scouring and sporadic rip-ups suggest these rocks have been reworked by subaqueous turbidity currents. Northwest-facing graded beds near the northwest margin of the depleted basalt suite suggest the latter is the youngest part of the Northern Belt volcanic sequence. However, the structural data are insufficient to determine the age of this volcanic suite, because the contact relationships with flanking sedimentary rocks to the southeast (Division C in Gilbert et al., 1980) and iron formation to the northwest are not known.

Geochemical data indicate the two lithostratigraphic components are parts of a single depleted basalt suite characterized by a transitional arc-type to MORB-like geochemical signature. The volcanic rock suite is distinguished by REE depletion relative to N-MORB, in contrast to the signature of more typical arc-type volcanic rocks such as high-LREE basalt, which is characterized by LREE and LILE enrichment (compare Figs. 5.5e, c and 7.6e, c). Depleted basalt is also characterized by HFSE depletion, typical of subduction-related magmas and commonly attributed to derivation from a refractory mantle source. Depleted basalt differs from most modern juvenile arc basalts (and high-LREE basalt) in its low Th content and relatively flat incompatible element profile. In the Th-Zr-Nb discriminant diagram for modern volcanic rocks, Northern Belt depleted basalts overlap the arc/E-MORB dividing line due to their low Th content (Fig. 6.4e), whereas in the TiO_2 vs. MgO diagram, these rocks plot in the field of modern arc basalt (Fig. 8.3e). The geochemical signature of depleted basalt is very similar to that of primitive low-Ti tholeiitic Welch Lake basalt and associated high-Ca boninite that form the basal part of the eastern Flin Flon-Snow Lake Greenstone Belt in the Snow Lake area (Bailes, pers. comm.; Table 1). Trace element depletion and relatively low values of SiO_2, TiO_2, and FeO^t/MgO indicate the depleted basalt suite at the northwest flank of the Northern Belt is less evolved than high-LREE basalt to the southeast. The high alumina content (Al_2O_3 >17 wt.%) noted in high-LREE basalt is also characteristic of the depleted basalt suite, except for a stratigraphic unit of 'normal-alumina' basalt (Al_2O_3 = 13.3-15.5 wt.%) that occurs in the area northwest of Arbour Lake.

Barrington Lake area basalts

The east part of the Northern Belt that extends along the south side of Barrington Lake (Map OF99-13-1 in back pocket) consists mainly of mafic volcanic flows designated here as 'Barrington (S) basalt'; the maximum width of the belt at this locality is 4.5 km, but the estimated true stratigraphic thickness is no more than 2 km (Gilbert et al., 1980). An arcuate supracrustal belt designated 'Barrington (N) basalt' that encircles the south part of Barrington Lake is interpreted as a segment of the Northern Belt that has been displaced northward, due to the emplacement of an ovoid granitoid stock (Gilbert, 1993). Whereas the majority of Barrington Lake area basalts are geochemically akin to the depleted basalt suite in the Lynn Lake-Eagle Lake area, representative units of all five mafic volcanic types identified in the latter area are also present in the Barrington Lake area.

Barrington (S) basalt

The eastern part of the Northern Belt immediately south of Barrington Lake contains all the lithologic types identified within the belt in the Lynn Lake area, as well as a substantial (450 m wide) oxide-facies iron formation (within the Agassiz Metallotect) that is best exposed at Farley Lake. Basaltic flows and related breccia are the predominant volcanic lithologies in the section south of Barrington Lake; these consist of plagioclase (± pyroxene) phyric units intercalated with subordinate aphyric basalt and associated intrusive phases. Flow lamination defined by diffuse trails of phenocrysts or amygdales is common; pillow structure is more rare, and is mainly confined to the area north of Gordon Lake, where small (<0.75 m) bun-shaped pillows face north. Sporadic epidotic or silicic alteration of probable sea-floor origin is common in Barrington (S) basalt, and is especially pervasive in the area south of Farley Lake, where carbonatization is also conspicuous.

Mafic tuff and crystal (± lapilli) tuff constitute approximately 30% of the Barrington (S) basalt suite. The tuffs are lithologically similar to equivalent rocks in the depleted basalt suite in the Lynn Lake area; sporadic turbidite-type features suggest the rocks have, in part, been redeposited by turbidity currents. Heterolithologic volcanic breccia of probable mass flow origin in the Barrington Lake area is mainly confined to the area west of White Owl Lake.

The extended element profile of Barrington (S) basalt, which is characterized by elevated Th, a negative Nb anomaly and depleted HFSE, indicates a volcanic arc affinity (Fig. 7.6f). The compositional similarity between Barrington (S) basalt and depleted basalt in the Lynn Lake-Eagle Lake area is apparent in Table 1, and is also readily demonstrated by comparing the respective plots of the two basaltic types (f and e in Figs. 5.5, 6.4, 7.6, 8.3 and 9.2). In particular, the incompatible element plots of these two volcanic suites are virtually coincident, except for Th and Nb values (Fig. 7.6f and e). The more evolved units within Barrington (S) basalt, which are characterized by high Th, SiO_2 and FeO^t/MgO values in the upper ranges for the volcanic suite, bridge the compositional gap between depleted and high-LREE basalt types in the Lynn Lake area (f, e and c in Figs. 4.2, 6.4 and 7.6). This suggests the latter volcanic types may in fact be parts of a geochemically continuous sequence, even though they are locally separated by a high-Mg basalt unit and/or a lensoid sedimentary formation.

A wide range of Al_2O_3 content is characteristic of Barrington (S) basalt, which is arbitrarily divided into 'high-alumina' and 'normal-alumina' types at Al_2O_3 = 17 wt.% (Table 2). Most analyzed rocks are plagioclase phyric, although aphyric types occur in both normal- and high-alumina groups. Thus Al_2O_3 content is not directly controlled by the degree of plagioclase fractionation, although high-alumina basalts are, on average, richer in plagioclase (average outcrop-based estimates of plagioclase phenocryst content in normal- and high-alumina basalt groups are 13% and 22% respectively). Geochemical data suggest the high-alumina basalt type is compositionally gradational with normal-alumina basalt (Table 2; Fig. 9.2f). Incompatible element and REE depletion, which is characteristic of the Barrington (S) basalt suite, is relatively more pronounced in the high-alumina type. Such depletion in arc volcanic rocks has been attributed to partial melting and basalt extraction prior to extrusion (Woodhead et al., 1993; Kerrich and Wyman, 1996). The most evolved units in Barrington (S) basalt (i.e., those with highest SiO_2, FeO^t/MgO, TiO_2, and overall REE contents) occur in the normal-alumina group (Table 2).

Barrington (N) basalt

Barrington (N) basalt contains the same range of volcanic lithologies as Barrington (S) basalt, with which it is laterally continuous. Barrington (N) basalt is locally pervaded by granitoid phases in marginal zones of the supracrustal belt, where the volcanic rocks are variously recrystallized to amphibolitic gneiss, locally with garnet or amphibole porphyroblasts. Barrington (N) basalt is of arc volcanic affinity and is geochemically comparable with Barrington (S) basalt (compare plots g and f in Figs. 5.5, 7.6 and 8.3). Extended element profiles show Barrington (N) basalt is akin to depleted basalt in the Lynn Lake-Eagle Lake area, except for one unit that is equivalent to high-LREE basalt (Fig. 7.6g). The latter unit, together with occurrences of E-MORB-like, transitional and high-Mg basalts in the Barrington Lake area (Fig. 7.6a, b and d) show that there is no difference in the geochemical range of basaltic rock types between the Lynn Lake and Barrington Lake areas. Thus the magmatic evolution of volcanic rocks in both the west and east parts of the Northern Belt was probably the same. Whereas the various basalt types are stratigraphically distinct in the Lynn Lake area, this is not the case in the Barrington Lake area, probably due to the effects of major folding and possibly faulting in the latter area (Gilbert et al., 1980).

FELSIC VOLCANIC ROCKS

Introduction

Felsic volcanic rocks and related intrusions constitute an areally minor but economically significant part of the Lynn Lake Belt, in view of the commonly observed relationship between base metal mineralization and felsic volcanism.

The largest felsic volcanic unit in the Lynn Lake Belt is the Lynn Lake rhyolite, which occurs at the base of the stratigraphic succession in the Northern Belt (Fig. 3.3 and Gilbert et al., 1980). Minor massive to fragmental felsic units, typically 1-20 m wide, occur elsewhere in the Northern Belt, within both the predominantly mafic volcanic suites described previously, and the sedimentary formation (Division C in Gilbert et al., 1980). Arbour Lake rhyolite is a minor flow or intrusion within the Agassiz Metallotect, northeast of Lynn Lake. The more prominent Barrington Lake rhyolite is a 230 m thick felsic flow and fragmental unit in the east part of the Northern Belt, close to the south shore of Barrington Lake (Map OF99-13-1 in back pocket).

In the Southern Belt, rhyolite bodies occur within the mafic to intermediate volcanic units of the Fox Mine succession and Hughes Lake calc-alkaline complex. Rocks of dacitic composition are the predominate felsic rock type in the south and southwest parts of the Southern Belt (Keewatin River area and Fox Mine area).

Trace element classification

Various geochemical schemes have been developed to help distinguish prospective rhyolites from those which likely do not host base metal massive sulphide mineralization. Lesher et al. (1986) subdivided Archean felsic metavolcanic rocks into FI, FII and FIII types based on their trace and rare earth element geochemistry. Type FI rocks (with steep negative REE slope) are considered to be barren of significant VMS deposits and are derived from deep magma chambers where fractional crystallization has taken place. Type FII felsic rocks (LREE-enriched, with small negative Eu anomalies) are considered to be derived either from high-degree partial melting of a crustal source or fractional crystallization of an intermediate parent magma, and in the Archean are only rarely associated with VMS deposits. Type FIII felsic rocks (relatively flat, elevated REE profiles with prominent negative Eu anomalies) are considered to be derived from subvolcanic, high level magma chambers that are interpreted to be the heat source for convective hydrothermal systems. Type FIII rhyolites are the most productive with respect to base metal mineralization. Although the empirical classification of Lesher et al. (1986) cannot be extended to all post-Archean terranes (see Syme, 1998), it provides a useful basis of comparison.

Lynn Lake Belt rhyolites have relatively low Zr/Y ratios because they are depleted in HFSE, and particularly Zr, relative to Archean felsic metavolcanic rocks. Mafic arc rocks (basalt, basaltic andesite) in the Lynn Lake Belt are similarly depleted in HFSE and are interpreted to have been derived from a highly refractory sub-arc mantle source, as in the Flin Flon Belt (Stern et al., 1995b).

The Zr/TiO_2 ratio is used as an index of fractionation and, in this report, as a basis for comparison with better known felsic volcanic rocks in the Flin Flon Belt, which provides a basis for tectonic discrimination between arc-assemblage rhyolite and extension-related rhyolite (Syme, 1998). The Flin Flon data also suggest that Th/Yb ratios are useful in distinguishing tholeiitic from calc-alkaline rhyolites and these ratios are plotted against chondrite-normalized Yb for the Lynn Lake Belt rhyolites.

Southern Belt

Snake Lake dacite

Five lens-shaped bodies of felsic volcanic rocks (<4 km long and <500 m thick) occur in the Fox Mine-Snake Lake-East Dunphy Lake area. They consist mainly of massive dacite, are locally plagioclase phyric, and are interpreted as endogenous domes. Much of the dacite is altered, commonly to assemblages containing several of the minerals staurolite, garnet, cordierite, anthophyllite and magnetite. Unaltered dacite was analyzed from the two largest domes. The domes have been interpreted to occupy a stratigraphic or structural position between Fox Lake porphyritic basalt and the Fox Mine succession (Fig. 3.1 and Gilbert et al., 1980).

Fine grained felsic rocks that are compositionally equivalent to low-SiO_2 rhyolite occur at the 'top' of the body at East Dunphy Lake and in thin elongate units further west in the Fox Mine succession. They include massive and tuffaceous rock types. The 'tuff' at West Dunphy Lake is sodic and therefore probably altered.

Snake Lake dacite has elevated LREE with a small negative Eu anomaly (Fig. 11a), a pattern that is typical for arc rhyolite in the Flin Flon Belt (Syme, 1998) and is also similar to the signature of type FII Archean rhyolite (Lesher et al., 1986). However, one sample of Snake Lake rhyolite has a more moderately inclined chondrite-normalized REE profile. Zr contents in all the felsic rocks in the west part of the Southern Belt are uniformly low, whereas TiO_2 is proportional to mafic mineral content, being highest in dacite. Snake Lake dacite and associated low-SiO_2 rhyolite plot in the field of Flin Flon arc rhyolites, based on Zr/TiO_2 ratios (Fig. 12a); Th/Yb ratios are high, similar to rhyolites in calc-alkaline assemblages at Flin Flon (Fig. 13a).

Geochemical data indicate the Snake Lake dacite is calc-alkaline; the rock unit is provisionally interpreted to be related to the underlying calc-alkaline Fox Lake porphyritic basalt. The Snake Lake dacite occurs at a significant break between older calc-alkaline and younger tholeiitic volcanic rocks. Widespread hydrothermal alteration occurred during this interval in the Snake Lake dacite, and in the overlying Fox Mine succession that hosts the Fox Lake VMS deposit.

A rhyolite unit above the Snake Lake dacite has a flatter REE slope, comparable to the profiles of rhyolites in tholeiitic assemblages at Flin Flon (Fig. 11b). The sample from the Fox Mine succession has a moderate Eu anomaly and is compositionally similar to rhyolite associated with the Flin Flon VMS deposit (Syme, 1998).

Rhyolites in the Hughes Lake calc-alkaline suite

As discussed in a previous section, the Hughes Lake calc-alkaline suite (Gilbert et al., 1980; Syme, 1985) occurs in three geographic segments: 1) Cartwright Lake-Pole Lake, 2) Hughes Lake and 3) Chepil Lake. Rhyolite analyses from all three segments are in the database and form two distinct compositional associations: i) rhyolites in the Cartwright Lake-Pole Lake and Hughes Lake segments have trace element compositions similar to the Lesher et al. (1986) FIII type (relatively flat REE profiles with prominent negative Eu anomalies, and ii) rhyolites from the Chepil Lake segment correspond to FII type (LREE-enriched, with small negative Eu anomalies).

Sampled "FIII" rhyolites from the Cartwright Lake-Pole Lake and Hughes Lake segments include the Cartwright Lake rhyolite (Gilbert et al., 1980), a rhyolite in the dominantly dacitic section at Pole Lake, and a rhyolite at the top of the calc-alkaline section east of Hughes Lake. These rhyolites are all relatively siliceous (77-79 wt.% SiO_2). They have moderately high Zr/TiO_2 ratios, in the range of extension-related rhyolites in the Flin Flon Belt, and interestingly plot along a line of constant Zr/TiO_2 (Fig. 12b). Th/Yb ratios are in the lower range of the field defined by Flin Flon Belt calc-alkaline rhyolites, consistent here with their association with the Hughes Lake calc-alkaline suite.

Although the REE profiles of these rhyolites from the Hughes Lake calc-alkaline suite are similar to Archean FIII rhyolites, they have significantly lower Zr/Y ratios than Archean rhyolites (1.8-3.3 vs. 3.4-9.3; Lesher et al., 1986). Th contents in these rhyolites are 5.7-8.5, within the range of Archean FIII rhyolites (1.5-16; Lesher et al., 1986) and considerably higher than similar "FIII" rhyolites at Flin Flon.

Rhyolites in the Chepil Lake segment of the Hughes Lake calc-alkaline suite are compositionally very distinct from those discussed above. These rhyolites are LREE-enriched (Fig. 11e), with lower Zr/TiO_2 ratios and higher Th/Yb ratios. They are intermediate between the Flin Flon-defined "arc" and "extension-related" fields on a Zr vs. TiO_2 diagram (Fig. 12b), and plot solidly in the calc-alkaline field on a Th/Yb vs. Yb_N diagram (Fig. 13b). The Zr/Y ratios of these rhyolites (6.5-9) are higher than for the Lynn Lake "FIII" rhyolites and are much higher than the Zr/Y of any rhyolite in the western Flin Flon Belt (cf. Syme, 1998).

Keewatin River Belt

Keewatin River dacite

A wedge-shaped unit of dacitic volcanic rocks occurs in the Keewatin River Belt and is the sole felsic extrusive component in the Keewatin River and Miskwa Lake supracrustal segments (Gilbert et al., 1980). The dacite youngs to the west and overlies Keewatin River basalt (described in a previous section). A thin (30-100 m) unit of mafic tuff, magnetite-silicate iron formation and felsic rocks occurs at the contact between the basalt and the dacite. The dacite, composed of subequal amounts of massive plagioclase phyric flows and crystal-lithic tuff, is conformably overlain by greywacke and siltstone, in part derived from the dacitic succession.

The dacite (62-70 wt.% SiO_2, 0.9-2.7 wt.% MgO) is characterized by concave-upwards, moderately LREE-enriched chondrite-normalized REE patterns which lack any Eu anomalies (Fig. 5.3h). On a MORB-normalized extended element plot (Fig. 7.3h) the dacite has prominent negative Nb and Ti anomalies, slight negative Zr anomalies, and a spike at Th. Like the mafic rocks in the Keewatin River Belt, the dacite has amongst the highest Th/Nb ratios of all rocks in the Southern Belt. Like the Keewatin River basalt it has a clear arc signature. Its trace element similarity with the underlying basalts suggests that the intermediate and mafic successions are likely related, possibly by crystal fractionation.

Hatchet Lake-Granville Lake Belt

Laurie Lake felsic rock

Fine grained felsic rocks, interpreted as volcanic, are rare in the Tod Lake basalt and absent in the Hatchet Lake MORB. One felsic volcanic unit sampled on Laurie Lake, which overlies amphibolite, is itself overlain by iron formation interpreted as part of the Tod Lake ocean-floor basaltic and sedimentary succession. This fine grained uniform felsic gneiss, which is interpreted as a tuff, has an unusually low K_2O content (0.3-0.4 wt. %). Samples from the lower and upper part of the unit have distinctive trace element signatures with relatively flat REE profiles and negative Eu anomalies, very similar to the REE profile of rhyolite that is implicated in arc rifting in the Flin Flon Belt (Fig. 11c; Syme, 1998). Low Zr/TiO_2 and relatively high Yb and Y also suggest that this is an extension-related rhyolite (Figs. 12a, 13a). The high Na_2O/K_2O and FeO^t/MgO ratios are typical for the final felsic fraction of a ferrobasalt/ferrogabbro fractionation sequence (e.g., Bailes, 1980, Zwanzig, 1994). This affinity is supported by a Y content >50 ppm, typical for 'oceanic' granitoids. Both on Laurie Lake and on the Flin Flon-Kisseynew margin, these rocks are associated with gold showings.

Northern Belt

Lynn Lake, Arbour Lake, Barrington Lake rhyolites

Lynn Lake rhyolite is a lensoid body up to 2400 m thick that extends for over 15 km along the south margin of the west part of the Northern Belt, between Frances Lake and northern Cockeram Lake (Fig. 10). The Lynn Lake rhyolite consists mainly of plagioclase ± quartz phyric massive felsic volcanic rock that is locally associated with minor epiclastic deposits. Widespread fragmentation in the rhyolite occurs in irregular zones that are gradational with massive, homogeneous domains; these zones are assumed to be due to in situ brecciation of the cooling felsic unit. Anastomosing biotite ± garnet-filled fractures are the focus of secondary alteration that has locally resulted in the development of 'pseudobreccia'. The north margin of the Lynn Lake rhyolite, which is intercalated with mafic volcanic rocks at the north shore of Frances Lake (Fig. 10), contains a zone of autoclastic rhyolite breccia with blocks up to 1 x 0.3 m. The 'Lynn Lake rhyolite (north)' sample (see below) was taken from one such fragment. The relative ages of rhyolite and basalt at Frances Lake are uncertain. Whereas the mafic rocks locally intrude the (supposedly older) rhyolite, graded bedding that faces southeast in the mafic volcanic section immediately north of the rhyolite suggests the felsic rocks are, in fact, relatively younger.

Geochemical data indicate three distinct felsic volcanic types in the Northern Belt.

(i) The Lynn Lake rhyolite is characterized by relatively elevated LREE, Zr, Zr/TiO_2 and Th/Yb, (Figs. 11f, 12c, 13c), typical of extension-related felsic volcanic rocks in the Flin Flon Belt (e.g., Grassy Narrows rhyolite; Syme, 1998).

(ii) Arbour Lake rhyolite is a massive porphyritic unit emplaced in plagioclase-phyric basalt within the Agassiz Metallotect, close to the north shore of Arbour Lake (Fig. 10). The dacite/rhyolite unit displays a fractionated trace element signature characterized by a pronounced, negative-sloping REE profile with HREE depletion, and elevated Th/Yb, typical of juvenile arc rhyolite (Figs. 11g, 13c). Arbour Lake rhyolite is comparable to the Solodiuk Lake rhyolite in the Flin Flon Belt (Syme, 1998), and is similar, in part, to Archean type FI rhyolite (Lesher et al., 1986).

(iii) Barrington Lake rhyolite is represented by three felsic volcanic units at the southeast corner of Barrington Lake that span a stratigraphic interval of 3.5 km. These rocks display relatively flat REE profiles with small negative Eu anomalies, similar to Flin Flon arc rhyolites. The REE pattern and relatively low Zr/TiO_2 and Th/Nb ratios (Figs. 11h, 12c, 13c) are comparable to the geochemical signature of tholeiitic juvenile arc rhyolite, including Flin Flon Mine rhyolite and associated Millrock Hill flows (Syme, 1998).

In summary, limited geochemical data for felsic volcanic rocks in the Northern Belt reveal a remarkable amount of variation in the setting of the various units. Of the three rhyolite types identified, arc-type Barrington Lake rhyolite appears to offer the best prospect for base metal mineralization, by virtue of its compositional similarity to the Flin Flon Mine rhyolite. The main felsic unit at Barrington Lake, which contains both massive and fragmental phases, is highly attenuated; thus the precise lithologic identity and the environment of emplacement of this unit are uncertain.

MAFIC INTRUSIVE ROCKS

Southern Belt

Mafic intrusive rocks from the Southern Belt in this database include fine- to medium-grained gabbros emplaced into 1) Hughes Lake basalt, northwest of One Island Lake, 2) Hughes Lake calc-alkaline suite, northwest of One Island Lake, 3) Cockeram Lake basalt, northwest of Foster Lake, and 4) Cockeram Lake basalt, south of Cockeram Lake. The MORB-normalized trace element patterns exhibited by these rocks (Fig. 7.4e) correspond to those of the units in which they are emplaced, suggesting they are synvolcanic intrusions. For example, the gabbro emplaced in Hughes Lake calc-alkaline suite rocks has the highest LREE, Th, and Nb contents and has a profile similar to that of mafic rocks in the calc-alkaline suite. Gabbros emplaced in tholeiitic Cockeram Lake basalt and Hughes Lake basalt have less evolved MORB-normalized trace element profiles, similar in general to arc tholeiitic basalts in the Lynn Lake Belt.

DISCUSSION AND ECONOMIC IMPLICATIONS

Grouping of the volcanic units based on their geochemical characteristics illustrates the wide variety of volcanic rocks in the Lynn Lake Belt (Table 3). The distribution of these geochemical groups and units is shown on Map OF99-13-1 (back pocket).

Geochemistry confirms the unique nature of the Northern and the Southern belts, and the Keewatin River Belt, Miskwa Lake Belt, and other narrow belts south of the Johnson Shear Zone. These geochemically unique suites, separated by chains of plutons, faults, shear zones or areas of no exposure, may be inferred to have become amalgamated during tectonic processes similar to those described for the better exposed and better studied Flin Flon Belt (Bailes and Syme, 1989, Lucas et al., 1996). Major discontinuities include:

1. the geochemical break that separates enriched and depleted tholeiitic suites in the Northern Belt. This break lies at or near the high-Mg basalt in the Agassiz Metallotect, locally coincident with a prominent shear zone; the MacLellan and Farley gold deposits lie in the metallotect;

2. the Johnson Shear Zone, which was host to the Burnt Timber gold deposit and is the focus of current geological field work (Beaumont-Smith and Rogge, 1999), separates Southern Belt assemblages from unrelated rocks in the Keewatin River and Miskwa Lake belts; and

3. major thrust faults inferred at the structural base of the MORB-like Hatchet Lake and Tod Lake basalts. These faults indicate that the Granville Lake ocean-floor assemblage (including the MORB-like basalts) was underthrust by the turbidites of the Burntwood Group at the margin of the Kisseynew Domain.

The new geochemical data confirm the arc volcanic origin of the majority of the extrusive rock types in the Lynn Lake Belt, important for focusing exploration for VMS deposits (Syme et al., in press). Major formations of geochemically similar arc volcanic suites, particularly those occurring along strike or in a similar stratigraphic position, may involve several related extrusive centres.

Depleted arc tholeiite in the Northern Belt, near Lynn Lake, extends west for ca. 70 km to Barrington Lake. These basalts were probably extracted from a refractory mantle source that had experienced previous basalt extraction and may represent part of the original forearc. Of specific importance, depleted arc tholeiites and boninites have been identified as favorable targets for VMS mineralization (Kerrich and Wyman, 1996; Swinden, 1996). The high-Mg basalt on the south margin of the depleted tholeiite extends a similar distance through the Northern Belt. The high-Mg basalt has a proven gold potential.

The high-LREE arc tholeiite in the southwestern part of the Northern Belt is bounded to the south by E-MORB-like and transitional basalts. The geochemical composition of these rocks suggests that intra-arc extension and rifting may have been important processes in the volcanic evolution of the Lynn Lake Belt. The narrow unit containing E-type MORBs may be a remnant or margin of a larger rift basin destroyed during the tectonic amalgamation of the thicker arc massifs. The rift geochemistry of basaltic rocks on the south margin of the Northern Belt and the extension-related chemistry of the Lynn Lake rhyolite make this zone another attractive exploration target.

Typical juvenile arc geochemistry with arc tholeiite and calc-alkaline units characterizes much of the Southern Belt, although high-Al arc rocks, weakly depleted arc tholeiite and basalts transitional to E-MORB also make up parts of the Southern Belt. Four calc-alkaline suites occur along strike in the core of the Southern Belt. Their correlation is problematic but they occur in a similar stratigraphic position (below LREE-enriched arc tholeiites). These various calc-alkaline suites are progressively more evolved from the Laurie Lake assemblage (8.5-18 wt.% MgO) in the southwest, to McVeigh Lake porphyritic basalt (6-9 wt.% MgO) and the Hughes Lake suite (2.3-6.5 wt.% MgO) in the northeast. The presence of these calc-alkaline rocks is a defining feature of the Southern Belt, perhaps indicating that it is a fragment of a single volcanic arc. At the southwest end of the Lynn Lake Belt, at Laurie Lake, these volcanic rocks structurally overlie younger sedimentary rocks of the Burntwood Group. This relation indicates that the southwest margin of the arc fragment was thrust over the Burntwood Group.

Distinctive geochemical suites that are in stratigraphic contact define chemo-stratigraphic 'breaks' in the succession. Such breaks, particularly where felsic volcanic rocks are present, are the site of the major VMS deposits in the Flin Flon Belt (Syme and Bailes, 1993) and probably correspond to the site of the VMS deposit at Fox Mine in the Lynn Lake Belt. If the structure of the Fox Mine area is as proposed by Gilbert et al. (1980), then the primitive (8-15 wt.% MgO) calc-alkaline Fox Lake porphyritic basalt is stratigraphically overlain by Snake Lake dacite, also of calc-alkaline affinity. The dacite occurs at the base of the

Fox Mine succession, the structure of which is poorly defined, but its proposed evolution includes an abrupt change to high-Al basalt at the start and then to arc tholeiite (Fig. 3.1). The mineralized stratum is also the site of thin sedimentary units and small felsic bodies, one of which has a geochemical similarity to rhyolite associated with the Flin Flon VMS deposit. Alteration is abundant and intense in much of the Snake Lake dacite and overlying Fox Mine succession.

Interestingly, the new geochemical data suggest that, at several localities southwest of Fraser Lake, McVeigh Lake porphyritic basalt is also overlain by a thin high-Al basalt with a very similar trace element pattern to that of the porphyritic basalt. This is overlain in turn by sedimentary, felsic volcanic and tholeiitic mafic volcanic rocks (Fig. 3.2). The succession may warrant further exploration because it shows a similar trend in volcanic evolution to the Fox Lake porphyritic basalt and the overlying, mineralized Fox Mine succession.

The volcanic sections west of McVeigh Lake and west of Wilmot Lake show a progressive decrease in LREE and Th (at constant TiO_2) toward the south or southeast, i.e., from the proposed base to the top of the section. This chemical trend may imply a progressively depleted mantle source at the present south margin of the Lynn Lake Belt, as occurs at the north margin of the Northern Belt.

Newly defined units (Tod Lake basalt, Hatchet Lake basalt, and Pickerel Narrows amphibolite) are interpreted as crustally contaminated MORB, N-MORB and OIB (ocean island basalt). They are stratigraphically associated with intrusive and sedimentary rocks similar to those found in modern ophiolites. These geochemically distinctive amphibolites, which extend for several hundred kilometres along the boundary between the Lynn Lake-Rusty Lake belts and the Kisseynew Domain, imply arc rifting and the development of an intra- or back-arc basin that evolved into the paleo-Kisseynew basin. Sulphide iron formation and gold showings are important features associated with these amphibolites south of the Lynn Lake Belt.

CONCLUSIONS

A number of conclusions can be made from this preliminary examination of new trace element data from the Lynn Lake Belt:

1. The Lynn Lake Belt is composed of a variety of volcanic tectonostratigraphic assemblages that are unlikely to have originated together in a single tectonic entity and are thus not a single stratigraphic group;

2. Volcanic rocks generated in an arc setting predominate, including normal, depleted and enriched tholeiites and calc-alkaline rocks;

3. E-MORB-like and OIB-like lithologies are subordinate but significant components of the supracrustal succession, and may in the Northern Belt signify intra-arc extension and rifting;

4. Calc-alkaline arc units are restricted to the Southern Belt and display a clear compositional polarity parallel to the length of the belt, from magnesian in the west to intermediate and felsic in the east;

5. Geochemical types in the Northern Belt include depleted and enriched arc tholeiites, high-Mg basalts and E-type MORBs. These are unlike rocks in the Southern Belt and emphasize the stratigraphic and geochemical discontinuity between these two entities in the Lynn Lake Belt;

6. Northern Belt depleted and enriched tholeiites are geochemically equivalent to along-strike Barrington Lake volcanic rocks;

7. MORB- and OIB-like rocks along the boundary between the Lynn Lake Belt and the Kisseynew Domain may mark the development of an ocean basin ancestral to the Kisseynew basin;

8. The occurrence of arc rocks, in particular depleted arc tholeiites, suggests that the Lynn Lake Belt has significant potential for volcanic-hosted massive sulphide deposits;

9. The occurrence of "FIII"-type and possible 'extension-related' rhyolites in the Lynn Lake Belt, despite significant differences from Archean FIII rhyolites, also demonstrates a VMS potential.

REFERENCES

Ansdell, K.M., Corrigan, D., Stern, R., and Maxeiner, R. 1999: Shrimp U-Pb geochronology of complex zircons from Reindeer Lake, Saskatchewan: implications for timing of sedimentation and metamorphism in the northwestern Trans-Hudson Orogen; *in* Geological Association of Canada - Mineralogical Association of Canada, Joint Annual Meeting, Abstract Volume 24, p. 3.

Bailes, A.H. 1980: Geology of the File Lake area; Manitoba Energy and Mines, Geological Report GR78-1, 313 p.

Bailes, A.H. and Syme, E.C. 1989: Geology of the Flin Flon - White Lake area; Manitoba Energy and Mines, Geological Report GR87-1, 313 p.

Baldwin, D.A., Syme, E.C., Zwanzig, H.V., Gordon, T.M., Hunt, P.A., and Stevens, R.P. 1987: U-Pb zircon ages from the Lynn Lake and Rusty Lake metavolcanic belts, Manitoba: two ages of Proterozoic magmatism; Canadian Journal of Earth Sciences, v. 24, p. 1053-1063.

Beaumont-Smith, C.J. and Rogge, D.M. 1999: Preliminary structural analysis and gold metallogeny of the Johnson Shear Zone, Lynn Lake greenstone belt (parts of NTS 64C/10, 11, 15); *in* Report of Activities, 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 61-66.

Corrigan, D., Pehrsson, S.J., MacHattie, T.G., Piper, L., Wright, S., Lassen, B., and Chakungal, J. 1999: Lithotectonic framework of the Trans-Hudson Orogen in the northwestern Reindeer Zone, Saskatchewan: an update from recent mapping along the Reindeer Lake transect; *in* Current Research 1999-C, Geological Survey of Canada, p. 169-178.

Fedikow, M.A.F. 1983: Geological and geochemical investigations at the Agassiz Au-Ag deposit, Lynn Lake, Manitoba; Manitoba Energy and Mines, Report of Field Activities, 1983, p. 94-97.

Ferreira, K.J. 1993: Mineral occurrences in the Laurie Lake area, NTS 64C/12; Manitoba Energy and Mines, Mineral Deposit Series Report No. 9, 101 p.

Gilbert, H.P. 1993: Geology of the Barrington Lake-Melvin Lake-Fraser Lake area; Manitoba Energy and Mines, Geological Report GR87-3, 97 p.

Gilbert, H.P., Syme, E.C., and Zwanzig, H.V. 1980: Geology of the metavolcanic and volcaniclastic metasedimentary rocks in the Lynn Lake area; Manitoba Energy and Mines, Mineral Resources Division, Geological Paper GP80-1, 118 p., with 5 maps 1:50 000 scale, 1 map 1:100 000 scale.

Kerrich, R. and Wyman, D. 1996: The trace element systematics of igneous rocks in mineral exploration: an overview; *in* D.A. Wyman (ed.), Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration, Short Course Notes, v. 12, p. 1-50.

Lesher, C.M., Goodwin, A.M., Campbell, I.H., and Gorton, M.P. 1986: Trace-element geochemistry of ore-associated and barren, felsic metavolcanic rocks in the Superior Province, Canada; Canadian Journal of Earth Sciences, v. 23, p. 222-241.

Lucas, S.B., Stern, R.A., Syme, E.C., Reilly, B.A., and Thomas, D.J. 1996: Intraoceanic tectonics and the development of continental crust: 1.92-1.84 Ga evolution of the Flin Flon Belt, Canada; Geological Society of America Bulletin, v. 108, p. 602-629.

Machado, N., Zwanzig, H., and Parent, M. in press: U-Pb ages of plutonism, sedimentation and metamorphism of the Paleoproterozoic Kisseynew metasedimentary belt, Trans-Hudson Orogen (Manitoba, Canada); Canadian Journal of Earth Sciences.

Manitoba Energy and Mines. 1986: Granville Lake; Manitoba Energy and Mines, Geological Services, Bedrock Geology Compilation Map Series, NTS 64C, scale 1:250 000.

NATMAP Shield Margin Working Group 1998: Geology, NATMAP Shield Margin Project area (Flin Flon Belt), Manitoba-Saskatchewan; Geological Survey of Canada Map 1968A, Manitoba Energy and Mines Map A-98-2, Sheets 1 to 7, Saskatchewan Energy and Mines Map 258A-1 to 7, scale 1:100 000, with accompanying notes.

Stern, R.A., Syme, E.C., and Lucas, S.B. 1995a: Geochemistry of 1.9 Ga MORB- and OIB-like basalts from the Amisk collage, Flin Flon Belt, Canada: Evidence for an intra-oceanic origin; Geochimica et Cosmochimica Acta, v. 59, p. 3131-3154.

Stern, R.A., Syme, E.C., Bailes, A.H., and Lucas, S.B. 1995b: Paleoproterozoic (1.86-1.90 Ga) arc volcanism in the Flin Flon Belt, Trans-Hudson Orogen, Canada; Contributions to Mineralogy and Petrology, v. 119, p. 117-141.

Sun, S.S. and McDonough, W.F. 1989: Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes; Geological Society Special Publication No. 42, p. 313-345.

Swinden, H.S. 1996: The application of volcanic geochemistry to the metallogeny of volcanic-hosted sulphide deposits in central Newfoundland; *in* Wyman, D.A. (ed.), Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration, Short Course Notes, v. 12, p. 329-358.

Syme, E.C. 1985: Geochemistry of metavolcanic rocks in the Lynn Lake Belt; Manitoba Energy and Mines, Geological Report GR84-1, 84 p.

1998: Ore-associated and barren rhyolites in the central Flin Flon Belt: case study of the Flin Flon Mine sequence; Manitoba Energy and Mines, Open File Report, OF98-9, 26 p.

Syme, E.C. and Bailes, A.H. 1993: Stratigraphic and tectonic setting of volcanogenic massive sulfide deposits, Flin Flon, Manitoba; Economic Geology, v. 88, p. 566-589.

Syme, E.C., Lucas, S.B., Bailes, A.H., and Stern, R.A. in press: Contrasting arc and MORB-like assemblages in the Paleoproterozoic Flin Flon Belt, Manitoba, and the role of intra-arc extension in localizing volcanic-hosted massive sulphide deposits; Canadian Journal of Earth Sciences.

Wood, D.A. 1980: The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the British Tertiary volcanic province; Earth and Planetary Science Letters, v. 50, p. 11-30.

Woodhead, J., Eggins, S., and Gamble, J. 1993: High field strength and transition element systematics in island arc and back-arc basin basalts: evidence for multi-phase melt extraction and a depleted mantle wedge; Earth and Planetary Science Letters, v. 114, p. 491-504.

Zwanzig, H.V. 1981: Granville Lake Project; *in* Manitoba of Energy and Mines, Mineral Resources Division, Report of Field Activities, 1981, p. 17-21.

1990: Kisseynew gneiss belt in Manitoba: stratigraphy, structure, and tectonic evolution; *in* The Early Proterozoic Trans-Hudson Orogen of North America (Lewry, J.F. and Stauffer, M.R., eds.); Geological Association of Canada, Special Paper 37, p. 95-120.

1994: Geologic setting of the Nokomis Lake gold deposit (NTS 63N/3); *in* Manitoba Energy and Mines, Minerals Division, Report of Activities, 1994, p. 35-38.

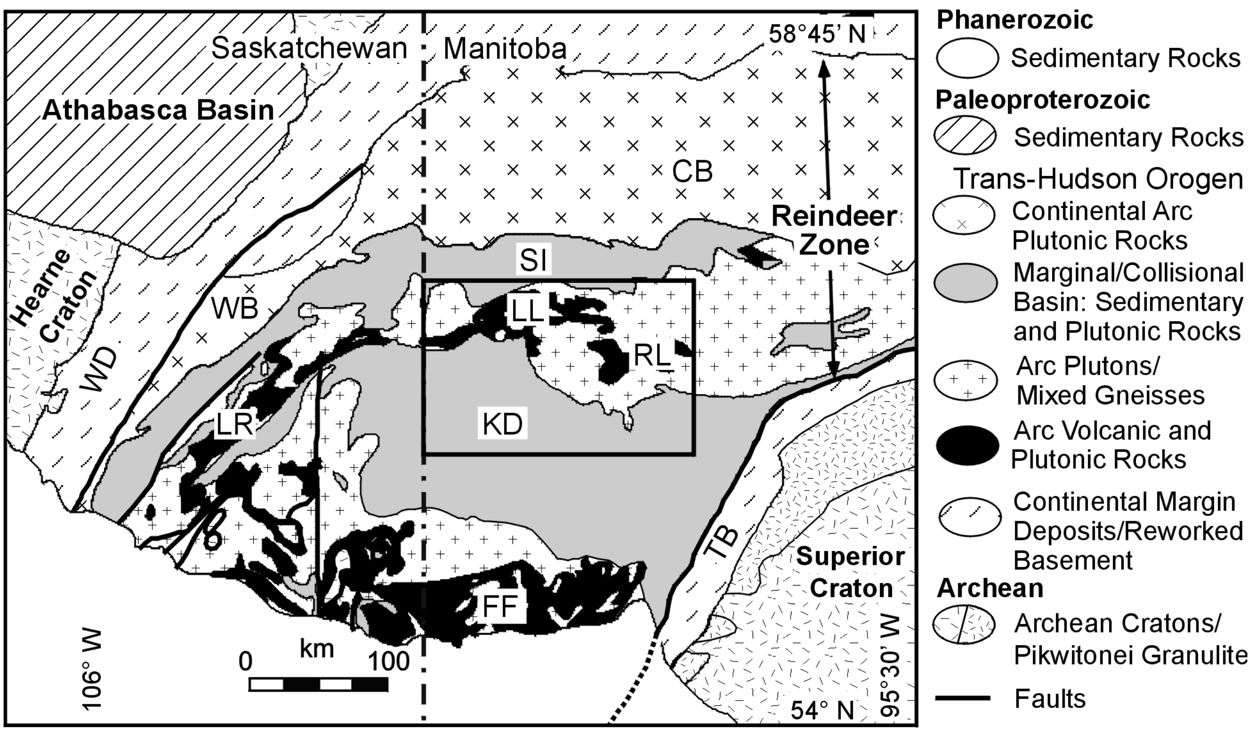

Figure 1: Trans-Hudson Orogen with location of greenstone belts; Lynn Lake Belt (LL), Rusty Lake Belt (RL), La Ronge Belt (LR) and Flin Flon Belt (FF). Also shown are Wathaman batholith (WB), Chipewyan batholith belt (CB), Southern Indian Domain (SI), Kisseynew Domain (KD), Wollaston Domain (WD) and Thompson Nickel Belt (TB). Area of Fig. 2 is outlined.

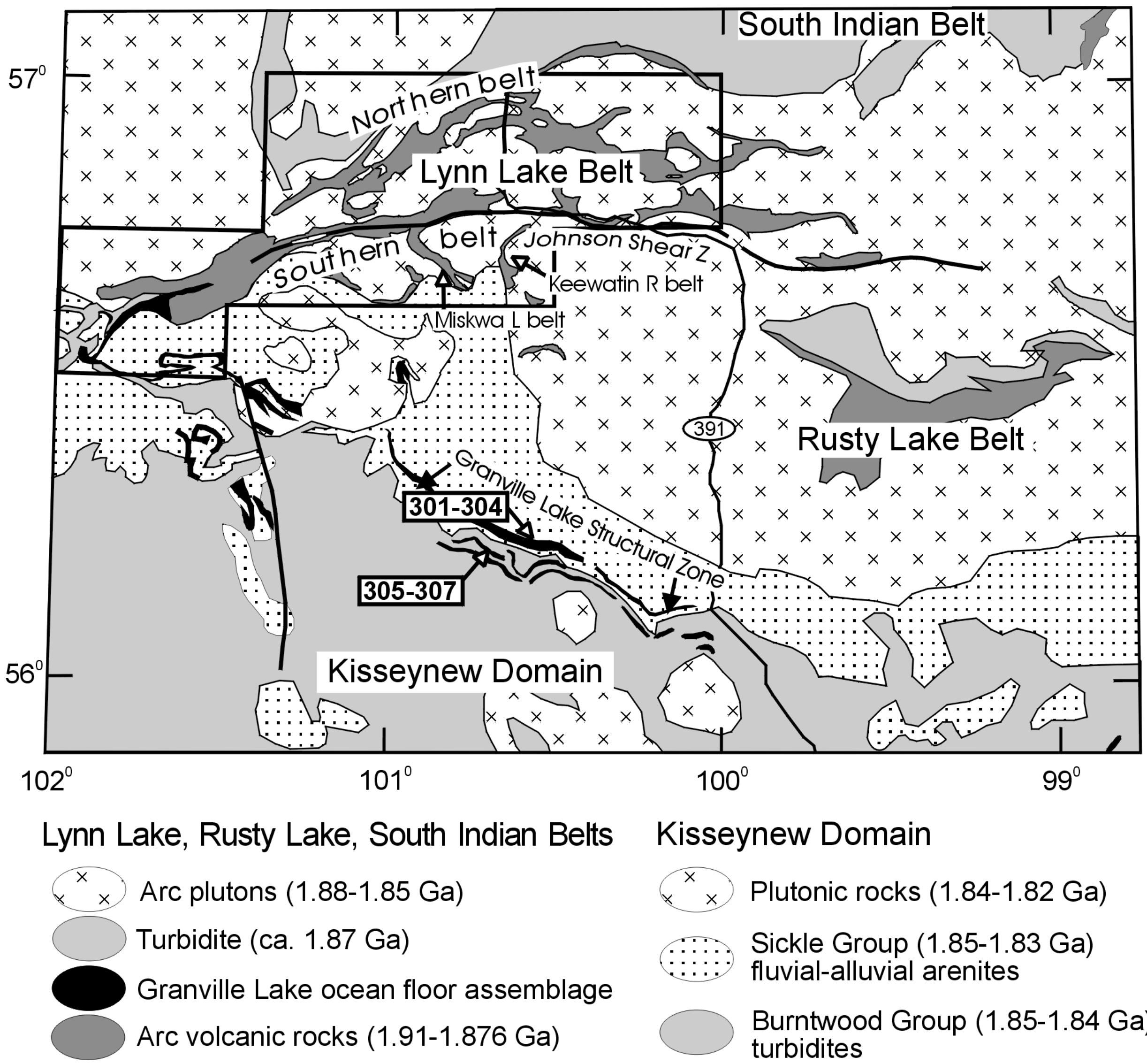

Figure 2: Regional setting of the Lynn Lake Belt showing the location of sub-belts used in the text and sample locations (boxes) in the Granville Lake area.

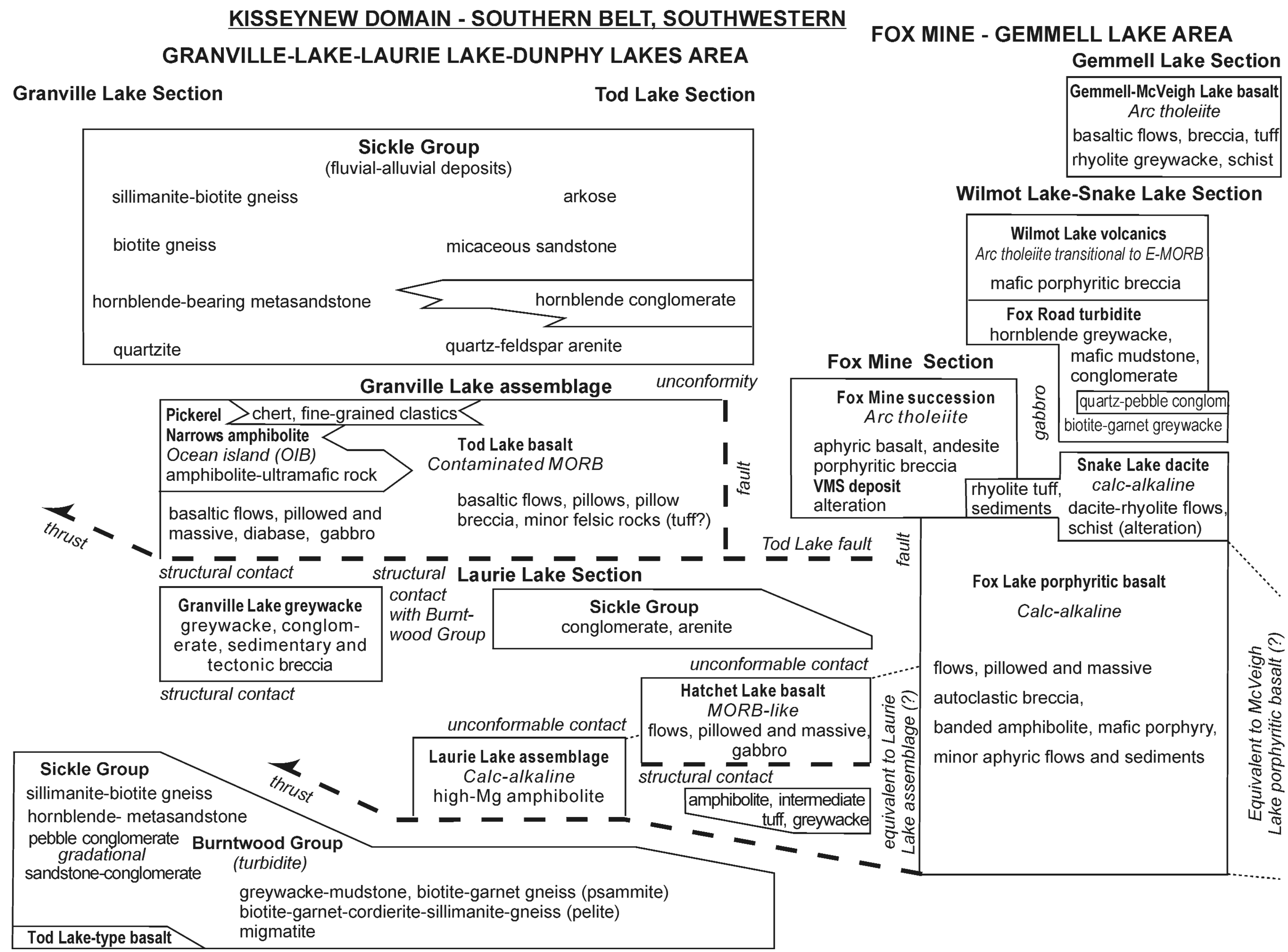

Figure 3.1: Tectonostratigraphic sections in the Lynn Lake region modified after Gilbert et al. (1980), showing inferred correlations (dotted lines) with stratigraphic thicknesses not to scale. Southwestern sections (Granville Lake-Gemmell Lake area) showing pre-Sickle faults and post-Sickle thrust faults that produced structural repetitions.

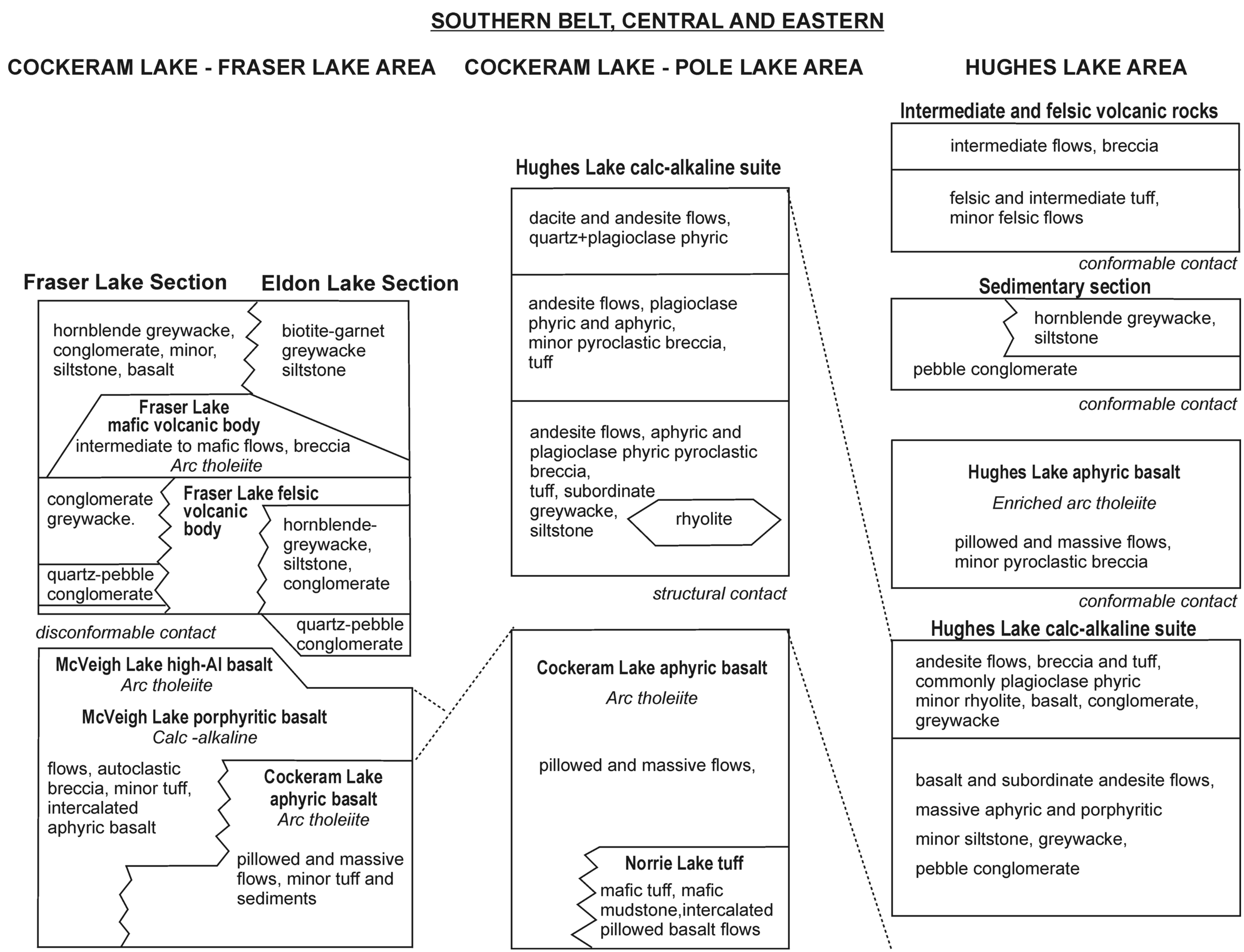

Figure 3.2: Tectonostratigraphic sections in the Lynn Lake region modified after Gilbert et al. (1980), showing inferred correlations (dotted lines) with stratigraphic thicknesses not to scale. Southern Belt (Fraser Lake-Hughes Lake area).

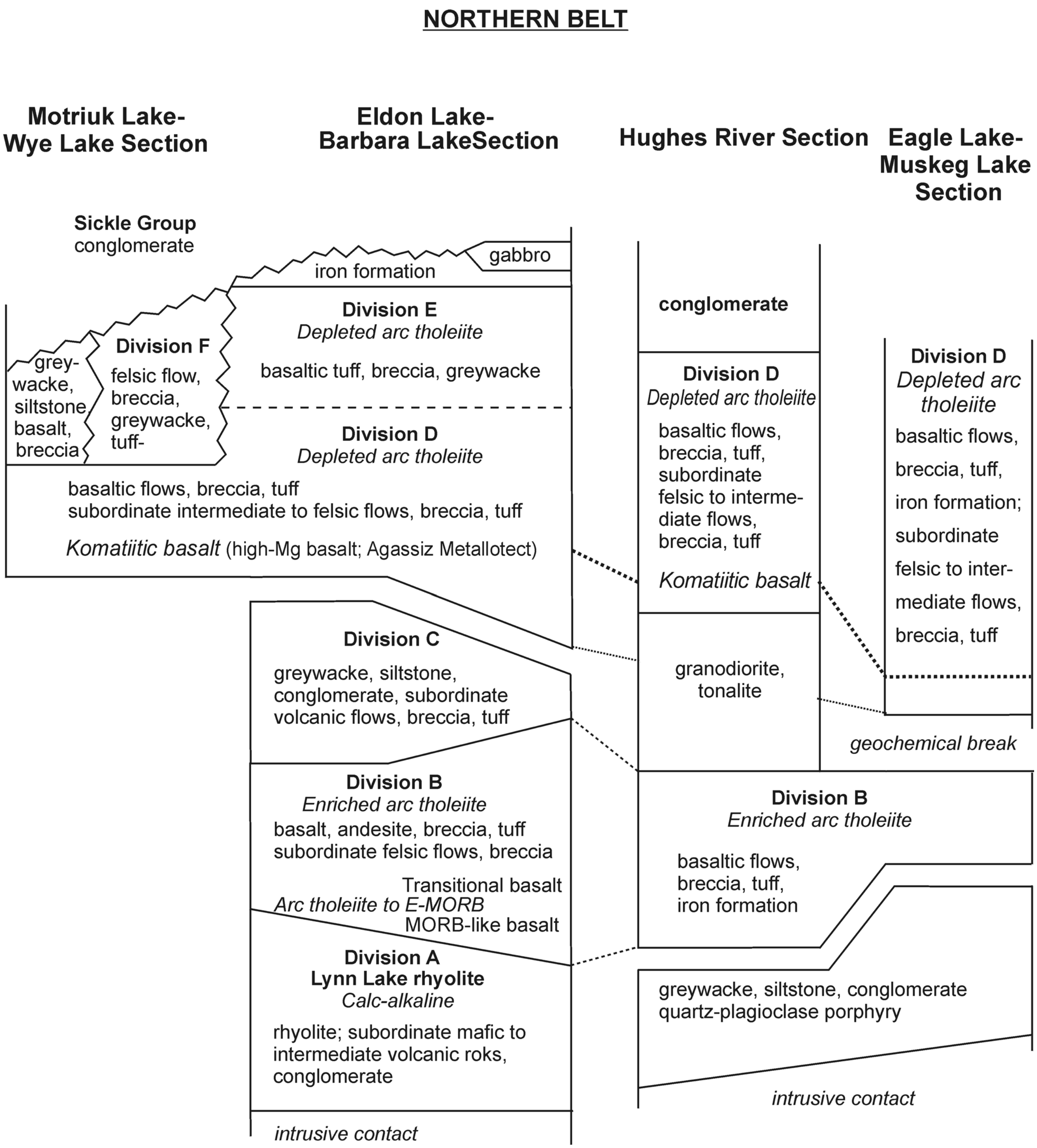

Figure 3.3: Tectonostratigraphic sections in the Lynn Lake region modified after Gilbert et al. (1980), showing inferred correlations (dotted lines) with stratigraphic thicknesses not to scale. Northern Belt (Motriuk Lake-Muskeg Lake area) showing the Agassiz Metallotect.

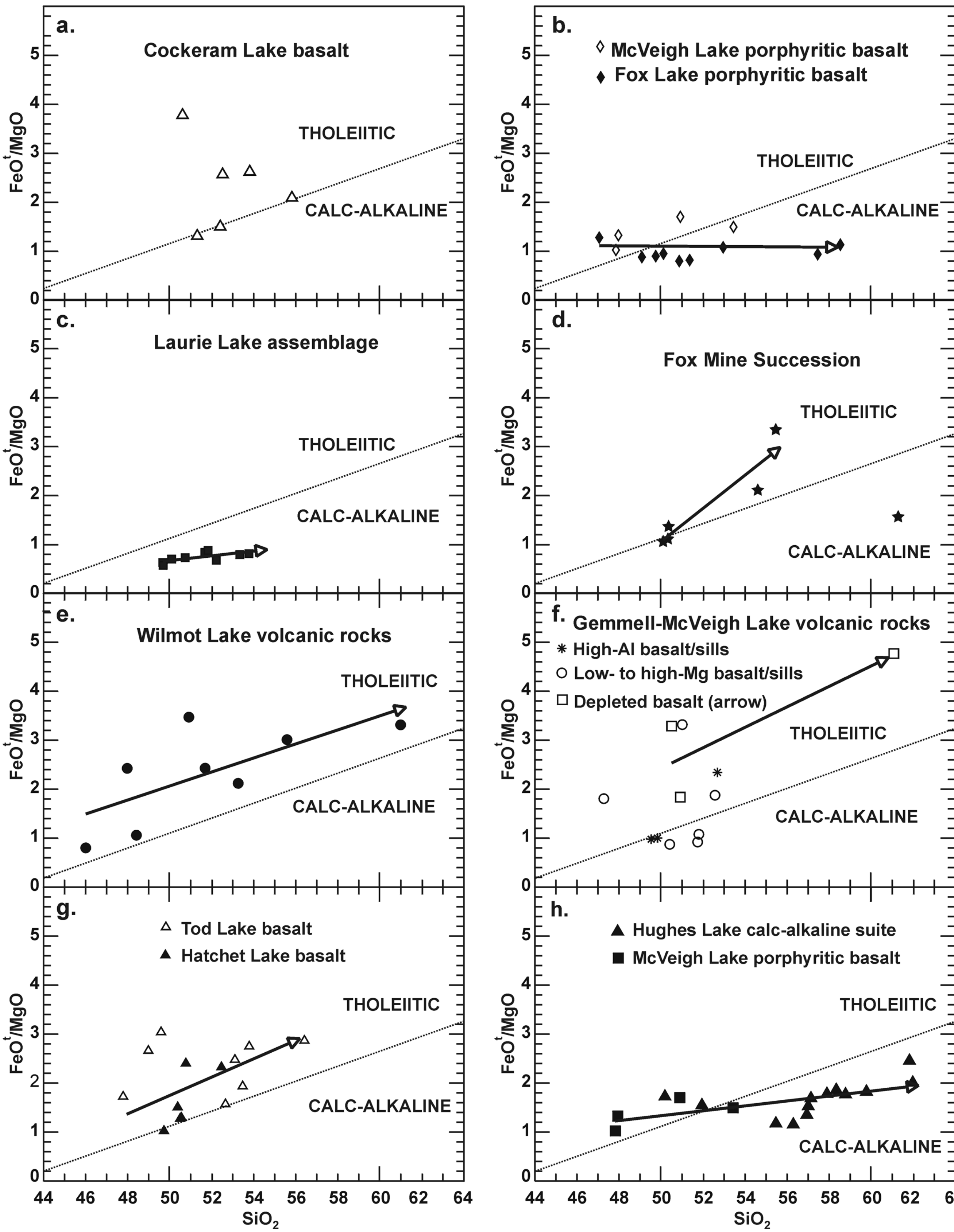

Figure 4.1: FeO^t/MgO vs. SiO_2 diagrams of mafic volcanic rocks. Selected rock suites in the Southern Belt showing calc-alkaline and tholeiitic fractionation trends (arrows).

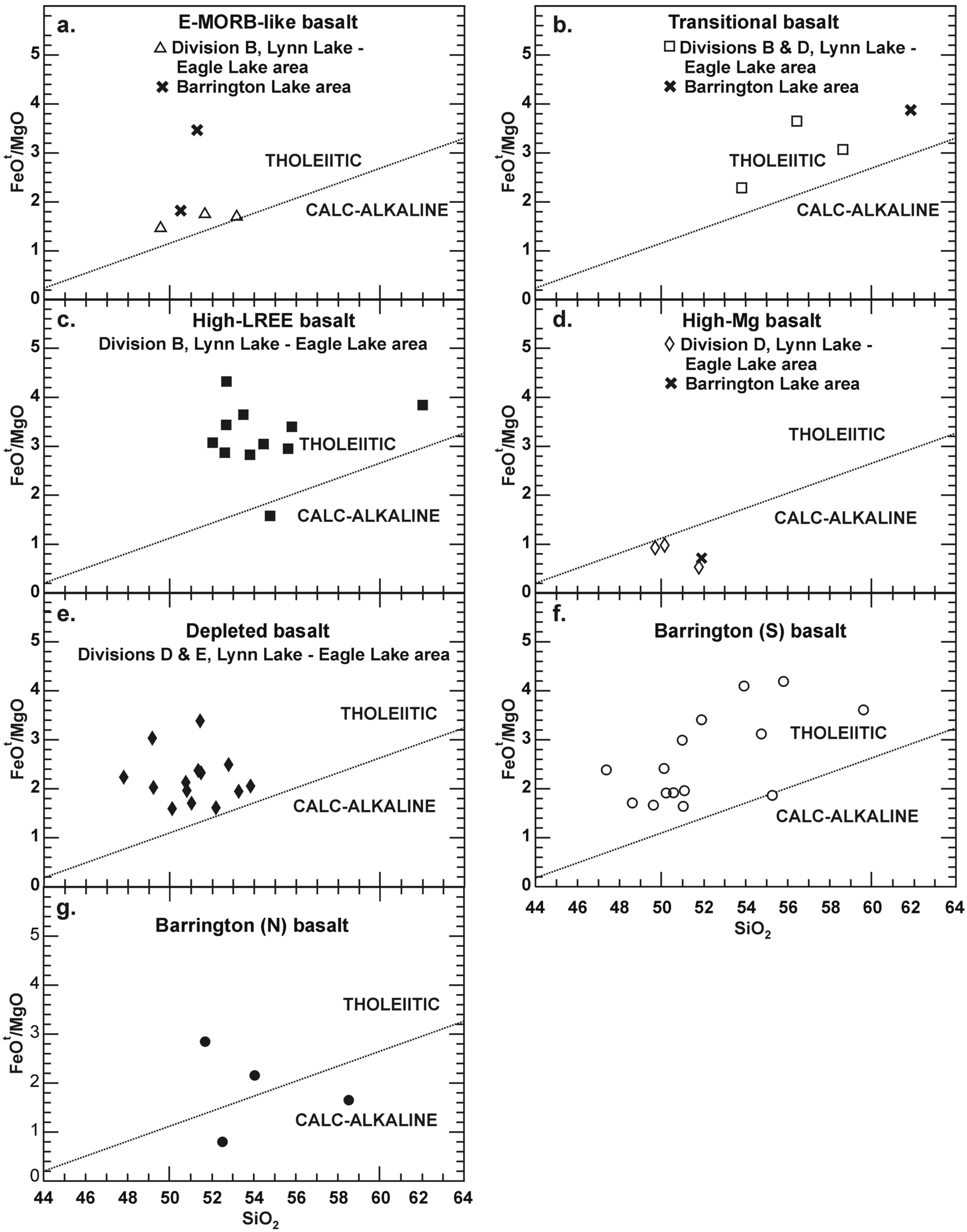

Figure 4.2: FeO^t/MgO vs. SiO_2 diagrams of mafic volcanic rocks. Northern Belt; a-e ordered from southeast to northwest, f - Barrington Lake area (S), g - Barrington Lake area (N). Several Barrington Lake area (S) rocks that are akin to rock types in the Lynn Lake-Eagle Lake area are included in plots a, b and d (bold cross symbols).

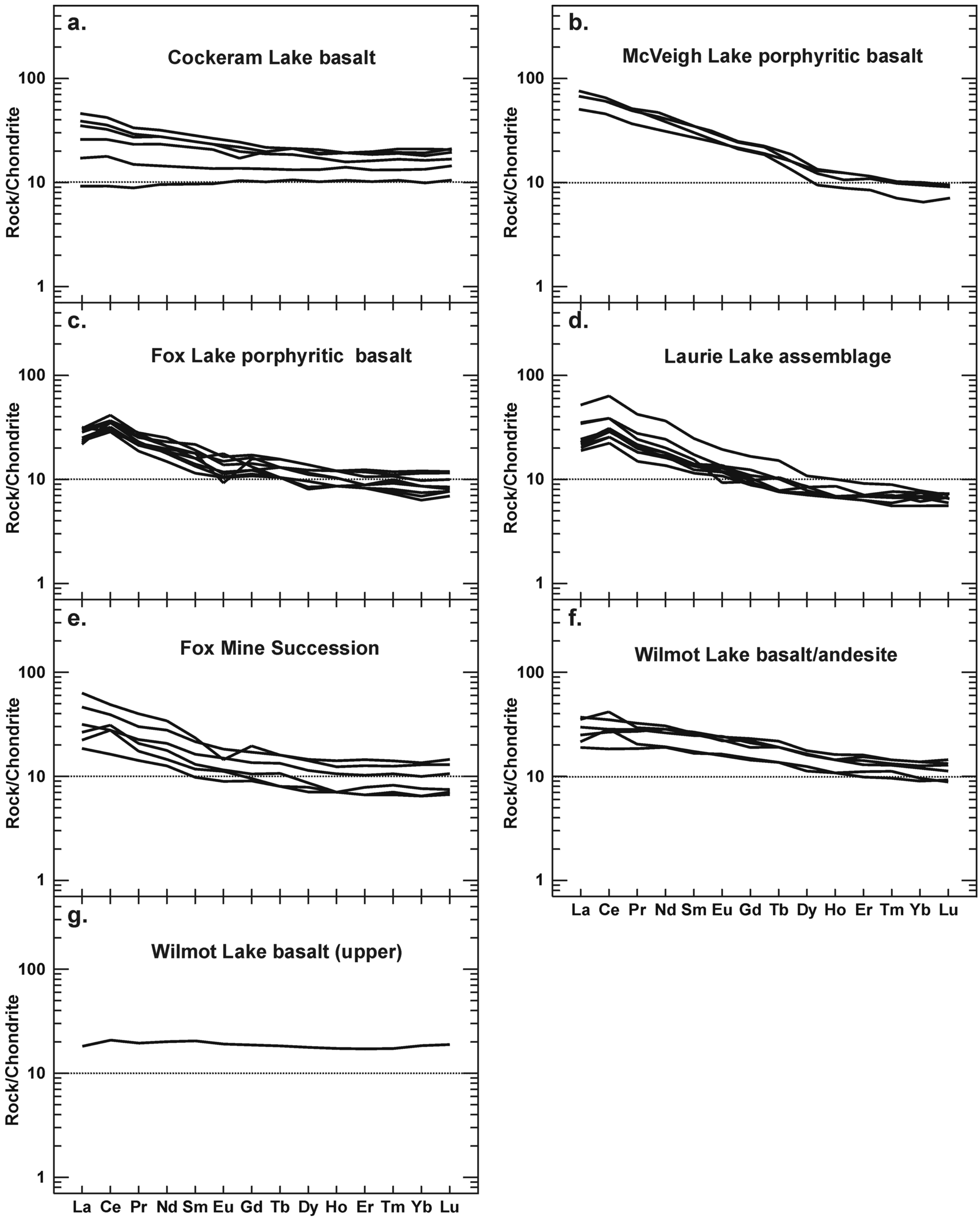

Figure 5.1: Chondrite-normalized rare earth element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt.

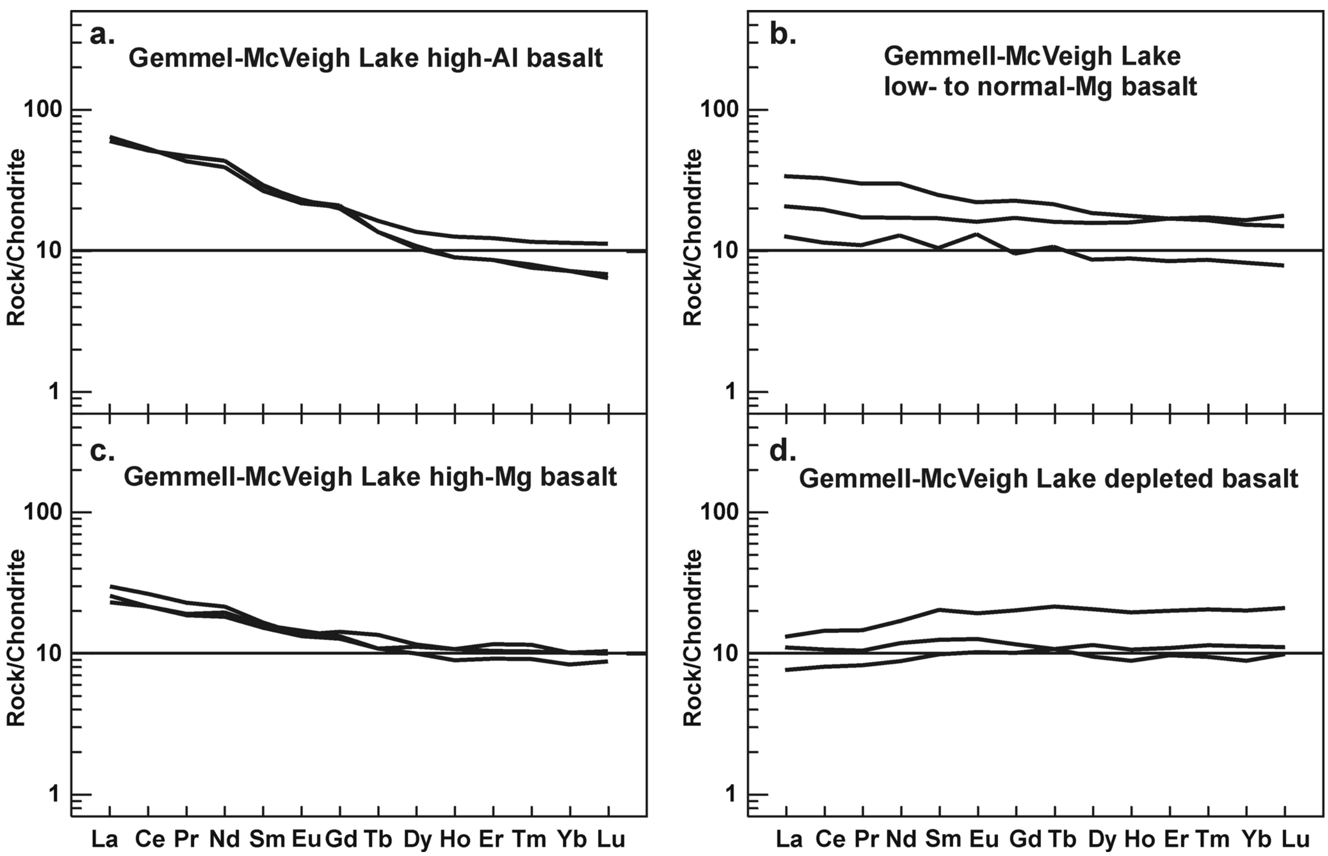

Figure 5.2: Chondrite-normalized rare earth element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt.

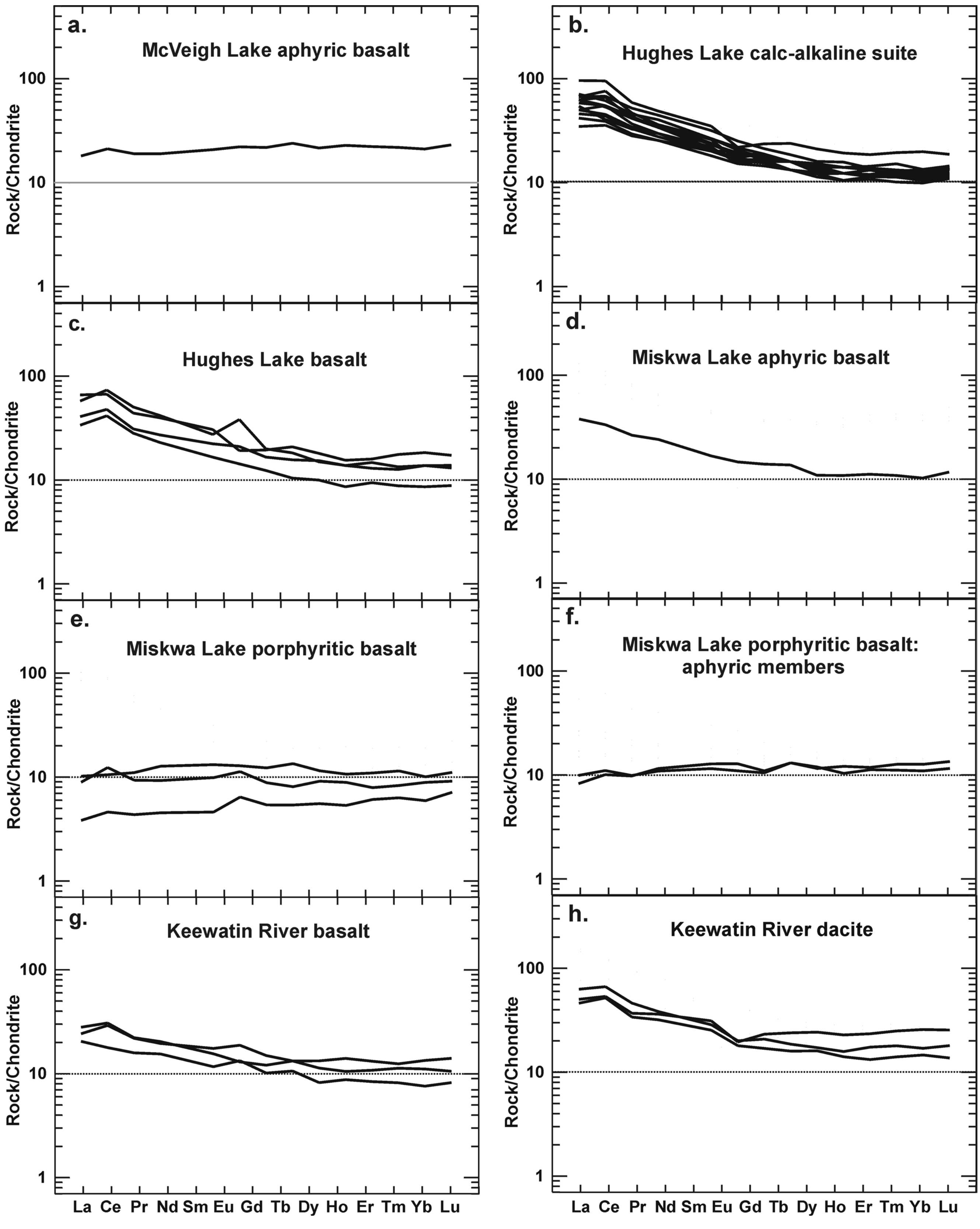

Figure 5.3: Chondrite-normalized rare earth element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt

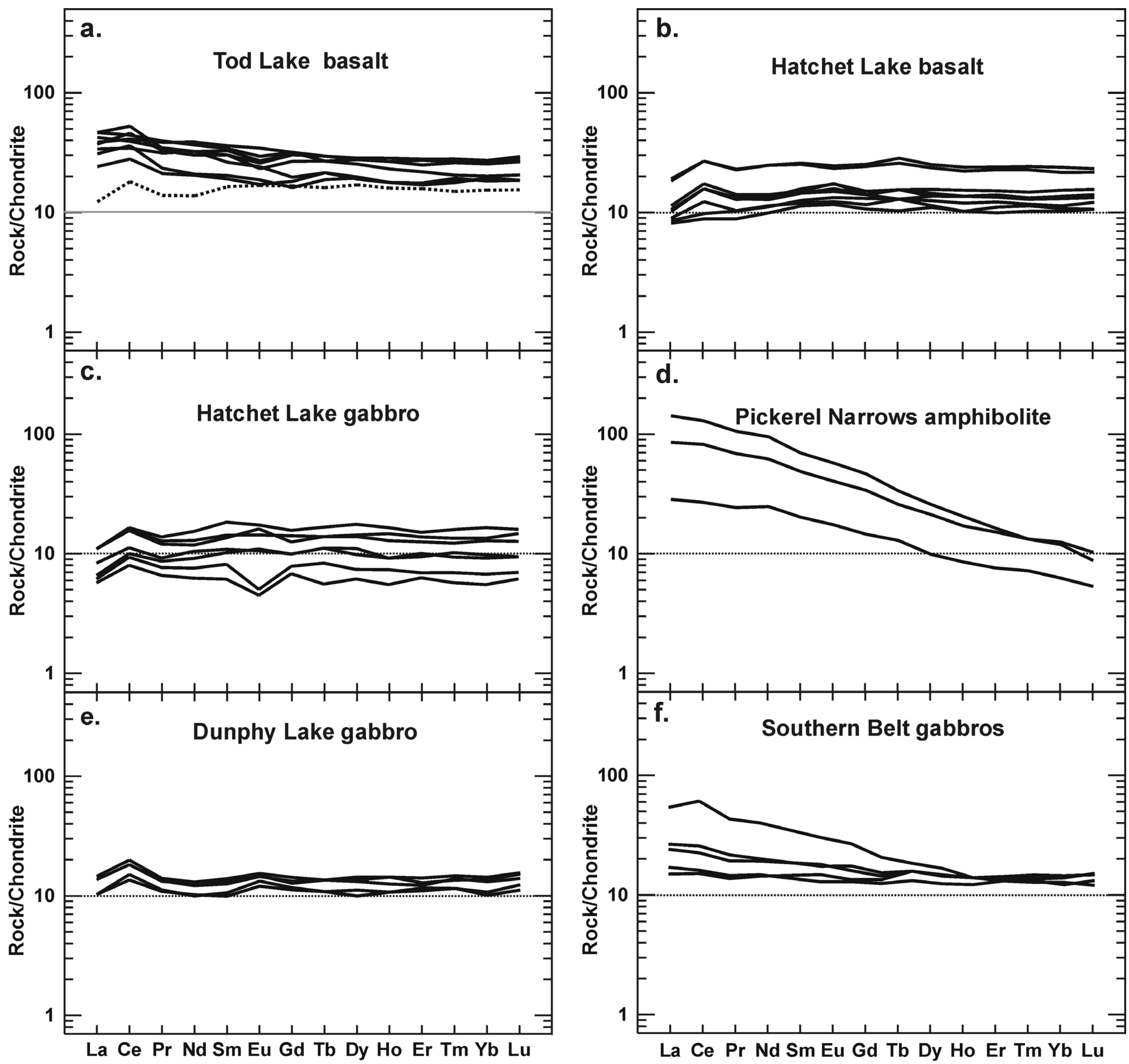

Figure 5.4: Chondrite-normalized rare earth element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt.

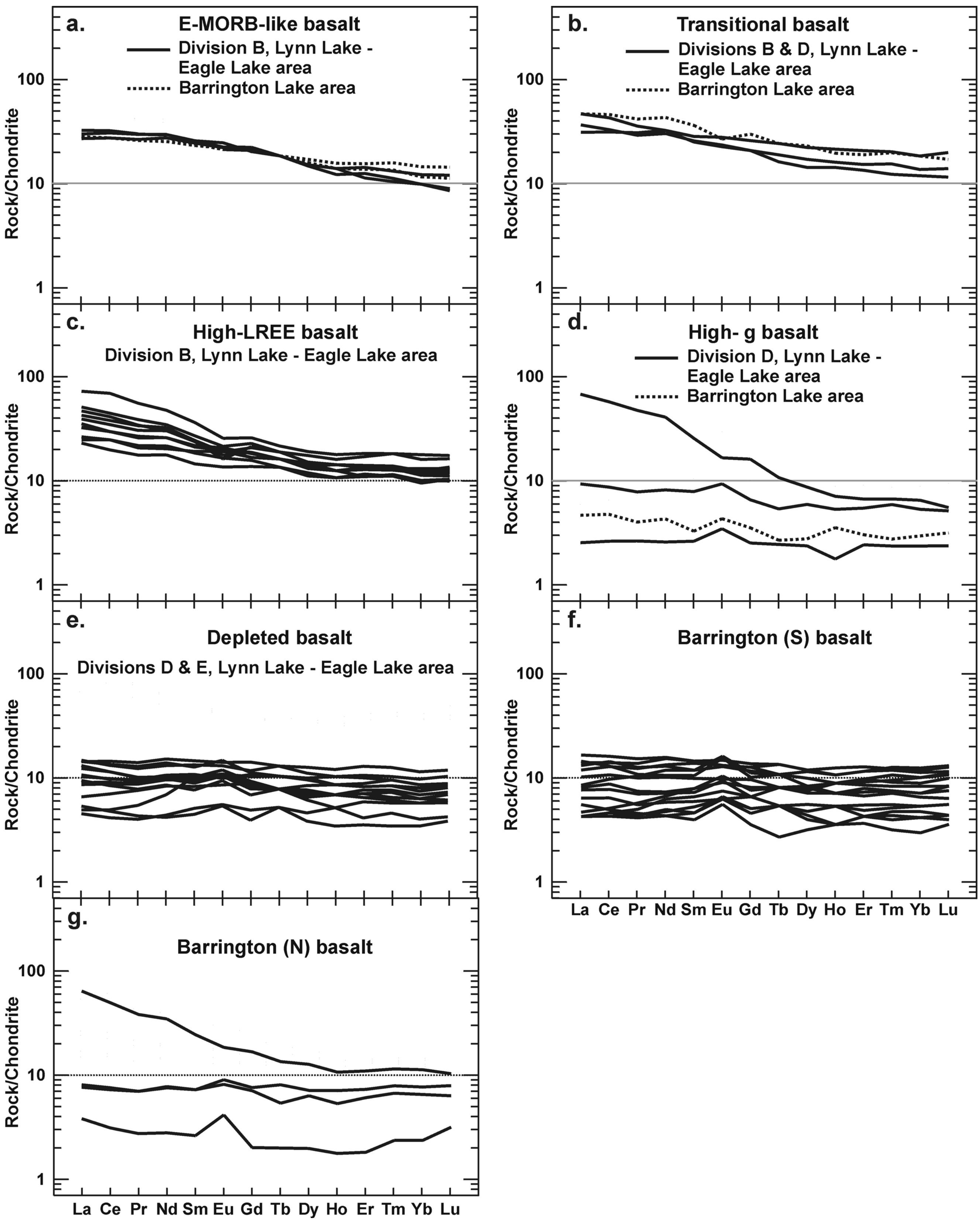

Figure 5.5: Chondrite-normalized rare earth element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Northern Belt (ordered as in Fig. 4.2).

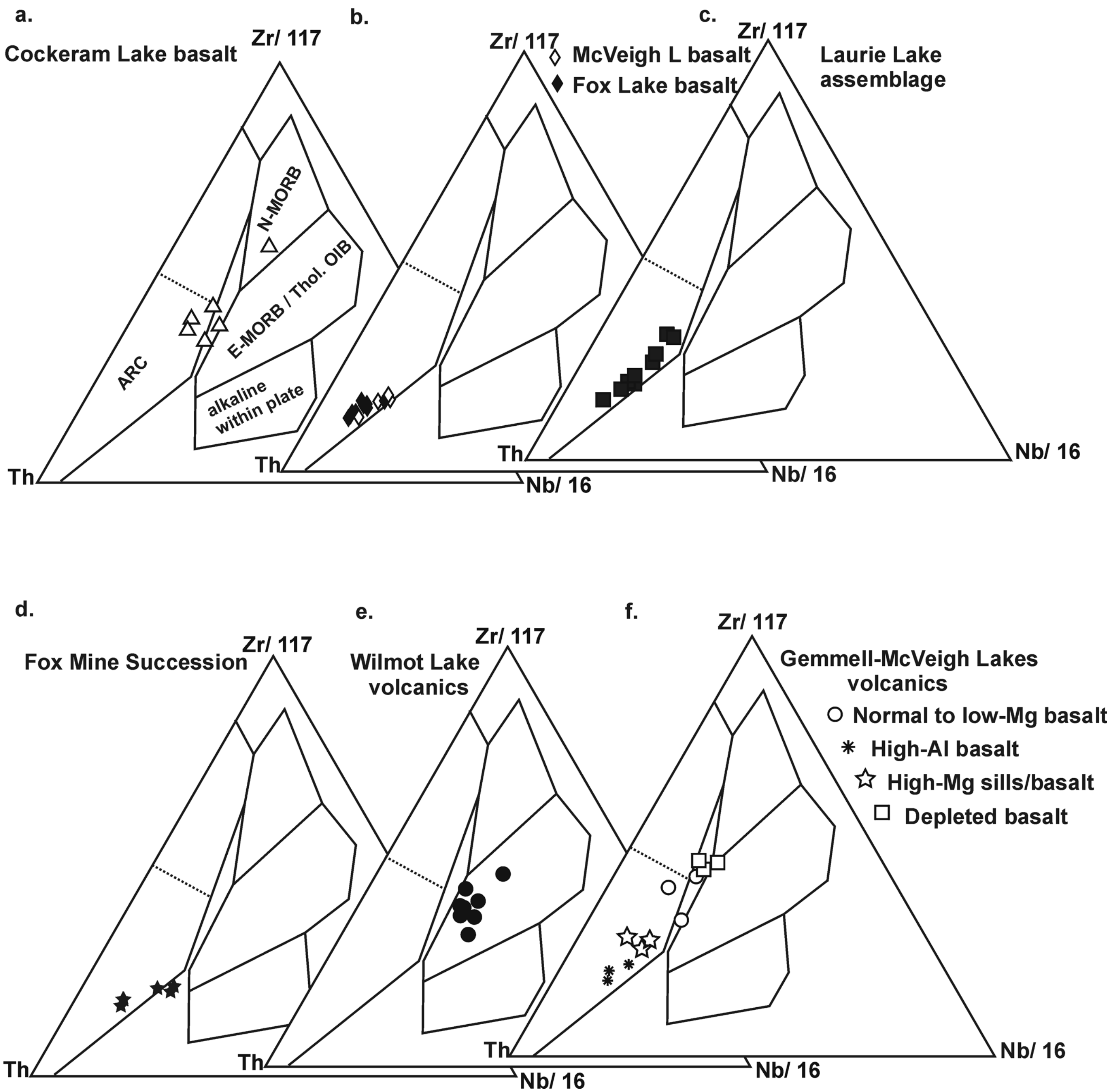

Figure 6.1: Th-Zr-Nb basalt discrimination diagrams for mafic volcanic rocks (compositional fields of modern volcanic rocks after Wood, 1980). Southern Belt.

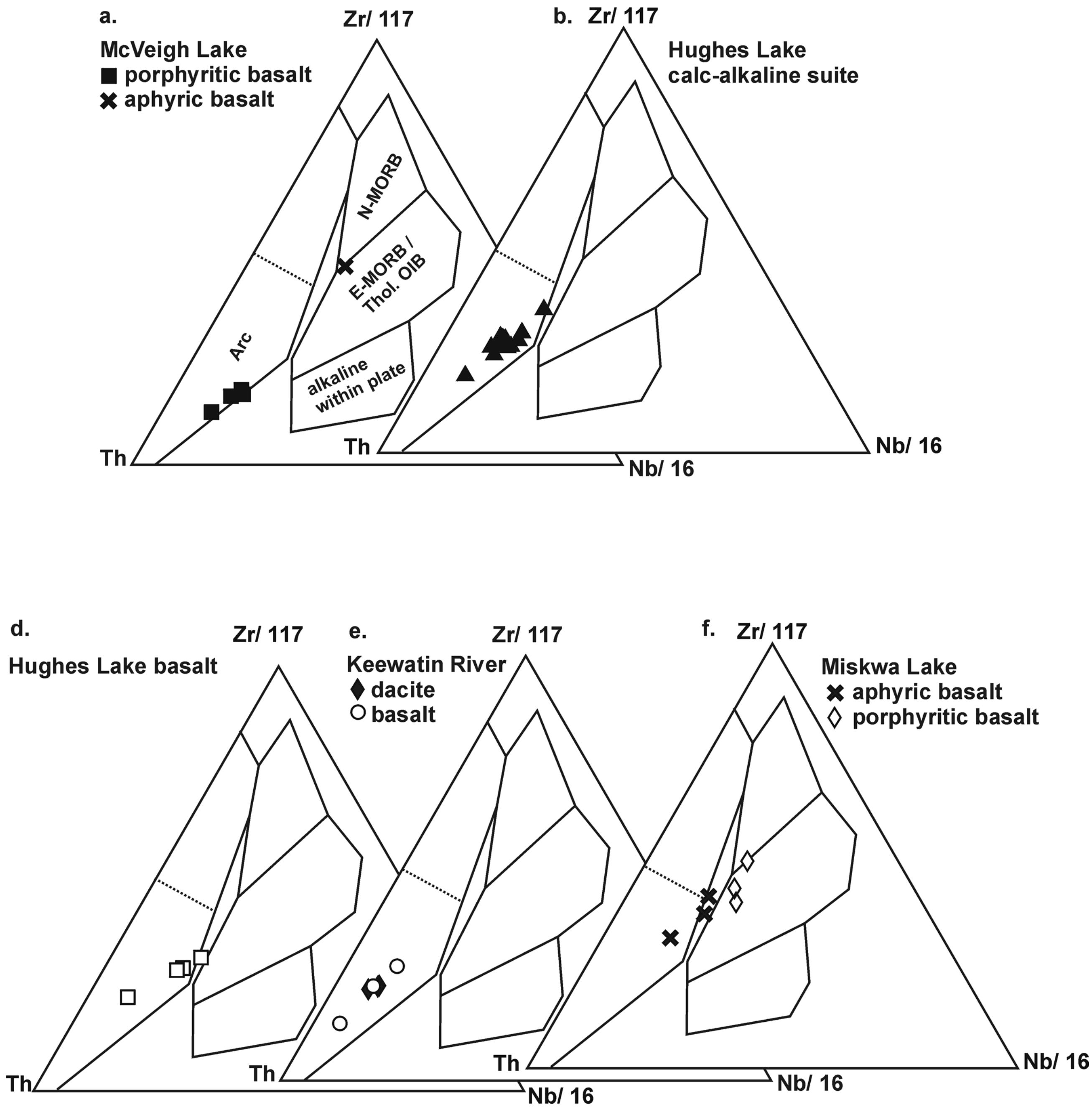

Figure 6.2: Th-Zr-Nb basalt discrimination diagrams for mafic volcanic rocks (compositional fields of modern volcanic rocks after Wood, 1980). Southern Belt.

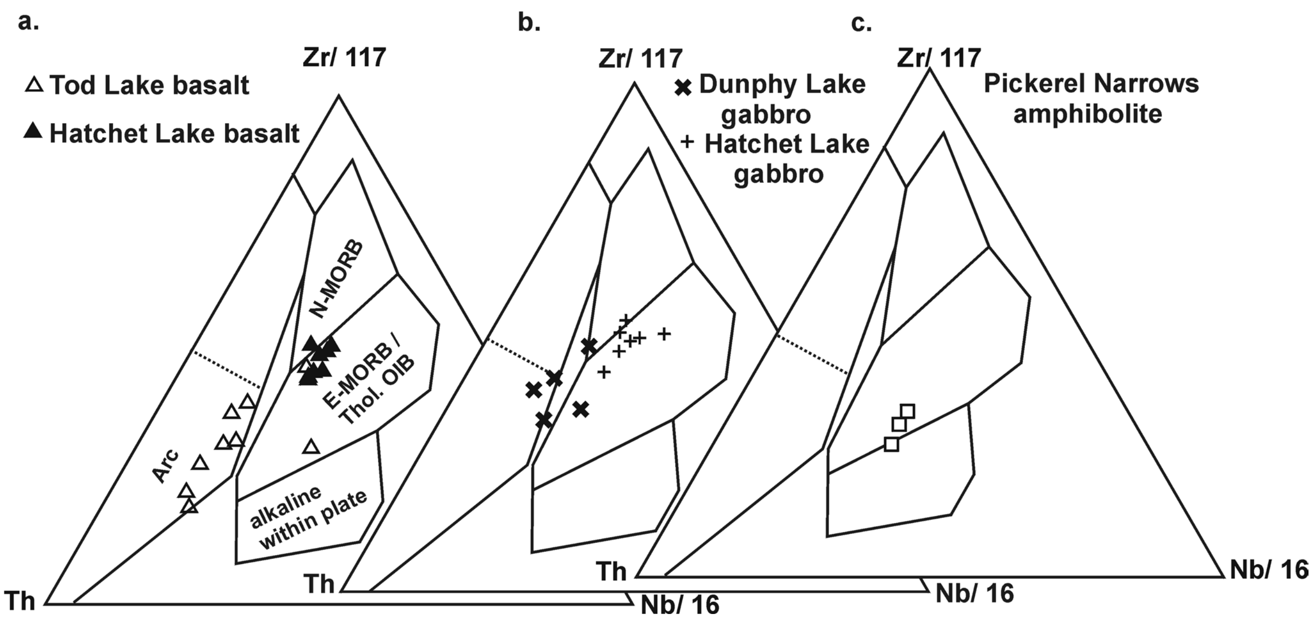

Figure 6.3: Th-Zr-Nb basalt discrimination diagrams for mafic volcanic rocks (compositional fields of modern volcanic rocks after Wood, 1980). Hatchet Lake-Granville Lake area.

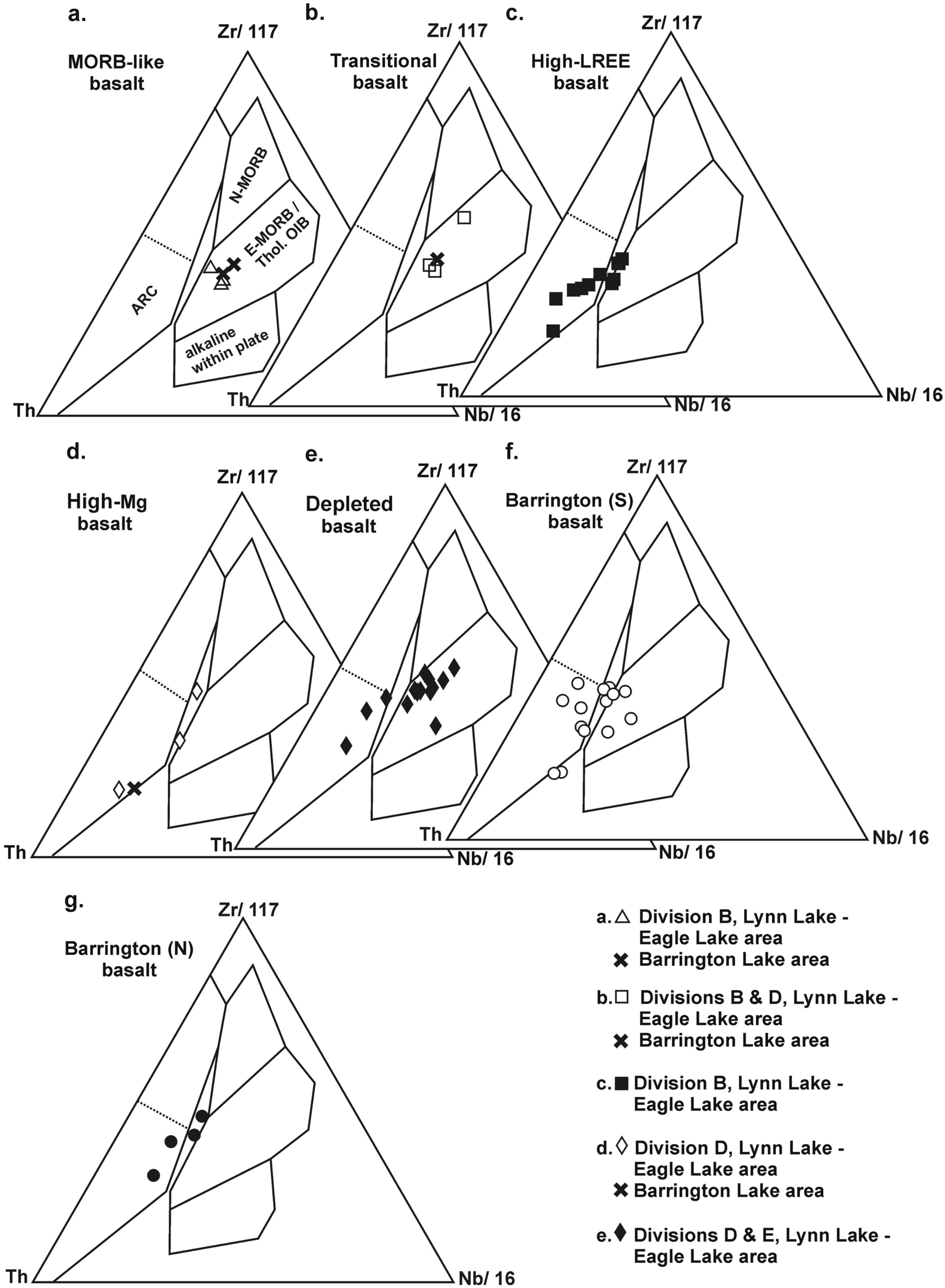

Figure 6.4: Th-Zr-Nb basalt discrimination diagrams for mafic volcanic rocks (compositional fields of modern volcanic rocks after Wood, 1980). Northern Belt (ordered as in Fig. 4.2).

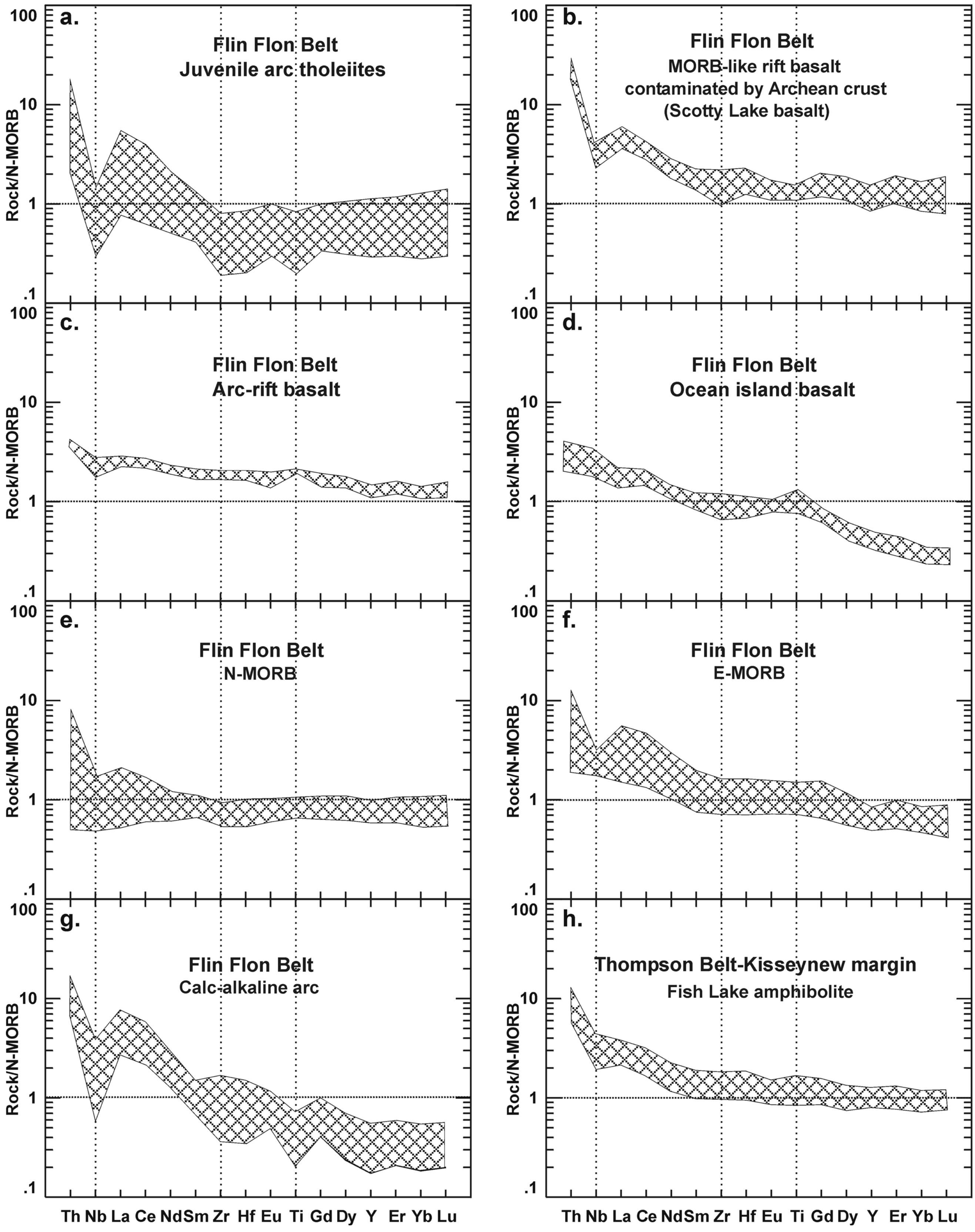

Figure 7.1: MORB-normalized extended element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Fields of various types of volcanic arc rocks, back-arc basin basalts, rift-related basalts and ocean island basalt from the Flin Flon Belt and Thompson Nickel Belt margin.

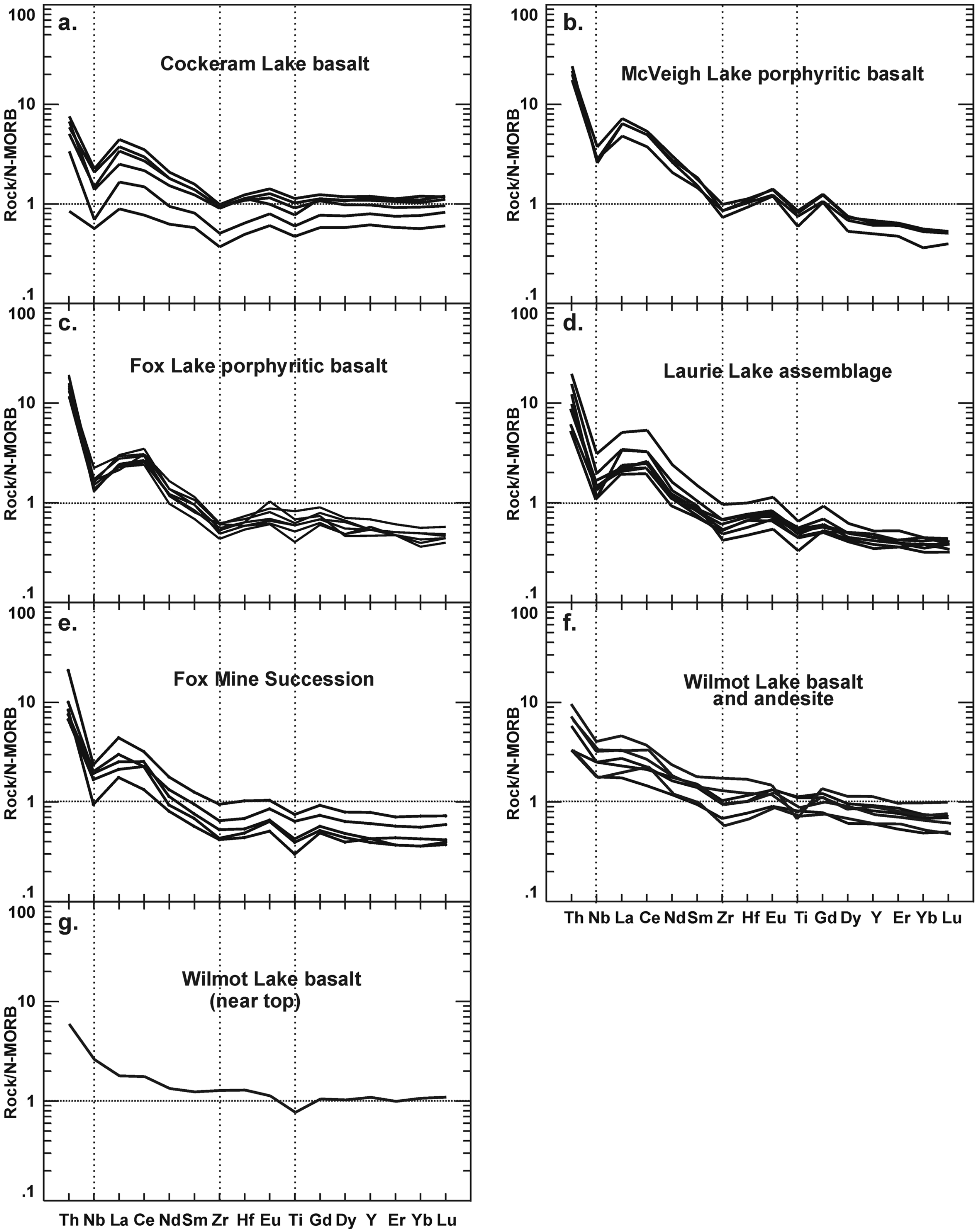

Figure 7.2: MORB-normalized extended element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt.

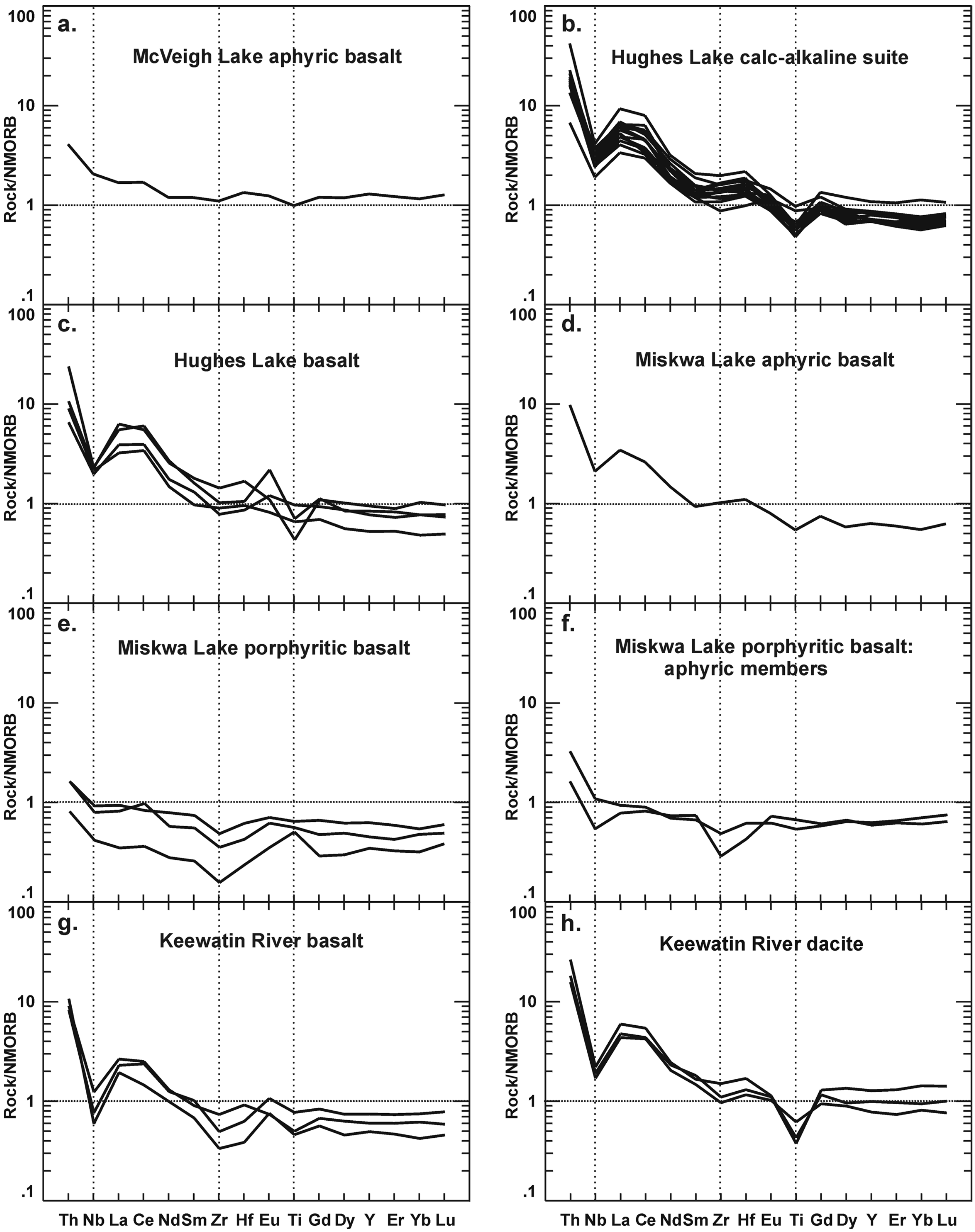

Figure 7.3: MORB-normalized extended element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt.

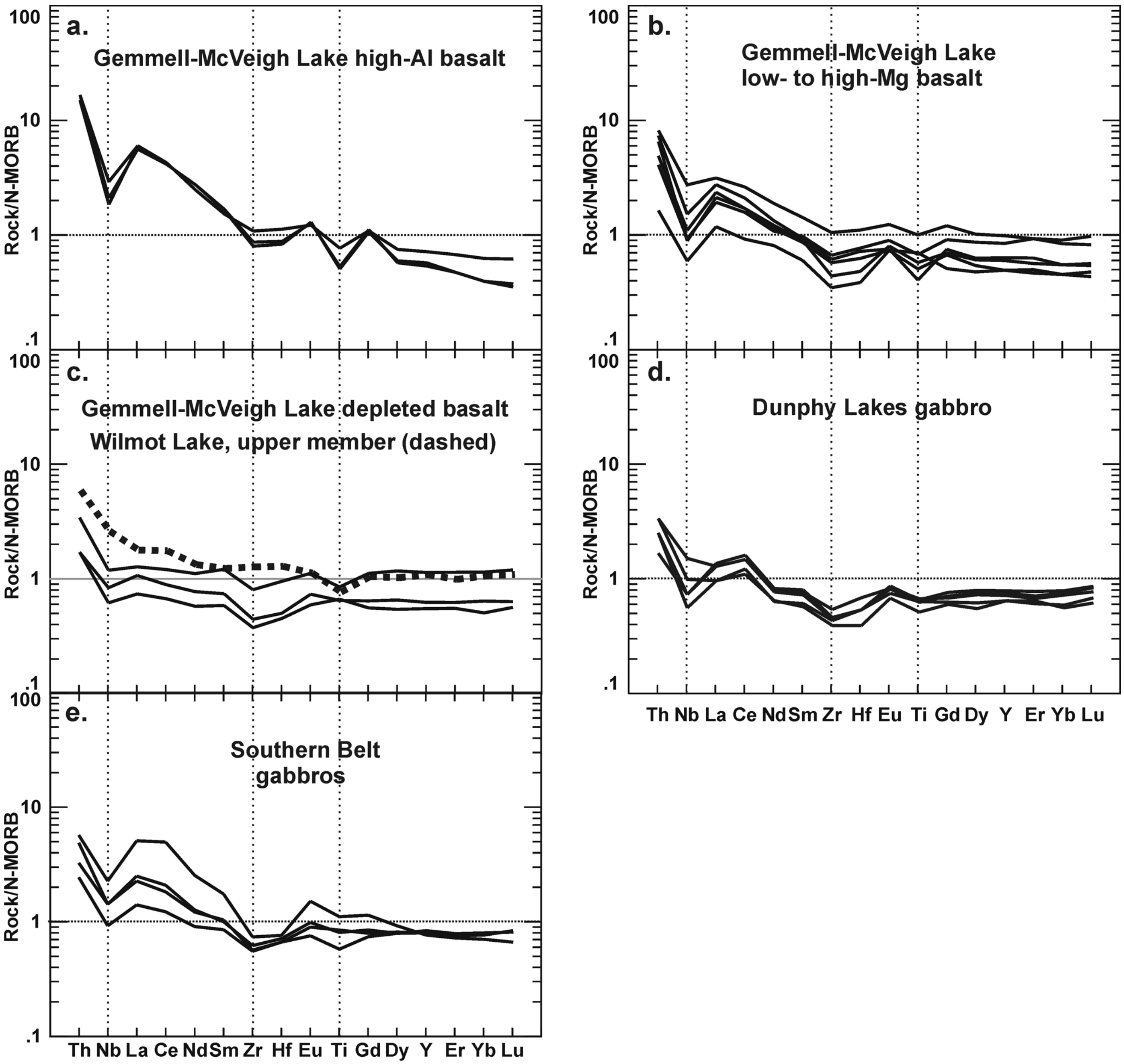

Figure 7.4: MORB-normalized extended element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Southern Belt.

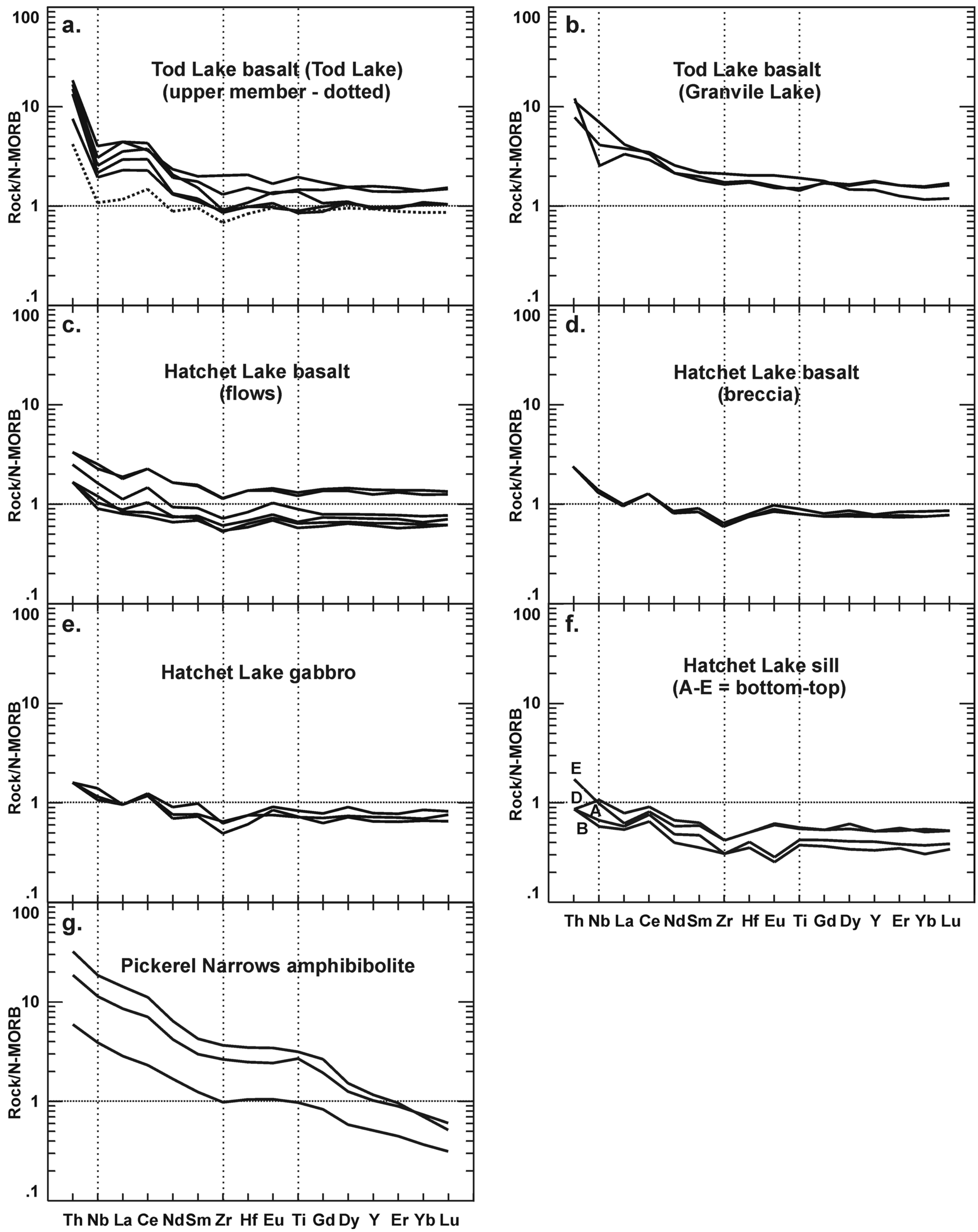

Figure 7.5: MORB-normalized extended element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Hatchet Lake-Granville Lake area.

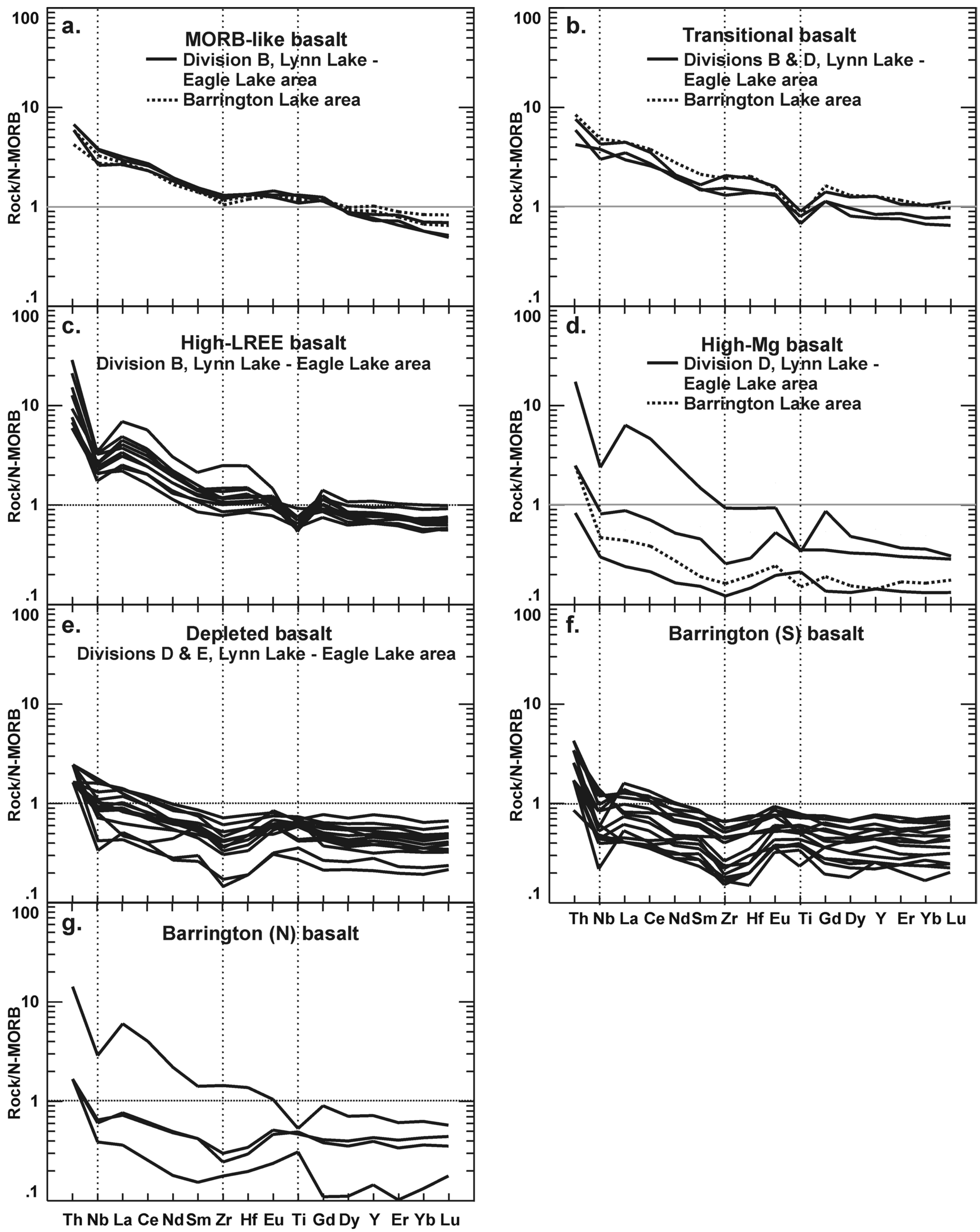

Figure 7.6: MORB-normalized extended element plots of mafic volcanic rocks (normalizing values from Sun and McDonough, 1989). Northern Belt (ordered as in Fig. 4.2).

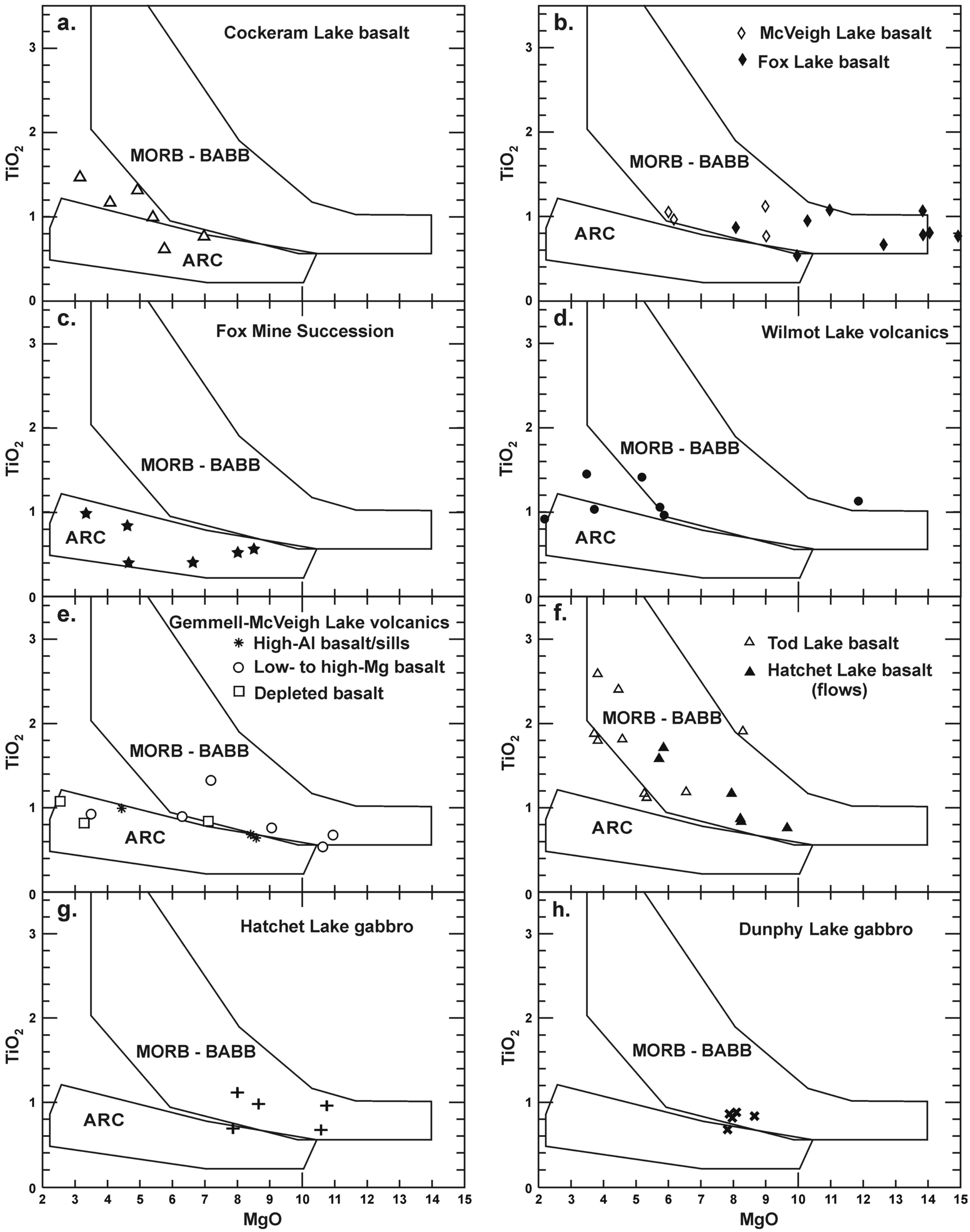

Figure 8.1: TiO_2 vs. MgO diagrams of mafic volcanic rocks (compositional fields from Stern et al., 1995a). Southern Belt to Granville Lake area.

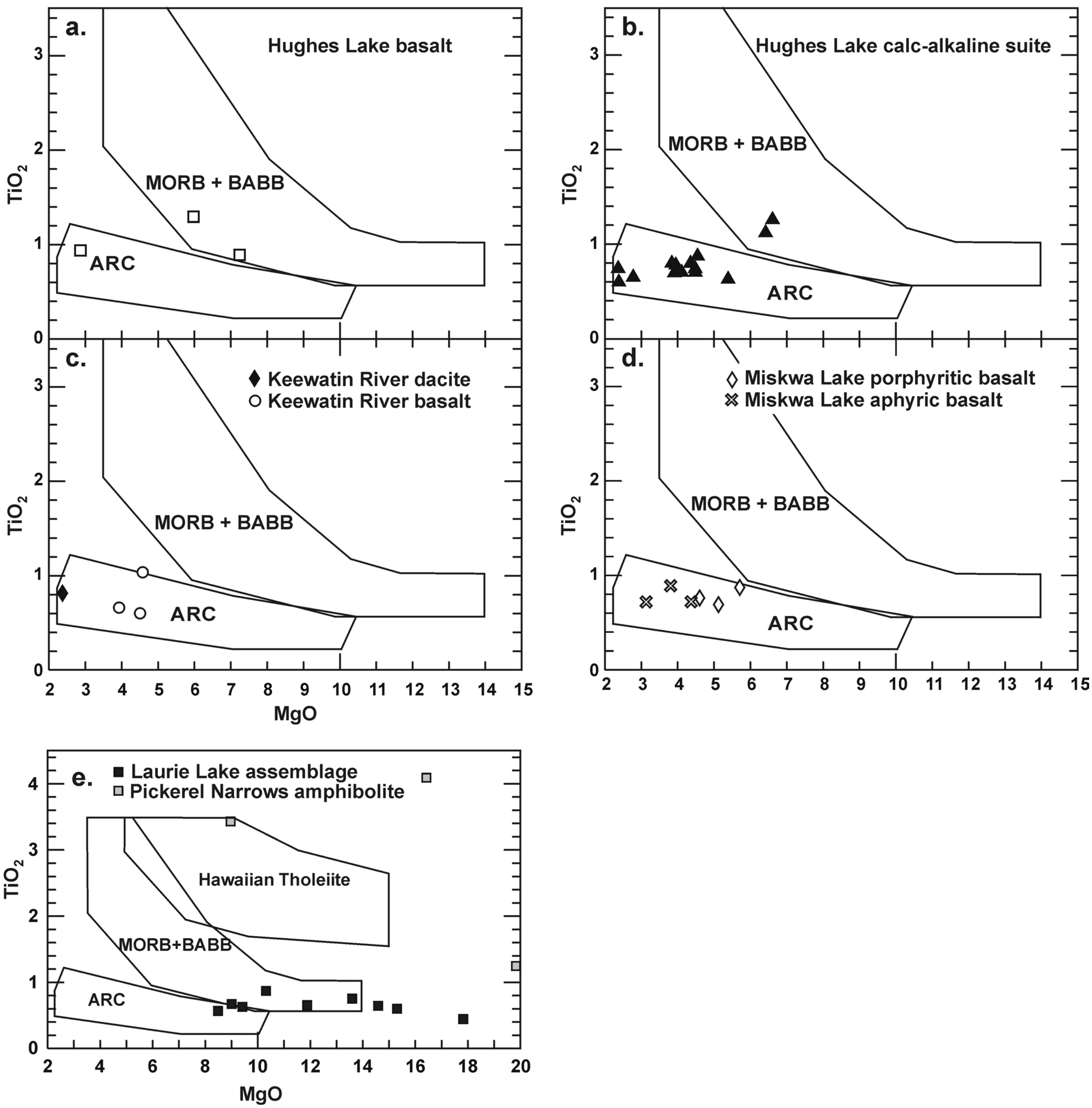

Figure 8.2: TiO_2 vs. MgO diagrams of mafic volcanic rocks (compositional fields from Stern et al., 1995a). Southern Belt to Granville Lake area.

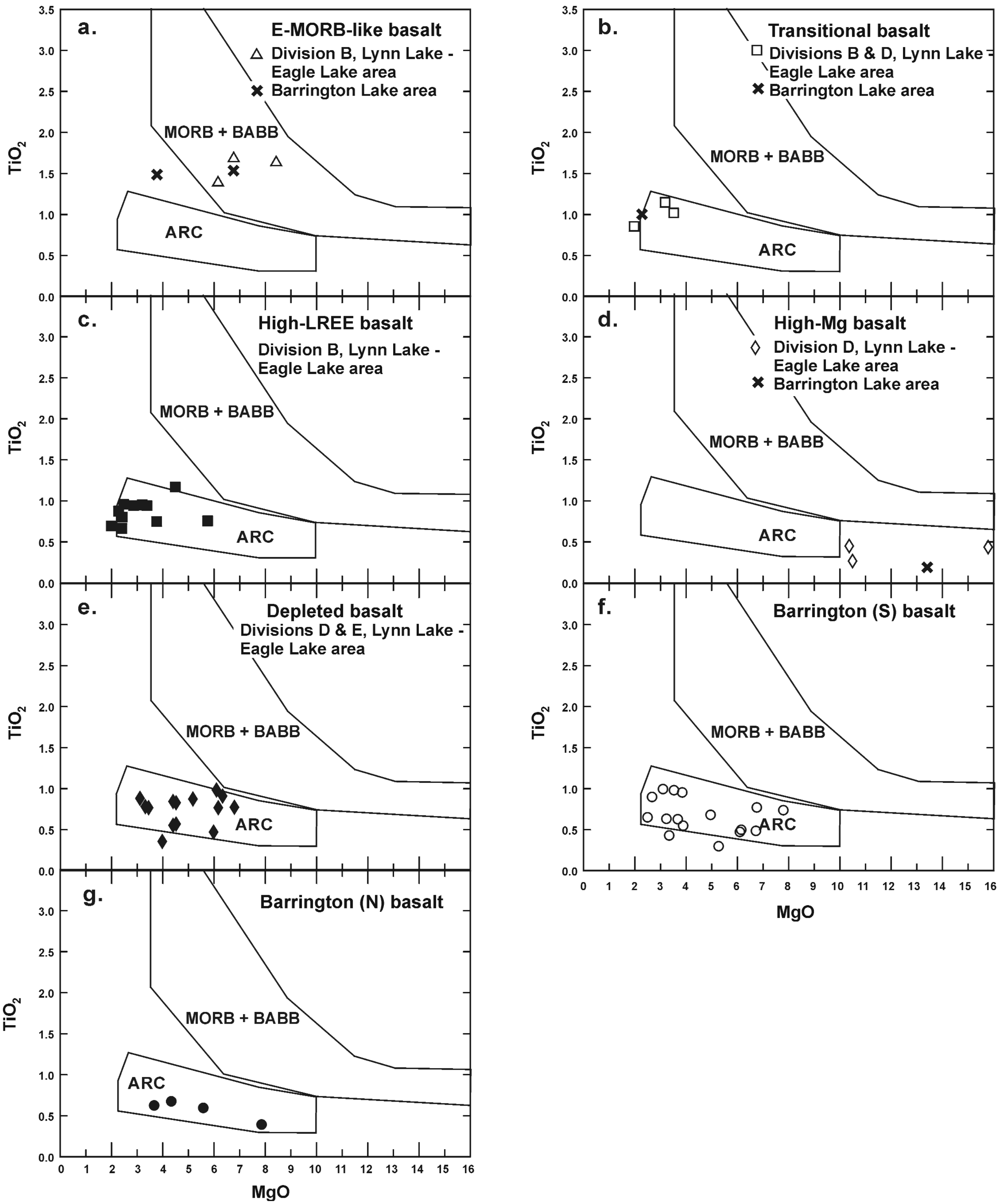

Figure 8.3: TiO_2 vs. MgO diagrams of mafic volcanic rocks (compositional fields from Stern et al., 1995a). Northern Belt (ordered as in Fig. 4.2).

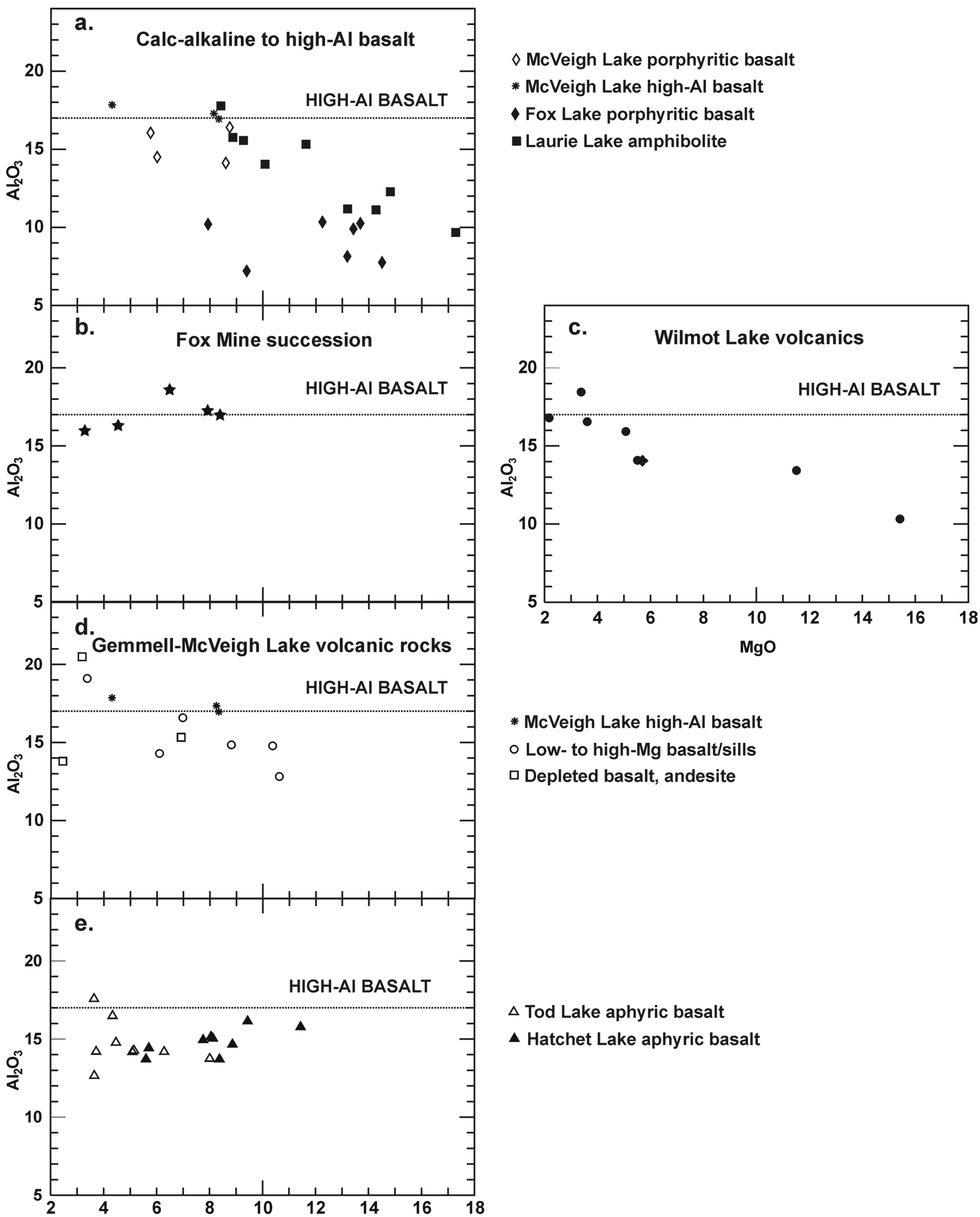

Figure 9.1: Al_2O_3 vs. MgO diagram of mafic volcanic rocks. Selected rock suites from the Southern Belt.

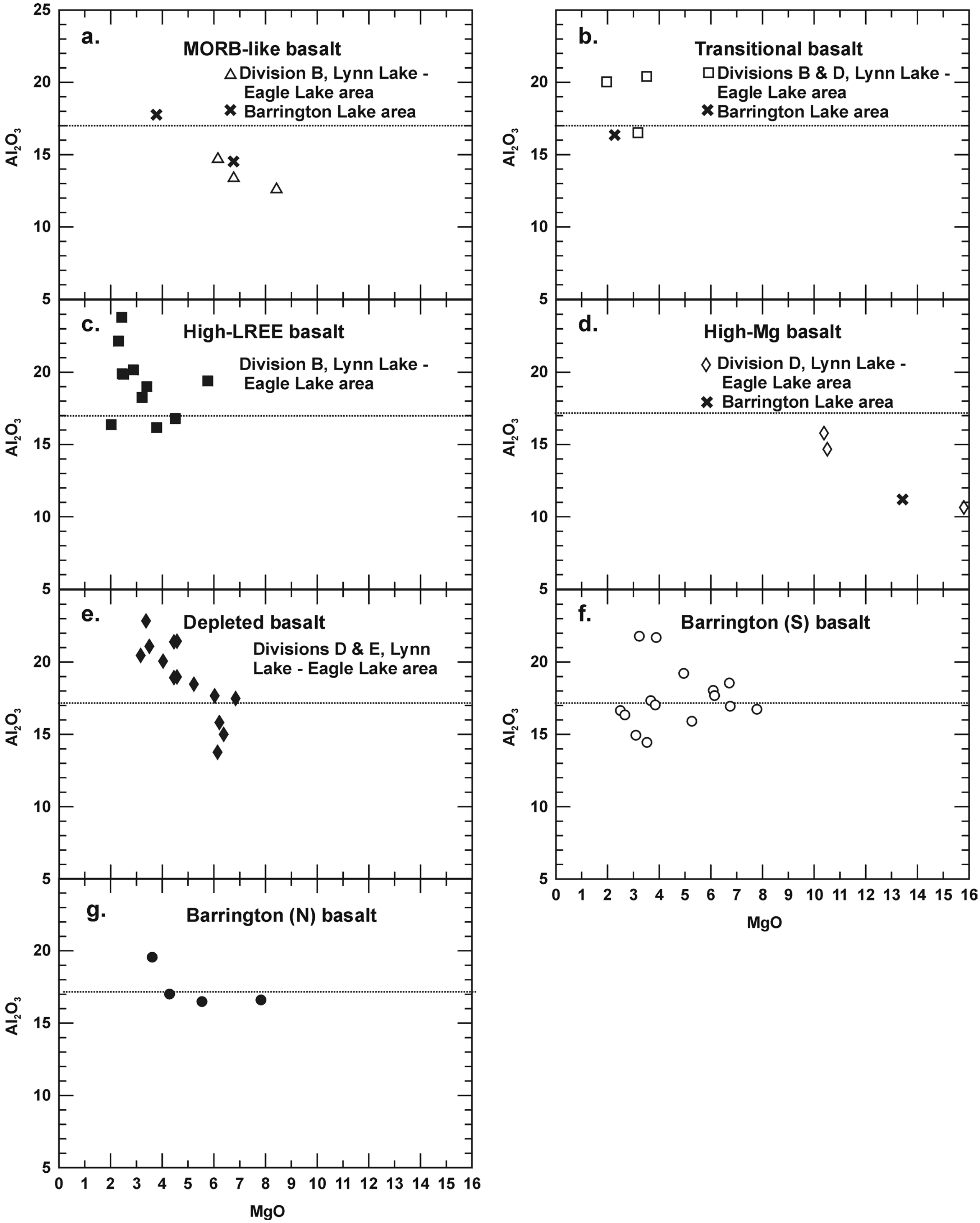

Figure 9.2: Al_2O_3 vs. MgO diagram of mafic volcanic rocks. Northern Belt (ordered as in Fig. 4.2).

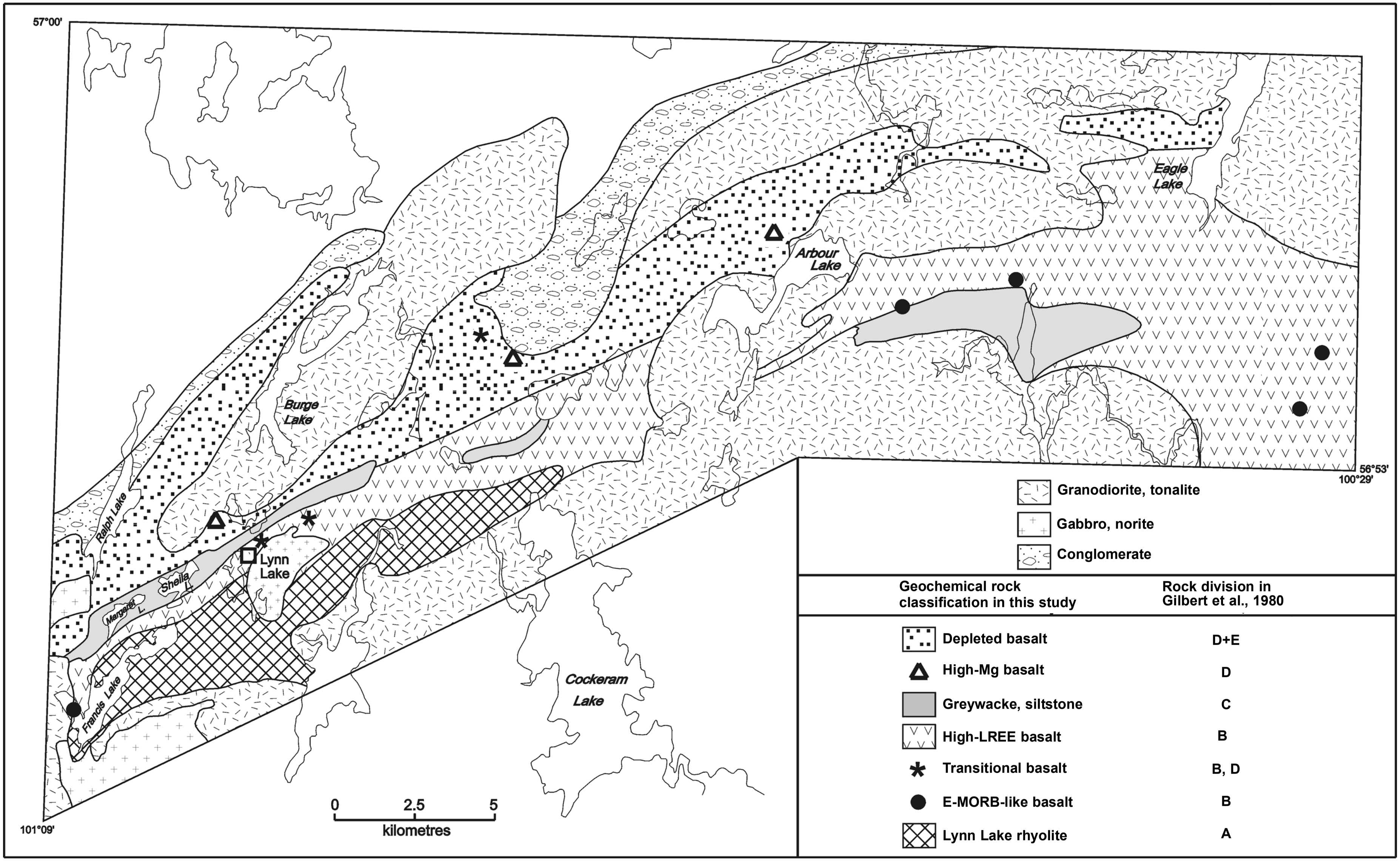

Figure 10: Simplified geological map of the Northern Belt, Francis Lake-Eagle Lake area, showing the distribution of major geochemically distinctive rock suites (patterned) and sample locations of the less abundant suites (symbols). The location of the depleted basalt/high-LREE basalt contact is approximate; the line may occur further northwest, coincident with the high-Mg basalt unit.

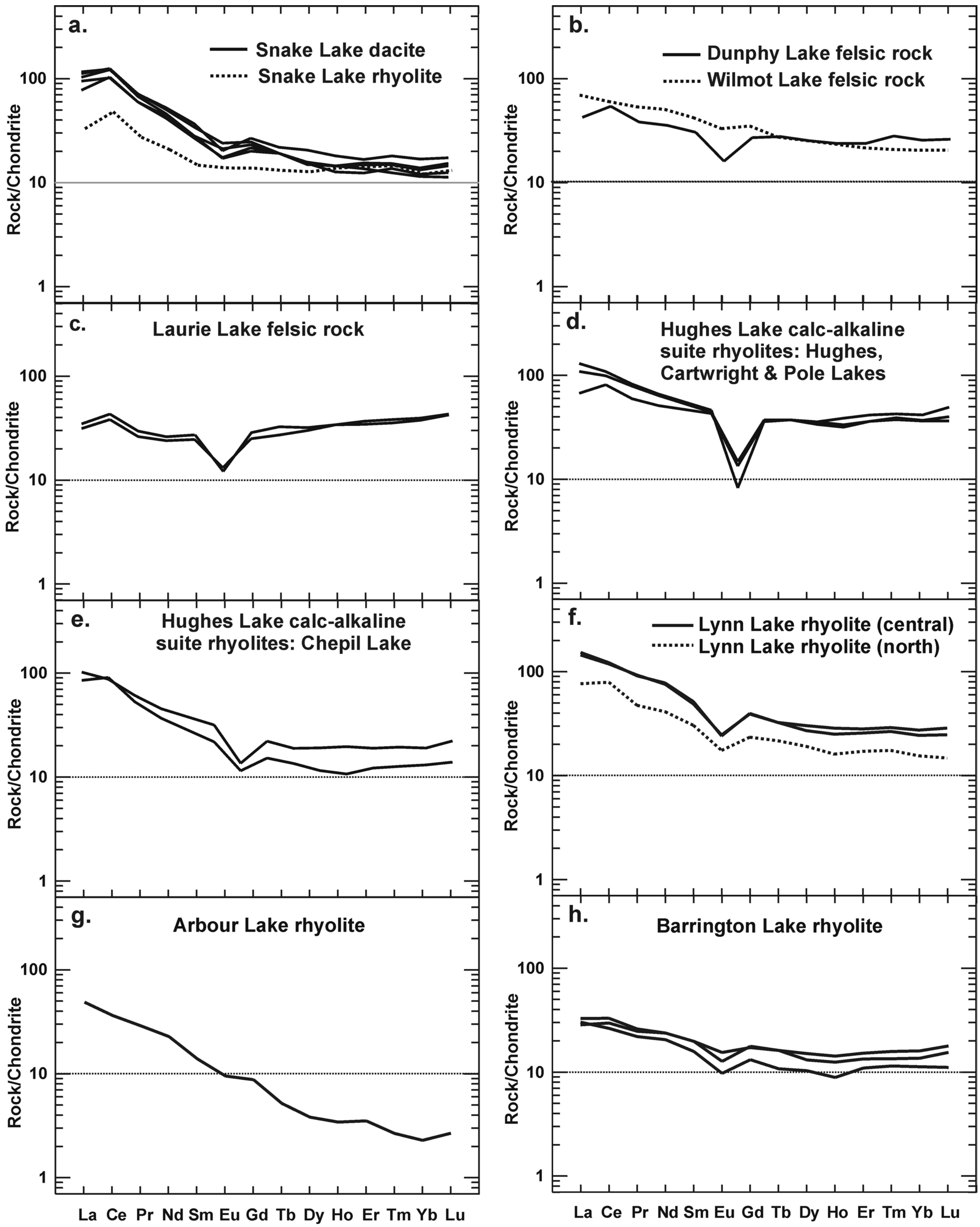

Figure 11: Chondrite-normalized rare earth element diagrams of felsic volcanic rocks in the Northern Belt (normalizing values from Sun and McDonough, 1989); a), e) and f) are patterns similar to rhyolite in calc-alkaline assemblages in the Flin Flon Belt and type FII Archean rhyolite (see text for explanation); c) and d) resemble type FIII; g) resembles type FI; b), c) and h) are rhyolites from tholeiitic rock suites.

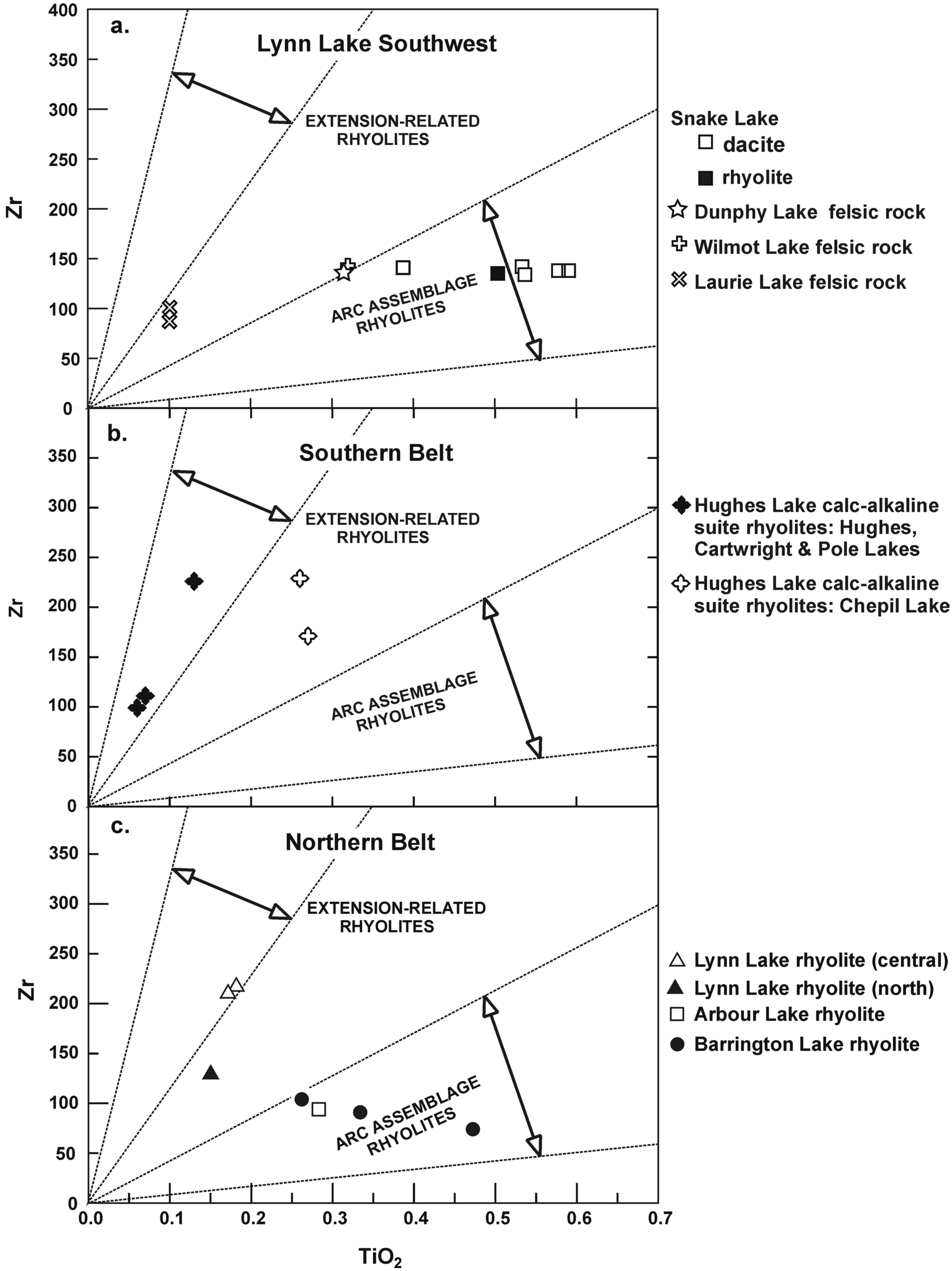

Figure 12: Zr vs. TiO_2 plot of felsic volcanic rocks. Limits of ratios for extension-related and arc-assemblage rhyolites are from the Flin Flon Belt (Syme, 1998).

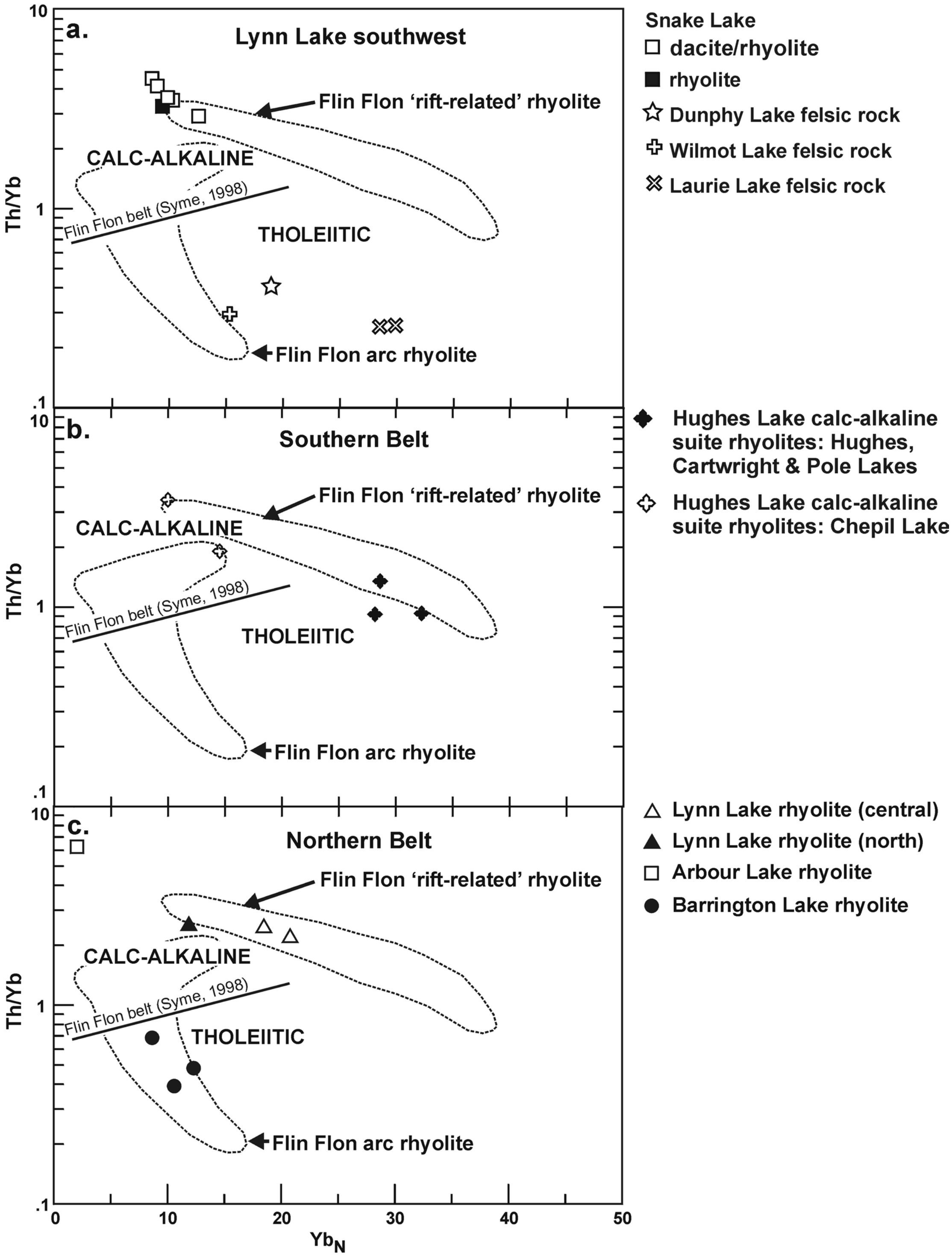

Figure 13: Th/Yb vs. 0.22Yb plot of felsic volcanic rocks. The dividing line and fields of rift-related and arc rhyolites are from the Flin Flon Belt (Syme, 1998).

Table 1: Selected geochemical data for basaltic rocks in the Northern Belt, Lynn Lake-Barrington Lake area (average, range). Data for Welch Lake basalt in the Flin Flon-Snow Lake belt (similar to Northern Belt depleted basalt) are included for comparison.

Rock suite	SiO_2 (%)	Al_2O_3 (%)	FeO^t (%)	CaO (%)	TiO_2 (%)	Th (ppm)	Nb (ppm)	Th/Nb	$(La/Yb)_{ch}$	FeO^t/MgO
E-MORB-like basalt	**50.55** (48.87 - 52.56)	**14.39** (12.42 - 17.51)	**11.74** (10.21 - 12.86)	**10.32** (8.98 - 12.63)	**1.52** (1.37 - 1.66)	**0.7** (0.5 - 0.8)	**7.4** (6.0 - 8.7)	**0.10** (0.08 - 0.12)	**5.0** (3.8 - 6.4)	**2.0** (1.5 - 3.5)
Transitional basalt	**57.16** (53.35 - 61.29)	**18.15** (16.19 - 20.21)	**8.43** (5.90 - 11.33)	**6.90** (3.18 - 9.21)	**0.99** (0.84 - 1.13)	**0.8** (0.5 - 1.0)	**9.1** (6.9 - 11.1)	**0.09** (0.06 - 0.10)	**5.3** (3.3 - 7.7)	**3.2** (2.3 - 3.9)
High-LREE basalt	**53.96** (51.42 -61.48)	**19.07** (15.98 - 23.64)	**9.64** (7.02 - 12.71)	**7.33** (4.50 - 10.61)	**0.86** (0.67 - 1.16)	**1.4** (0.7 - 3.4)	**5.9** (4.0 - 7.8)	**0.22** (0.14 - 0.44)	**6.1** (3.7 - 8.4)	**3.2** (1.6 - 4.4)
High-Mg basalt	**50.37** (49.19 - 51.37)	**12.98** (10.59 - 15.67)	**9.42** (8.39 - 10.20)	**11.70** (10.95 - 12.29)	**0.34** (0.20 - 0.45)	**0.7** (0.1 - 2.1)	**2.3** (0.7 - 5.6)	**0.24** (0.14 - 0.38)	**7.2** (2.09 - 20.3)	**0.8** (0.5 - 1.0)
Depleted basalt	**50.49** (47.25 - 53.26)	**18.57** (13.58 - 22.61)	**10.28** (7.80 - 12.27)	**10.83** (7.69 - 16.05)	**0.73** (0.35 - 0.97)	**0.2** (0.2 - 0.3)	**2.4** (0.8 - 4.2)	**0.12** (0.05 - 0.30)	**2.8** (1.2 - 4.5)	**2.2** (1.6 - 3.4)
Barrington (S) basalt	**52.21** (46.97 - 63.57)	**17.88** (14.29 - 24.82)	**10.60** (6.52 - 14.27)	**9.60** (7.00 - 11.41)	**0.66** (0.30 - 0.97)	**0.3** (0 - 0.5)	**1.7** (0.5 - 3.2)	**0.16** (0 - 0.40)	**2.3** (1.2 - 3.6)	**2.6** (1.6 - 4.2)
Barrington (N) basalt	**53.62** (51.07 - 58.01)	**17.29** (16.31 - 19.39)	**8.95** (6.39 - 11.94)	**10.02** (7.49 - 12.93)	**0.57** (0.40 - 0.68)	**0.6** (0.2 - 1.7)	**2.6** (0.9 - 6.7)	**0.19** (0.13 - 0.25)	**4.6** (1.9 - 11.0)	**1.9** (0.8 - 2.9)
Snow Lake area (pers. comm., A. Bailes, unpublished data)										
Low-Ti Welch Lake basalt (samples with <54% SiO_2)	**51.50** (50.15 - 53.62)	**15.39** (13.98 - 17.44)	**12.37** (9.58 - 16.84)	**10.55** (8.96 - 12.94)	**0.70** (0.41- 1.20)	**0.3** (0.1 - 0.5)	**1.2** (0.9 - 1.5)	**0.13** (0.11 - 0.15)	**1.7** (1.3 - 2.7)	**2.3** (1.1 - 3.9)

Table 2: Selected geochemical data for normal- and high-Al basaltic rocks in the Northern Belt, Barrington Lake area (average, range).

Rock suite	SiO_2 (%)	Al_2O_3 (%)	FeO^t (%)	TiO_2 (%)	La (ppm)	Yb (ppm)	Th (ppm)	Nb (ppm)	Th/Nb	FeO^t/MgO
Barrington (S) normal-Al bslt	**54.39** (47.92 - 63.57)	**16.00** (14.29 - 16.86)	**10.95** (6.52 - 14.27)	**0.78** (0.30 - 0.99)	**2.5** (1.1 - 3.9)	**1.7** (1.1 - 2.1)	**0.3** (0 - 0.5)	**2.0** (1.0 - 3.1)	**0.15** (0 - 0.31)	**2.8** (1.6 - 4.2)
Barrington (S) high-Al bslt	**50.04** (46.97 - 54.10)	**19.76** (17.19 - 24.82)	**10.24** (7.92 - 11.60)	**0.54** (0.43 - 0.68)	**1.6** (1.0 - 3.4)	**0.9** (0.5 - 1.4)	**0.2** (0 - 0.4)	**1.4** (0.5 - 3.2)	**0.16** (0 - 0.40)	**2.3** (1.7 - 3.1)

Table 3: Geochemical subdivisions in the Lynn Lake Belt volcanic rocks

1 Arc tholeiite

a Cockeram Lake aphyric basalt	Southern Belt, east-central	-flat REE on chondrite-normalized plot to slightly enriched LREE -moderate TiO_2, but negative anomalies of Ti and other HFSE on MORB-normalized plots
b Gemmell-McVeigh Lake basalt	Southern Belt, southwest	
c Fox Mine succession	Southern Belt, southwest	-slightly LREE enriched -low TiO_2 and other HFSE (normal for arc) -high Th/Nb
d Keewatin River basalt (more fractionated)	Southern Belt, southeast	

2 Calc-alkaline basalt to andesite

a Laurie Lake assemblage (8.5-18% MgO)	Southern Belt, southwest end	-very primitive in the southwest to evolved in the northeast (basalt to dacite) -LREE enriched -MORB-normalized plots with high Th and negative Nb, Zr, Nd, Ti anomalies
b Fox Lake porphyritic basalt (8-15% MgO)	Southern Belt, Fox Mine area	
c McVeigh Lake porphyritic basalt (6-9% MgO)	Southern Belt, central	
d Hughes Lake calc-alkaline suite (2.3-6.5% MgO)	Southern Belt, east central	

3 Enriched arc tholeiite

a McVeigh Lake high-Al basalt (17% Al_2O_3)	Southern Belt, west-central	-LREE enriched (steep slope on MORB-normalized plots) with high Th and negative Nb, Zr, Nd, Ti anomalies (c.f. calc-alkaline basalts) -high Al_2O_3
b High-LREE basalt (16-24% Al_2O_3)	Northern Belt, southwest	
c Hughes Lake basalt (olivine normative)	Southern Belt, east central	-LREE enriched (steep slope on MORB-normalized extended element plots) -high Th and negative Nb, Zr, Nd, Ti anomalies
d Miskwa Lake aphyric basalt	Southern Belt, south central	

4 Depleted arc tholeiite

a Depleted basalt (14-23% Al_2O_3)	Northern Belt, northwest	-depleted in REE and HFSE -prominent negative Zr, Hf anomalies on MORB-normalized multi-element plots -low Th/Nb for arc basalt
b Barrington Lake (N, S) basalt (14-25% Al_2O_3)	Northern Belt, east	
c Miskwa Lake porphyritic basalt	Southern Belt, south central	

5 Komatiitic basalt

a High-Mg basalt (10-16% MgO, <0.5% TiO_2)	Northern Belt, east-west	-generally REE and HFSE-depleted

6 Weakly depleted arc tholeiite

a Wilmot Lake basalt (uppermost sample)	Southern Belt, southwest	-flat MORB-normalized plots, close to N-MORB and lacking or with weak negative HFSE anomalies -moderate positive Th anomaly
b McVeigh Lake aphyric basalt (one sample)	Southern Belt, central	
c Gemmell-McVeigh Lake depleted basalt	Southern Belt, southwest	

7 Arc tholeiite transitional to E-MORB

a E-MORB-like basalt (12-18% Al_2O_3)	Northern Belt, southwest	-slightly elevated LREE but low Th/Nb -smooth, moderately sloping MORB-normalized plots with very weak negative Nb and Zr anomalies
b Transitional basalt/andesite (16-20% Al_2O_3)	Northern Belt, west	-slightly elevated LREE -low to moderate Th/Nb -smooth, moderately sloping MORB-normalized plots with weak negative Nb, Ti ± Zr anomalies
c Wilmot Lake basalt/andesite (14-22% Al_2O_3)	Southern Belt, southwest	

8 MORB-like basalt

a Hatchet Lake basalt	Southern Belt to Kisseynew	-very weakly LREE enriched -smooth MORB-normalized multi-element plots, weakly concave up, with very slightly elevated Th
b Tod Lake basalt (contaminated-fractionated)	Southern Belt to Kisseynew Domain	-weakly to moderately LREE enriched -no HFSE anomalies on MORB-normalized plots -moderately enriched Th compared to MORB -elevated TiO_2 (1.1-2.6%)

9 Ocean island basalt (OIB)-ultramafic rock

a Pickerel Narrows amphibolite	Kisseynew Domain, north margin	-high MgO (9-20%) and TiO_2 (1.2-4.1%) -steep negative REE slopes on chondrite- and MORB-normalized plots with positive Ti anomalies

10 Dacite

a Snake Lake dacite	Southern Belt, southwest	-calc-alkaline -high Th/Yb -low Zr/Ti
b Keewatin River dacite	Southern Belt, central	

11 Rhyolite

a Lynn Lake rhyolite (calc-alkaline)	Northern Belt, southwest	-high Th/Yb -moderate to high Zr/Ti -Lesher, type FII
b Chepil Lake rhyolite	Southern Belt, central	
c Arbour Lake rhyolite	Northern Belt, west	-very high Th/Yb; low Zr/Ti -steep negative REE slope (Lesher type FI)
d Dunphy/Wilmot lakes rhyolite	Southern Belt, southwest	-low Th/Yb -low Zr/Ti -flat to moderately negative REE slope
e Barrington Lake rhyolite	Northern Belt, east	
f Cartwright Lake-Pole Lake rhyolite (calc-alkaline)	Southern Belt, east central	-low Th/Yb -high Zr/Ti -high REE, negative Eu anomaly (Lesher, type FIII)
g Laurie Lake felsic rock Na-rhyolite (?)	Kisseynew Domain, north margin	