

**Geochemistry of Paleoproterozoic
Volcanic Rocks in the
Lac Aimée-Naosap Lake Area
Flin Flon Belt
(Parts of NTS 63K/13SE and 63K/14SW)**

OPEN FILE REPORT



By
H.P. Gilbert



Cover:

Lineal topographic cleft in Animus Lake ocean floor basalt terrane (northwest of Lac Aimée), coincident with the faulted margin of a greywacke unit. The exotic, arc-affiliated greywacke is a fault sliver that was probably tectonically emplaced in the volcanic rocks during 1.88-1.87 Ga tectonic accretion of Amisk Collage.

GEOREF

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Geochemistry of Paleoproterozoic Volcanic Rocks in the Lac Aimée-Naosap Lake Area, Flin Flon Belt (Parts of NTS 63K/13SE and 63K/14SW)

by H.P. Gilbert
Winnipeg, 1999

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MAPS

OF99-1: Lac Aimée-Naosap Lake (1:20 000).	in pocket
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SUMMARY

Field and geochemical investigations in the Lac Aimée-Naosap Lake area (1996-1997) have revealed a high degree of structural complexity and geochemical diversity in this comparatively small area (13 by 8 km) at the north flank of the Flin Flon Belt (Figs. 1, 2). Animus Lake block (northwest of Lac Aimée) is a highly deformed tectonic wedge of MORB-like basalt, structurally juxtaposed against arc volcanic rocks to the southeast (Lac Aimée block). These contrasting structural elements are separated by the crustal-scale, northeast-trending Lac Aimée Fault Zone. In the north part of the map area, arc volcanic rocks (Wabishkok Lake block) are separated from Animus Lake MORB-like basalt by faults and by the North Aimée Gabbro, a lensoid intrusion that is compositionally similar to MORB-like basalt. West of Animus Lake fault, at the west margin of the map area, tectonically separate arc and MORB-like basalts are parts of the Tartan Lake and Mikanagan Lake blocks respectively (Gilbert, 1996a, in press). In the east part of the area, arc volcanic rocks at Naosap Lake are part of yet another tectonic unit (Sourdough Bay block; Gilbert, 1997).

Animus Lake block contains both N- and E-type MORB (LeRoex, 1987) volcanic rock suites; these contrasting rock types are stratigraphically conformable. N-type MORB occupies the axial zones of synclines in a series of repeated early folds and thus overlies E-type MORB (Fig. 2). Animus Lake N-type MORB is conspicuously depleted in rare earth elements (REE) and Zr, in contrast to most N-type MORB suites elsewhere in the Flin Flon Belt (Stern et al., 1995a). Animus Lake block is interpreted as analogous to ocean floor basalt in the Elbow-Athapuskow ocean floor assemblage in the south-central part of the Flin Flon Belt (Stern et al., 1995a).

Rhyolite and related intrusive porphyry units comprise approximately 5% of the arc volcanic sequence in Lac Aimée block. These felsic rocks are characterized by enriched REE (10-100 × chondrite) and smooth negative sloping profiles (LREE > HREE), with only very slight negative Eu anomalies. Felsic volcanic units are virtually absent in Animus Lake block, except for a porphyritic unit that occurs as several lenses along the southeast margin of the block; the geochemical signature of the porphyry suggests it is synvolcanic with respect to the MORB-like volcanic rocks that are the main component of the fault

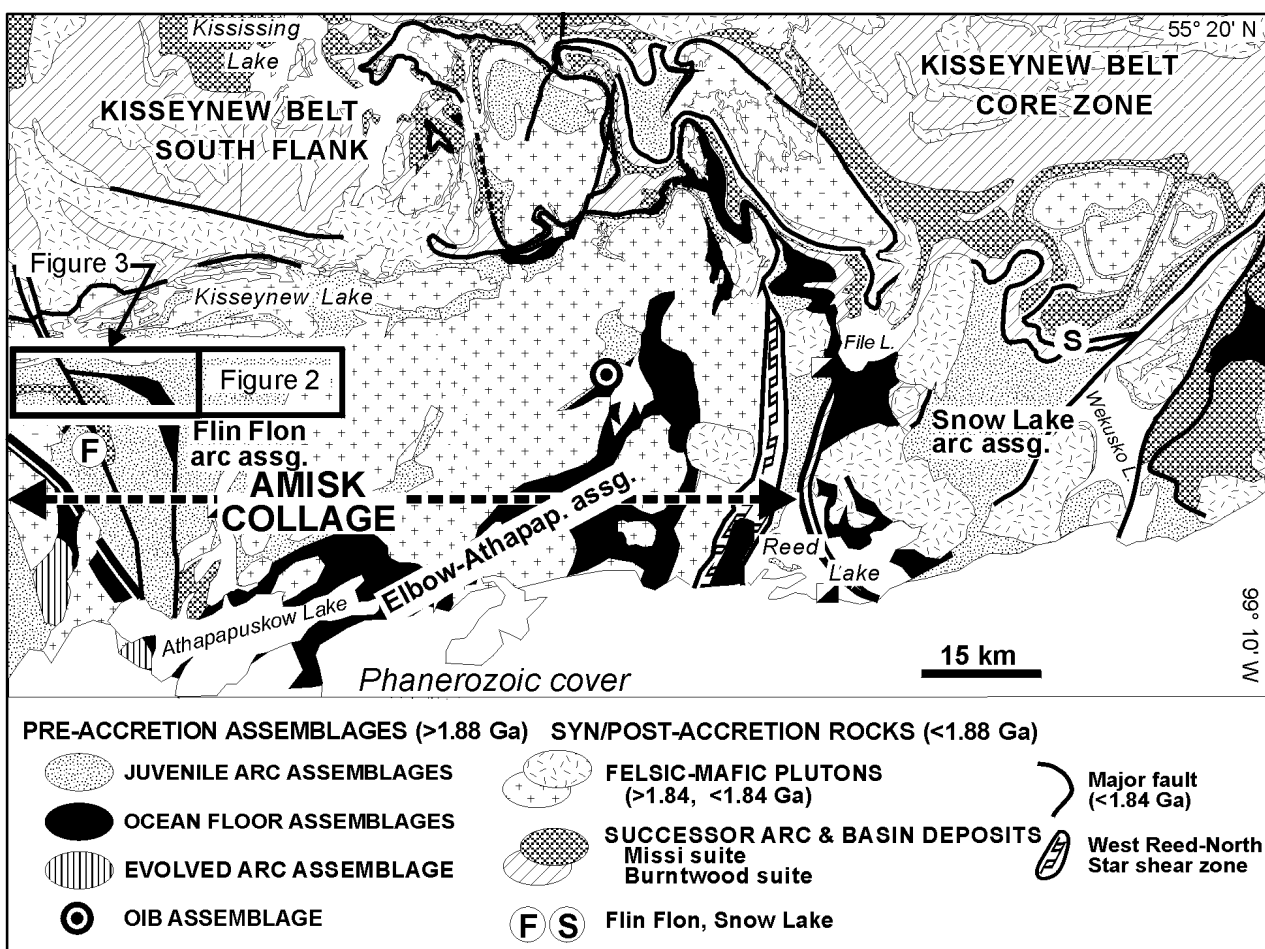


Figure 1: Map of the Flin Flon Belt showing the major tectonostratigraphic assemblages and location of the Lac Aimée-Naosap Lake area (Figure 2, inset). The Amisk collage extends through the central Flin Flon Belt from File and Reed lakes in the east to the area approximately 50 km west of Flin Flon.

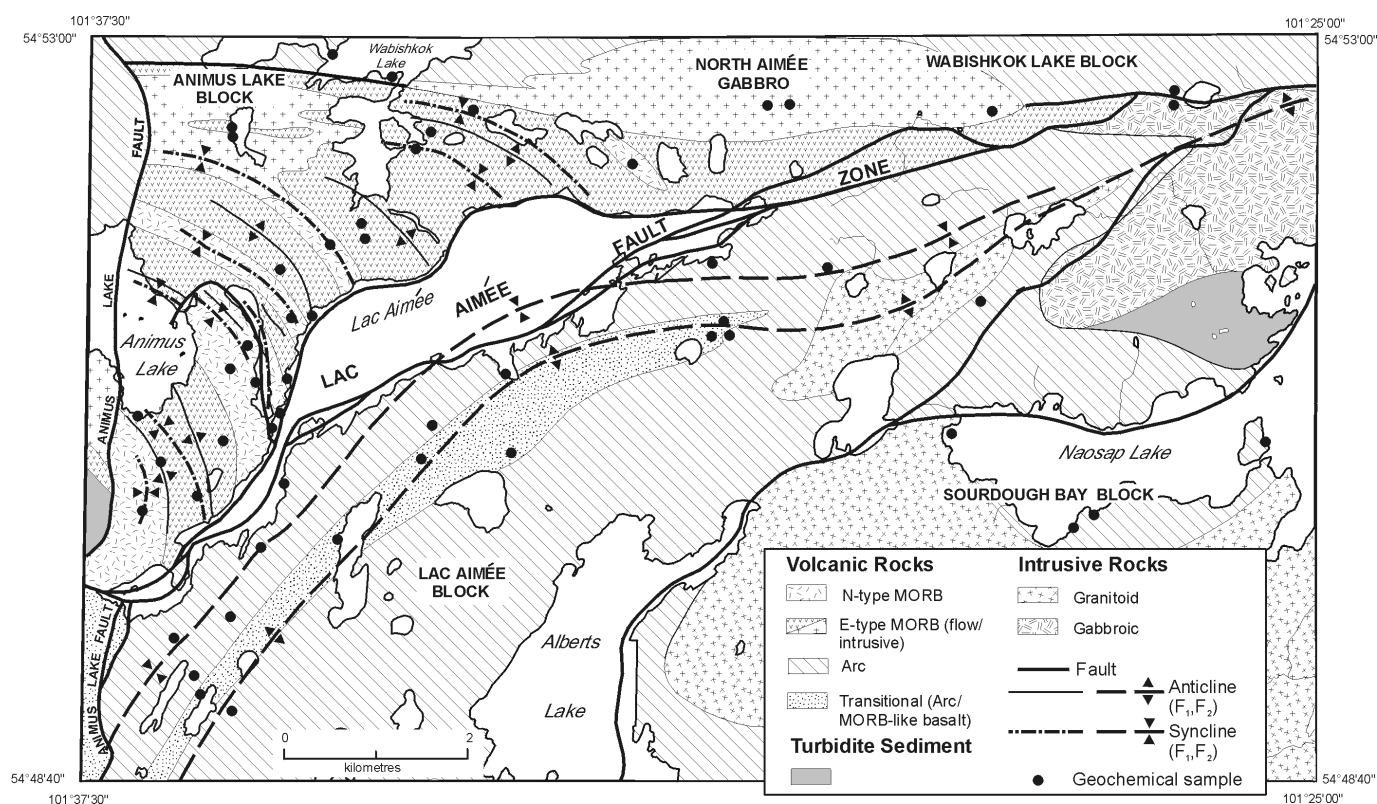


Figure 2: Map showing the main structural subdivisions and geochemical rock suites in the Lac Aimée-Naosap Lake area.

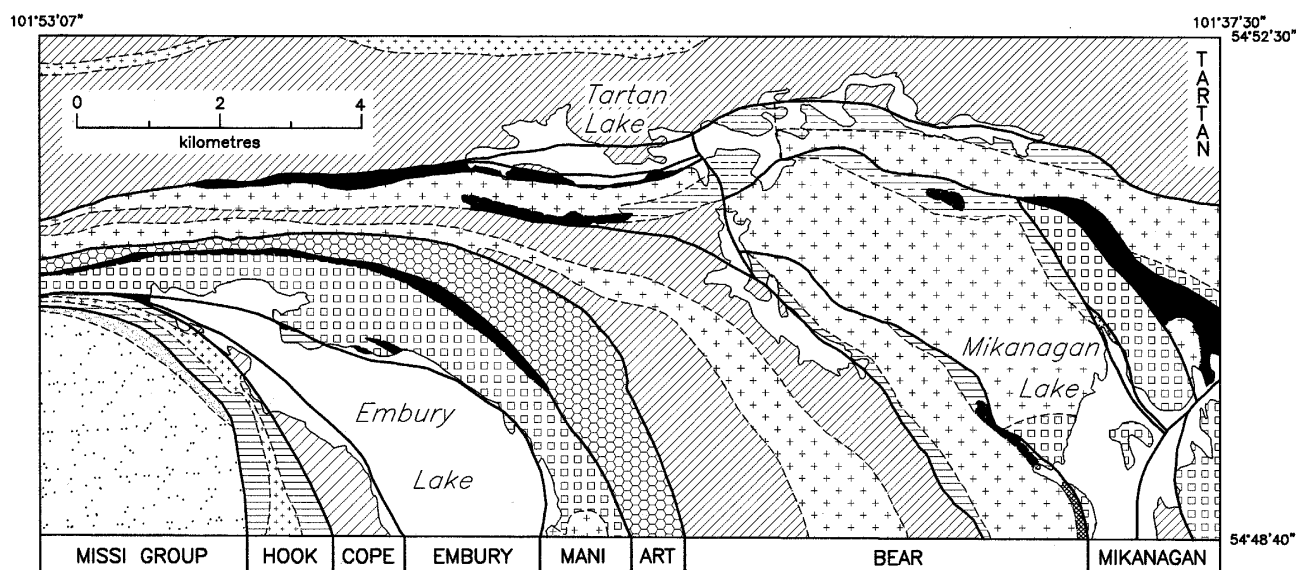
block. Although the felsic porphyry unit is lithologically similar to felsic intrusions of arc affinity in the contiguous Lac Aimée block to the southeast, it displays a different REE profile, with relatively higher REE content and a marked negative Eu anomaly. It is similar to extension-related rhyolites in the Flin Flon-White Lake area to the south (e.g. Grassy Narrows rhyolite; Two Portage Lake rhyolite tuff; Syme, 1998). The REE signature of the felsic porphyry, together with its location close to the margin of the Lac Aimée Fault Zone, indicate the unit may have potential for hosting base metal mineralization.

INTRODUCTION

Geological mapping (1: 20 000) in the north-central part of the Flin Flon Belt (Fig. 1) was carried out in the Tartan-Embury-Mikanagan lakes (TEM) area (Fig. 3) between 1986 and 1990 (Gilbert, 1990). Subsequent 1: 20 000 scale mapping extended this coverage eastward into the Lac Aimée-Naosap Lake area (Fig. 2), as far as the conjunction of Flin Flon Belt volcanosedimentary rocks with the granitoid terrane at Naosap Lake. The results of recent mapping in the area of the present study (Lac Aimée-Naosap Lake) have been described in summary reports (Gilbert, 1996b, 1997, 1998), and incorporated into the NATMAP Shield Margin Project compilation map (NATMAP Shield Margin Project Working Group, 1998); geochemical studies have been discussed in Gilbert (in press).

The tectonic history and geochemical diversity of the TEM area are described in Gilbert (1996a, in press). In summary, this 15 by 7 km area, though a minor part of the north-central Flin Flon Belt, consists of 12 tectonically distinct blocks that contain volcanic rock suites of 3 geochemically distinct volcanic assemblage types — arc, E-type MORB and N-type MORB — together with related intrusive and epiclastic rocks. Arc volcanic suites are laterally transitional with equivalent rocks in the Flin Flon arc assemblage to the south, in the Flin Flon-White Lake area (Bailes and Syme, 1989). MORB-like volcanic suites do not extend to the south, although possibly analogous, geochemically similar rocks (e.g. Scotty Lake basalt, Two Portage Lake basalt; Bailes and Syme, 1989) occur in fault blocks in the Flin Flon-White Lake area.

Parts of no less than six tectonostratigraphic assemblages occur in the Lac Aimée-Naosap Lake area (13 by 8 km), which is separated from the TEM area by the major north-trending Animus Lake fault that is approximately coincident with Longitude 101° 37' 30" W (Fig. 2). These assemblages consist of distinctive arc and MORB-like volcanic rock suites (as in the TEM area) and are separated by major faults. Lac Aimée Fault Zone is a crustal-scale break that extends across the map area between the MORB-like volcanic rocks of Animus Lake block to the northwest, and arc-type volcanic rocks of Lac Aimée block to the southeast (Fig. 2; Gilbert, 1998). Lac Aimée volcanic rocks are continuous with strati-



PALEOPROTEROZOIC

YOUNGER SEDIMENTARY ROCKS (1.87–1.83 Ga;
POSTDATE AMALGAMATION OF THE AMISK COLLAGE)

MISSI GROUP

- Sandstone
- Polymictic conglomerate, sandstone

INTRUSIVE ROCKS (1.89–1.84 Ga)

- Granodiorite, tonalite, quartz diorite
- Gabbro, diorite, quartz diorite

SEDIMENTARY ROCKS (AGE UNKNOWN)

TURBIDITE (volcanic-derived)

- Greywacke-mudstone

VOLCANIC AND INTRUSIVE ROCKS
(AMISK COLLAGE; 1.92–1.88 Ga)

JUVENILE ARC

- Rhyolite, dacite
- Tholeiitic basalt, basaltic andesite, gabbro
- Tholeiitic/calc-alkaline transitional basalt, basaltic andesite

ARC-RIFT

- Basalt, aphyric

OCEAN FLOOR

- Basalt, gabbro; plagioclase-megaphyric to aphyric
- Basalt, geochemical affinity unknown

----- Geological Contact

———— Fault

Figure 3: Map showing the main structural subdivisions and geochemical rock suites in the Tartan-Embury-Mikanagan lakes area. MANI = Manistiwkan; ART = Arthurs.

graphically equivalent arc volcanics in the Whitefish-Mikanagan lakes block to the south (Bailes and Syme, 1989). Animus Lake block, in contrast, is a highly deformed tectonic wedge that may be related to the Elbow-Athapapuskow ocean floor assemblage; the latter constitutes a large part of the south-central Flin Flon Belt, ca. 20 km to the south of Lac Aimée (Stern et al., 1995a; Lucas et al., 1996; NATMAP Shield Margin Project Working Group, 1998). Elsewhere in the Lac Aimée-Naosap Lake area, arc volcanic rocks extend along the north margin (Wabishkok Lake block), and occupy the east part (Naosap Lake vicinity) and northwest part of the map area (Tartan Lake block); MORB-like basalt of Mikanagan Lake block occupies the southwest corner of the map area (Gilbert, 1996a, in press).

The purpose of this study is to investigate the geology and geochemistry of volcanic rock suites in the Lac

Aimée-Naosap Lake area, and to identify the distinctive lithologic and geochemical features that define their tectonostratigraphic setting. Field and geochemical data are largely derived from Animus Lake and Lac Aimée fault blocks, which together contain all three volcanic assemblage types in the north-central Flin Flon Belt (arc, E-type and N-type MORB). Map coverage of Wabishkok Lake and Naosap Lake arc volcanic suites is restricted to the south margin of the Wabishkok Lake section and the west part of Naosap Lake (Fig. 2); geochemical data for these rock suites is therefore limited. Rocks west of Animus Lake fault are parts of Tartan Lake and Mikanagan Lake fault blocks that have been described previously (Gilbert, 1996a, in press).

REGIONAL SETTING

Volcanic and subordinate sedimentary rocks in the north-central part of the Flin Flon Belt (Figs. 2, 3) are part of a Paleoproterozoic accretionary complex (1.92-1.87 Ga Amisk collage; Lucas et al., 1996). Fault-bound volcanic rock suites within the collage include analogues of modern intraoceanic arc basalt, and MORB-like rocks of possible arc-rift and/or ocean floor origin (Stern et al., 1995a, b; Syme et al., 1996; Gilbert, 1996a). Younger volcanic and sedimentary rocks (e.g. Missi Group, Fig. 3) are part of the 1.87-1.84 Ga successor arc that postdates formation of the Amisk collage (Lucas et al., 1996). The present configuration of juxtaposed fault blocks within the accretionary complex can be interpreted as the result of disruption of the arc and adjacent ocean basin during convergent crustal movements at approximately 1.88-1.87 Ga, overprinted by significant subsequent deformation (Lucas et al., 1996, and references therein). Arc volcanic rocks in the north-central Flin Flon Belt are, in part, continuous with rocks of the Flin Flon arc assemblage to the south (Stern et al., 1995b); subordinate MORB-like basaltic rock suites are tectonically emplaced within the arc volcanic rocks. Whereas some MORB-like rocks may represent an arc-rift setting, others are similar to, and possibly comagmatic with, the Elbow-Athapapuskow ocean floor assemblage in the south-central part of the Flin Flon Belt (Stern et al., 1995a; Gilbert, in press). The latter is coeval with early (tholeiitic) arc volcanism (1.904-1.901 Ga; David et al., 1993; Stern et al., in press) and is interpreted as a back-arc basin component of the intraoceanic arc system.

Contacts between volcanic rock suites are invariably faulted and schistose, with localized carbonatization and emplacement of minor felsic to mafic intrusive sheets (Gilbert, 1990). The contacts include major shear zones that may have been initiated during 1.88-1.87 Ga tectonic accretion as well as younger, post-accretion faults (Syme, 1990, 1995). Major shear zones were reactivated following successor arc volcanism and sedimentation, as shown by the occurrence of fault slices of successor basin deposits within several major shear zones (e.g. basal Missi Group conglomerate occurs in a 20 m wide northwest-trending fault sliver within arc-rift basalt in the north part of Mikanagan Lake; Fig. 3).

GEOLOGY AND TECTONOSTRATIGRAPHIC SETTING OF VOLCANIC ROCK ASSEMBLAGES

Arc volcanic rocks

Flin Flon arc assemblage rocks in the central part of the Flin Flon Belt are characterized by a wide range of lithologic types that include massive flows, related fragmental and intrusive rocks, and associated turbidite deposits. Lac Aimée arc volcanic suite (in the north-central Flin Flon Belt) is a part of this assemblage, and consists

mainly of massive basalt/basaltic andesite flows intercalated with subordinate mafic tuff, massive to fragmental rhyolite and heterolithic volcanic breccia (Gilbert, 1996b, 1997). Pillow structure is not widely preserved in basaltic flows within this rock suite, possibly due, in part, to the loss of primary structures as a result of multiphase deformation. Mafic volcanic flows are texturally diverse and include aphyric to plagioclase- or pyroxenophyric, and/or amygdaloidal types. Mafic layered tuff intercalations are locally graded, in contrast to heterolithic breccia units, which are unsorted. The breccia deposits, which are confined to a few localities near the shore of Lac Aimée and in the northeast part of the fault block (unit 4c in Open File Map OF99-1, in pocket), are interpreted as mass flows derived from unconsolidated volcanic fragmental debris (Fig. 4). Sporadic greywacke/siltstone turbidite lenses are also intercalated with the volcanic rocks. Synvolcanic gabbro and diabase are a minor part of Lac Aimée fault block, whereas felsic porphyry is a more conspicuous component. The felsic units (up to 220 m thick) are largely massive and plagioclase+quartz phyrlic,



Figure 4: Heterolithic volcanic breccia of inferred mass flow origin in Lac Aimée arc volcanic suite.

and are interpreted as flows and related sills; a flow-laminated rhyolite lobe was observed at one locality (Fig. 5). Subordinate volcanic fragmental rocks occur within some massive felsic units.

Naosap Lake suite appears to consist mainly of massive and pillowed intermediate flows, with associated volcanic fragmental rocks and related epiclastic deposits. The south part of Wabishkok Lake block consists of massive to pillowed mafic flows (Fig. 6) that are compositionally equivalent to Lac Aimée arc basalt. On the basis of iron enrichment trends, Wabishkok and Lac Aimée volcanic suites are tholeiitic. Most other arc basalts in the north-central Flin Flon Belt are less fractionated, transitional tholeiitic/calc-alkaline types (Gilbert, in press) except for Hook Lake suite (tholeiitic) and Naosap Lake arc volcanic suite, which is calc-alkaline.

The andesitic to dacitic compositional range of Naosap Lake rocks contrasts with that of arc volcanic rock suites elsewhere in the central part of the Flin Flon Belt, which are typically bimodal (basalt/rhyolite), with only very minor intermediate volcanic rocks. Naosap Lake volcanic rocks were originally mapped as basaltic; however, the available geochemical data indicate an intermediate compositional range (Table 1; Appendix A) which is interpreted as a primary magmatic signature, rather than the result of secondary alteration. There is no evidence for regional alteration within the rock suite, although volcanic rocks at the margin of the granitoid terrane east of Naosap Lake display localized silicic/feldspathic metasomatic alteration (Fig. 7).

The conspicuous lithologic and compositional diversity of arc volcanic rocks compared to relatively homogeneous

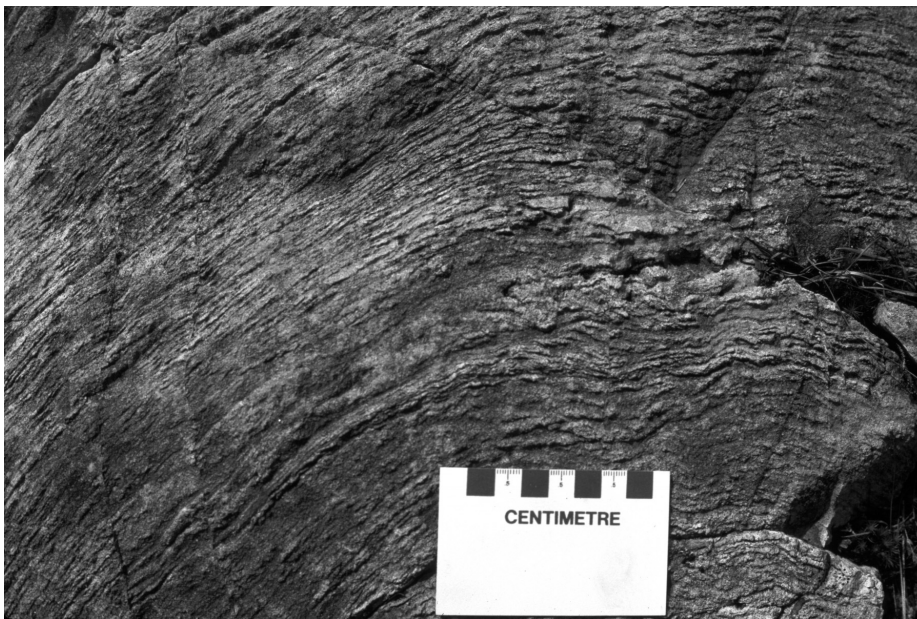


Figure 5: Flow lamination at the margin of a rhyolite lobe in a felsic flow unit, Lac Aimée arc volcanic suite.

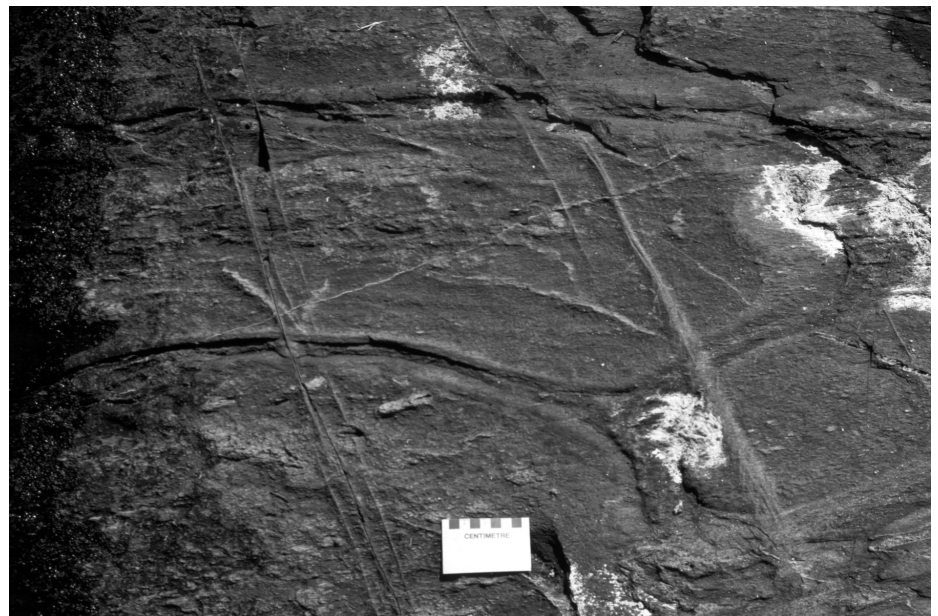


Figure 6: Aphyric pillowed basalt, Wabishkok Lake arc volcanic suite.

Table 1
Selected geochemical data for Naosap Lake arc volcanic suite, compared with average values for arc volcanic rocks elsewhere in the north-central Flin Flon Belt.

	Naosap Lake arc volcanic suite	Lac Aimée arc volcanic suite	North-central Flin Flon Belt arc volcanic (excl. Naosap Lake)
SiO ₂	64.9	56.1	53.5
Fe ₂ O ₃ total	7.9	12.5	11.2
MgO	4.1	6.2	6.1
Th	1.1	1.3	0.7
Nb	2.6	3.2	2.8
Th/Nb	0.42	0.43	0.42
La/Yb _{ch} ¹	5.0	8.5	5.5

Major element averages based on wt.%, calculated to 100% volatile free. Trace element averages in ppm.

¹ Normalizing values from Sun and McDonough (1989).

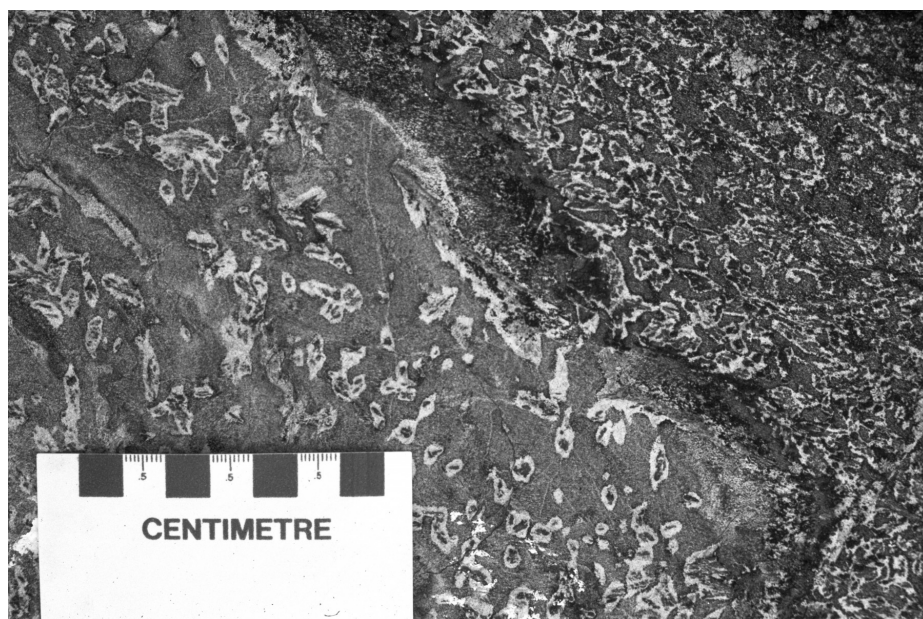


Figure 7: *Metasomatic alteration of basalt in contact with tonalite-granodiorite at the south shore of western Naosap Lake. Epidote porphyroblasts occur within irregular to dendritic quartzofeldspathic domains.*

MORB-like volcanic sequences in the north-central Flin Flon Belt serves as an effective field discriminant where these contrasting rock types are structurally juxtaposed. These differences may be attributed, in part, to the more variable physicochemical conditions in the subduction zone environment where arc magmas are generated, compared to the source regions for ocean floor/back-arc basin magmas, thought to be the modern analogues of MORB-like basaltic rocks in this study (Stern et al., 1995a, b; Lucas et al., 1996). The lithologic and textural diversity of arc volcanic rocks elsewhere in the Flin Flon Belt (and, by inference, in the study area) is also due, in part, to a shallower water depositional environment compared to the ocean floor/back-arc basin (Ayres, 1982; Bailes and Syme, 1989).

E-MORB type volcanic rocks

E-MORB type volcanic rocks akin to modern back-arc basin basalt (BABB) are predominant in Animus Lake block. These rocks occur as uniform sequences of pillowed to massive flows with intercalated synvolcanic gabbro sills (five to several hundred metres thick) that constitute approximately 25% of the fault block. In contrast to arc basalt, Animus Lake E-MORB type basalt is very largely aphyric and non-vesicular; sparse plagioclase phenocrysts (0.5-2 mm) and amphibole pseudomorphs occur in a few flows. The sequence is devoid of intercalated sedimentary and volcanic fragmental units, except for rare tuff and flow-top breccia zones (Fig. 8). Animus Lake E-type MORB is typically medium to dark green weathering, in

Figure 8: *Flow-top breccia in E-MORB type pillowed basalt, Animus Lake volcanic suite.*



contrast to generally paler weathering N-type MORB, and arc basalt in the Lac Aimée area. Ovoid to bun-shaped pillows (0.2-2 m; Fig. 9) are virtually ubiquitous in Animus Lake basalt; in spite of polyphase deformation, the pillows are generally well preserved, and afford reliable top determinations which indicate a complex structural pattern. The MORB-like volcanic sequence is characterized by repeated folding, with at least 11 anticline-syncline fold pairs (F_1) with axial planes dipping steeply northeast (Open File Map OF99-1); the early folds were subsequently deformed in a regional southwest-plunging synform (Gilbert, 1997).

N-MORB type volcanic rocks

Five conformable zones of N-MORB type basalt have been delineated in Animus Lake block (Fig. 2). Initial field mapping indicated that the fault block consisted of MORB-like volcanic rocks of possible arc-rift origin (Gilbert, 1997). Subsequent geochemical data confirmed the MORB-like affinity of the mafic volcanic rocks, and further indicated the presence of both E-type and N-type MORB within Animus Lake block (Gilbert, 1998). These types are not distinct in the field, except for a somewhat paler (beige-green) weathered surface for N-type MORB

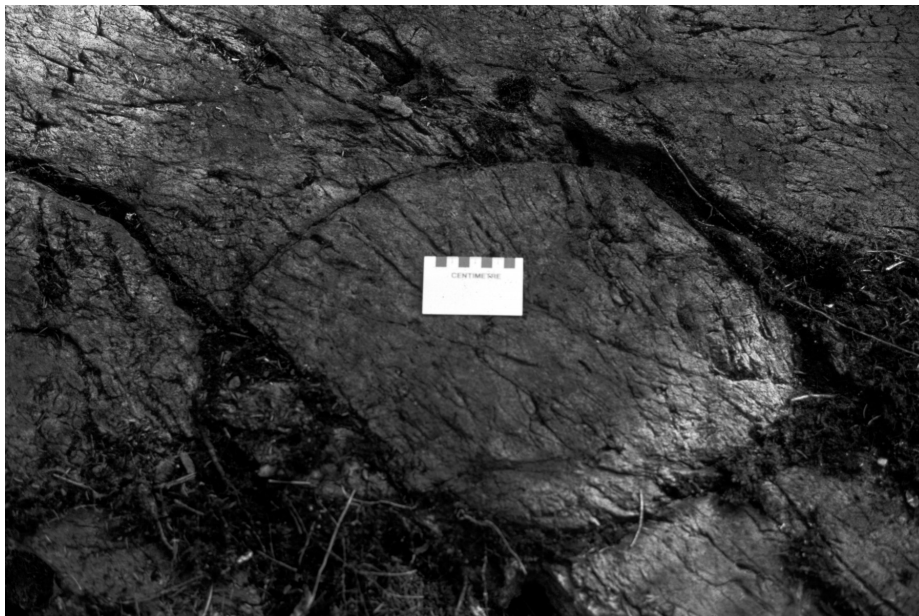


Figure 9: *Aphyric pillowed basalt of E-type MORB affinity, Animus Lake volcanic suite.*

compared to E-type MORB (medium to dark green weathering), due to the paler green variety of amphibole (in contrast to the green hornblende in Animus Lake E-type MORB). In other respects (flow type, texture, pillow structure, internal stratigraphy, etc.), E-type and N-type MORBs are very similar (Figs. 9, 10). The distribution of the two basalt types, based on 26 sample sites (Fig. 2), shows N-type MORB occupies the cores of major syndinal folds, and thus overlies the E-type MORB. Contacts between E- and N-type MORBs are largely conformable, although the E-type/N-type MORB contact at the lake east of Animus Lake is locally coincident with a major fault (Open File Map, OF99-1).

The relative ages of arc and MORB-like volcanic rocks in the Lac Aimée area are not known, but a younger age for some arc-type magmatism is suggested by an inferred synvolcanic mafic dyke of arc affiliation that intrudes E-type MORB flows within Animus Lake block, close to the south end of Wabishkok Lake (Fig. 11). On the other hand, North Aimée Gabbro, which is geochemically akin to and assumed comagmatic with E-type MORB (Fig. 12E), appears to postdate the block-bounding fault between Animus Lake MORB and Wabishkok Lake arc basalt (Fig. 2), suggesting some MORB-affiliated magmatism is younger than the arc volcanic rocks at Wabishkok Lake.

'Transitional' volcanic rocks

Although arc and MORB-like basalts are lithologically and stratigraphically distinct, volcanic rocks geochemically intermediate between these types occur locally. For example, within Lac Aimée arc volcanic rocks, a 'transitional' (arc/MORB-like) basalt unit up to 600 m wide extends for 8 km along the hinge line of Lac Aimée anticline

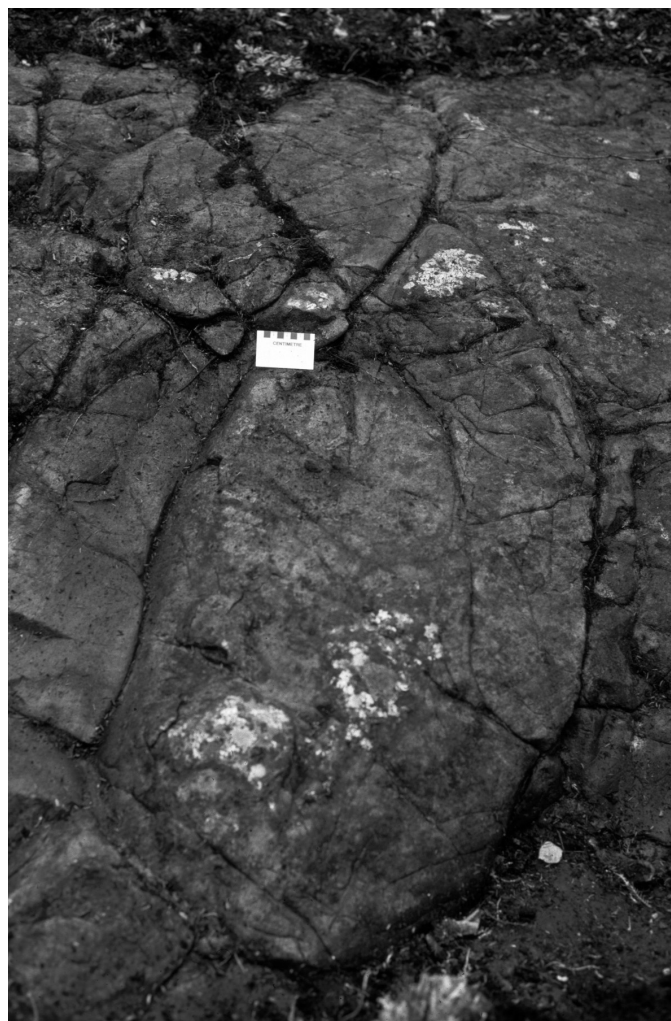


Figure 10: Aphyric pillowed basalt of N-type MORB affinity, Animus Lake volcanic suite.

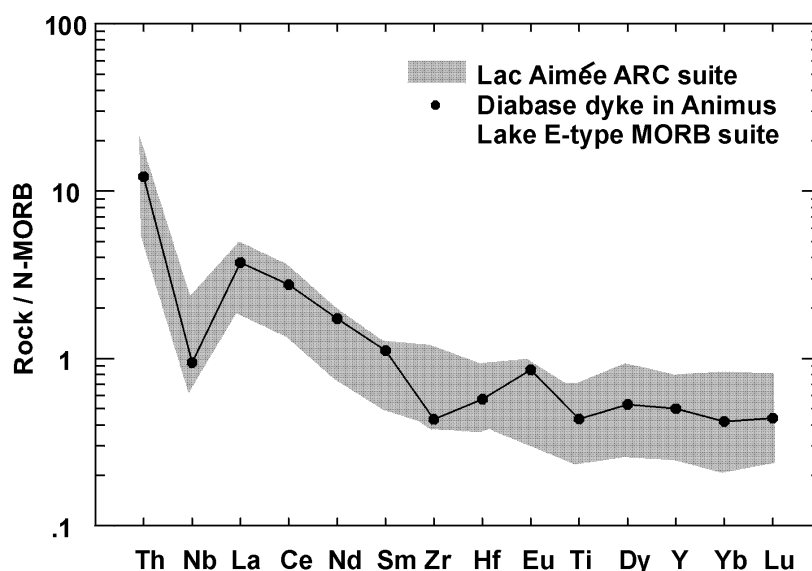


Figure 11: N-MORB normalized extended element plot of a diabase dyke that intrudes Animus Lake E-type MORB near the south end of Wabishkok Lake. The arc-like signature of the dyke suggests some arc-type magmatism postdated Animus Lake ocean floor volcanism. Normalizing values from Sun and McDonough (1989).

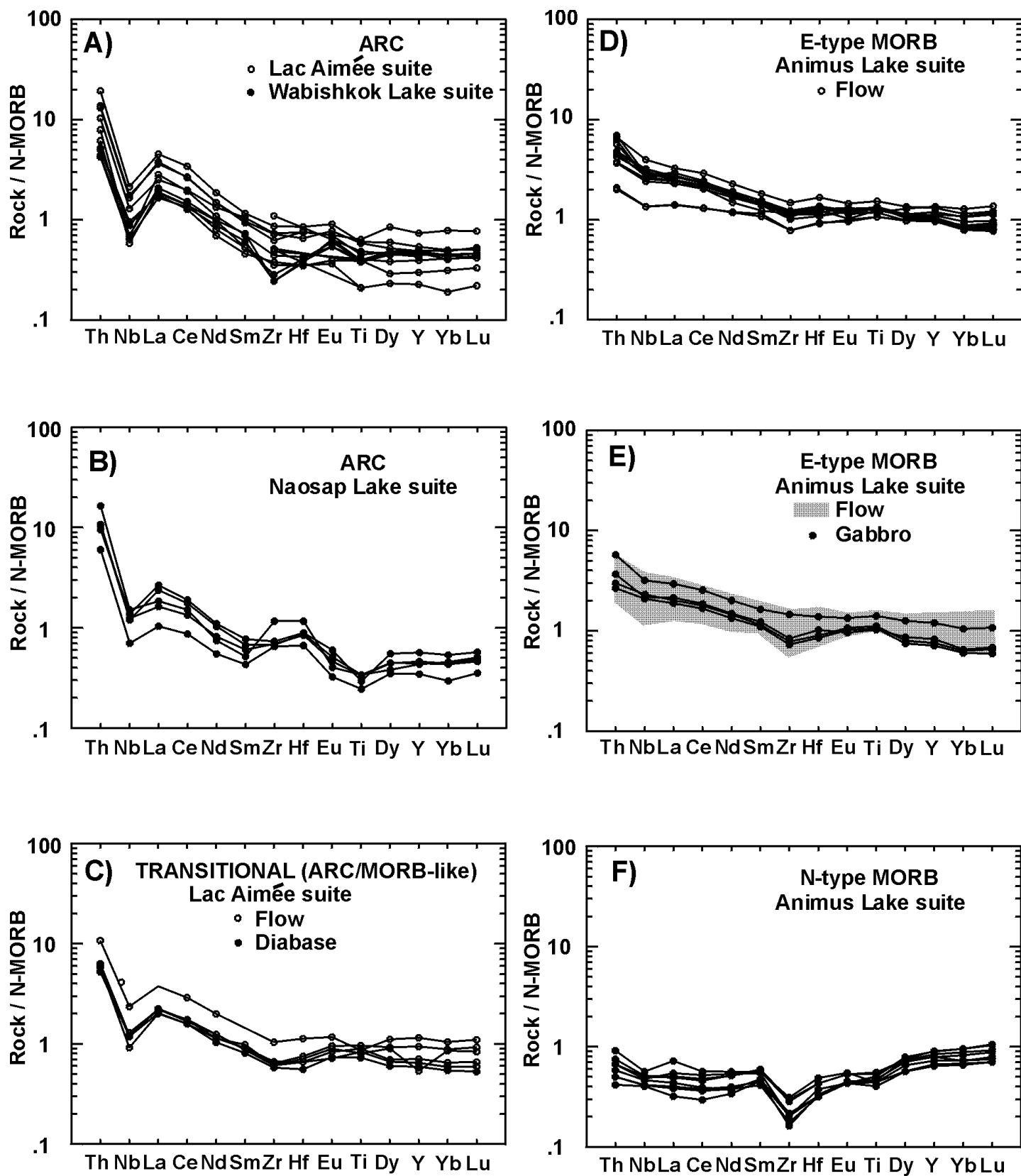


Figure 12: N-MORB normalized extended element plots of volcanic rocks in the Lac Aimée-Naosap Lake area, showing the distinctive signatures of arc and MORB-like volcanic rock assemblages. Normalizing values from Sun and McDonough (1989).

(Fig. 2; Gilbert, 1998); similar transitional rocks occur in the southeast part of Mikanagan Lake block (Figs. 2, 3). The occurrence of transitional massive to pillowed basalt zones that are conformable with adjacent arc or MORB-like rocks is consistent with the existence of a continuum between these volcanic assemblage types in the modern oceanic arc/back-arc basin setting (Price et al., 1990; Kerrich and Wyman, 1996). For example, MORB-like BABB in the western Pacific Lau Basin becomes progressively more arc-like toward the Tofua volcanic arc (Pearce et al., 1995). By analogy with modern volcanic rocks, therefore, transitional basalt in the study area may represent an extensional, rifted environment associated with the onset of back-arc basin development. In this context, the apparent superposition of arc basalt relative to transitional volcanic rocks in the core of Lac Aimée anticline is enigmatic.

GEOCHEMISTRY OF VOLCANIC ROCK ASSEMBLAGES

The distinctive arc and MORB-like geochemical rock types characteristic of the Lac Aimée-Naosap Lake area are compositionally very similar to counterparts in the TEM area (Gilbert, 1996a, in press), as shown by N-MORB normalized extended element profiles (Figs. 12, 13). The contrasting rock suites in the study area are also clearly distinguished by the contents and element ratios of trace and incompatible elements (Table 2), especially high field strength elements (HFSE) such as Ti and Zr (Fig. 14), and Th/Nb (Figs. 15, 16). TiO₂, Zr and Nb are typically lower in arc than MORB-like basalt; HFSE-depletion in arc volcanic rocks is commonly attributed to the refractory nature of the source magmas, which have undergone partial melting and basalt extraction

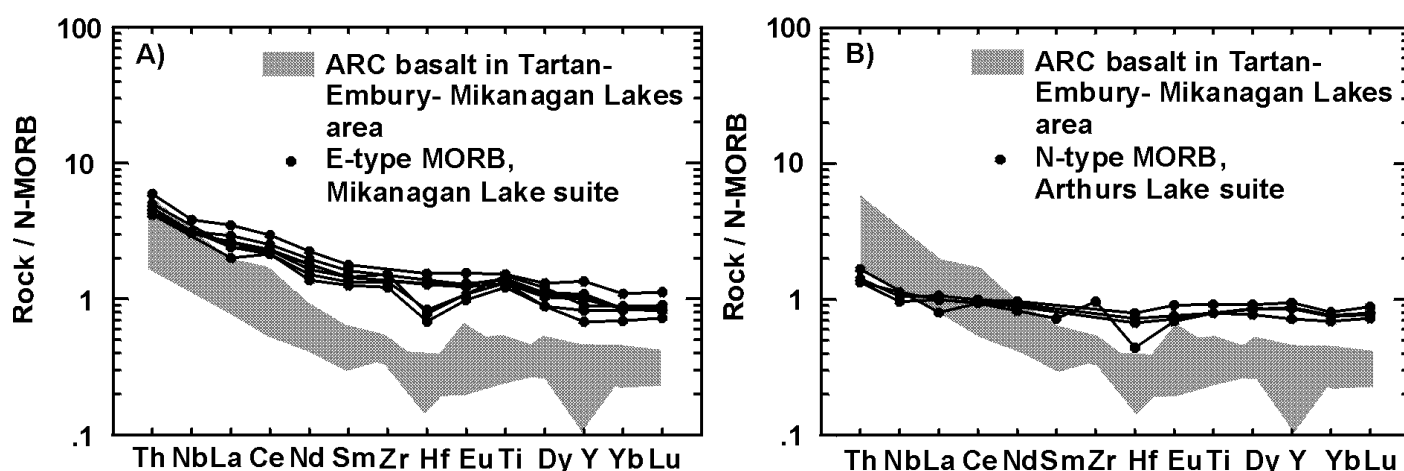


Figure 13: N-MORB normalized extended element plots of arc and MORB-like mafic volcanic rocks in the Tartan-Embury-Mikanagan lakes area. Note that TEM area arc volcanic rocks do not display the negative Nb spike typical of arc basalts due to the absence of Nb data. Normalizing values from Sun and McDonough (1989).

Table 2
Selected geochemical data for basaltic rocks in the Lac Aimée-Naosap Lake area (average, range).

Rock suite	SiO ₂ (%)	Al ₂ O ₃ (%)	TiO ₂ (%)	Ni (ppm)	Zr (ppm)	Th (ppm)	Nb (ppm)	Th/Nb	(La/Yb) _{ch} ¹
Lac Aimée Arc	56.1 (52.1-59.6)	13.5 (9.0-17.9)	0.60 (0.27-0.94)	30 (<3-91)	47 (26-81)	1.32 (0.51-2.32)	3.2 (1.4-5.0)	0.43 (0.28-0.61)	8.5 (3.7-10.7)
Animus Lake E-type MORB	50.9 (47.8-57.1)	13.8 (12.8-14.7)	1.65 (1.37-2.04)	35 (<3-49)	82 (58-108)	0.56 (0.24-0.83)	6.3 (3.1-9.3)	0.09 (0.07-0.13)	3.1 (1.9-3.6)
Animus Lake N-type MORB	49.0 (46.8-55.1)	16.8 (15.4-19.8)	0.62 (0.52-0.72)	95 (65-171)	17 (12-23)	0.08 (0.05-0.11)	1.1 (0.9-1.3)	0.07 (0.05-0.08)	0.7 (0.4-1.1)
Lac Aimée Transitional	54.2 (51.2-57.5)	14.9 (13.6-17.5)	1.11 (0.96-1.26)	9 (<3-26)	51 (43-77)	0.81 (0.63-1.29)	3.2 (2.1-5.5)	0.26 (0.23-0.33)	3.7 (2.7-4.4)

Major element averages based on wt.%, calculated to 100% volatile free. Trace element averages in ppm.

¹ Normalizing values from Sun and McDonough (1989).

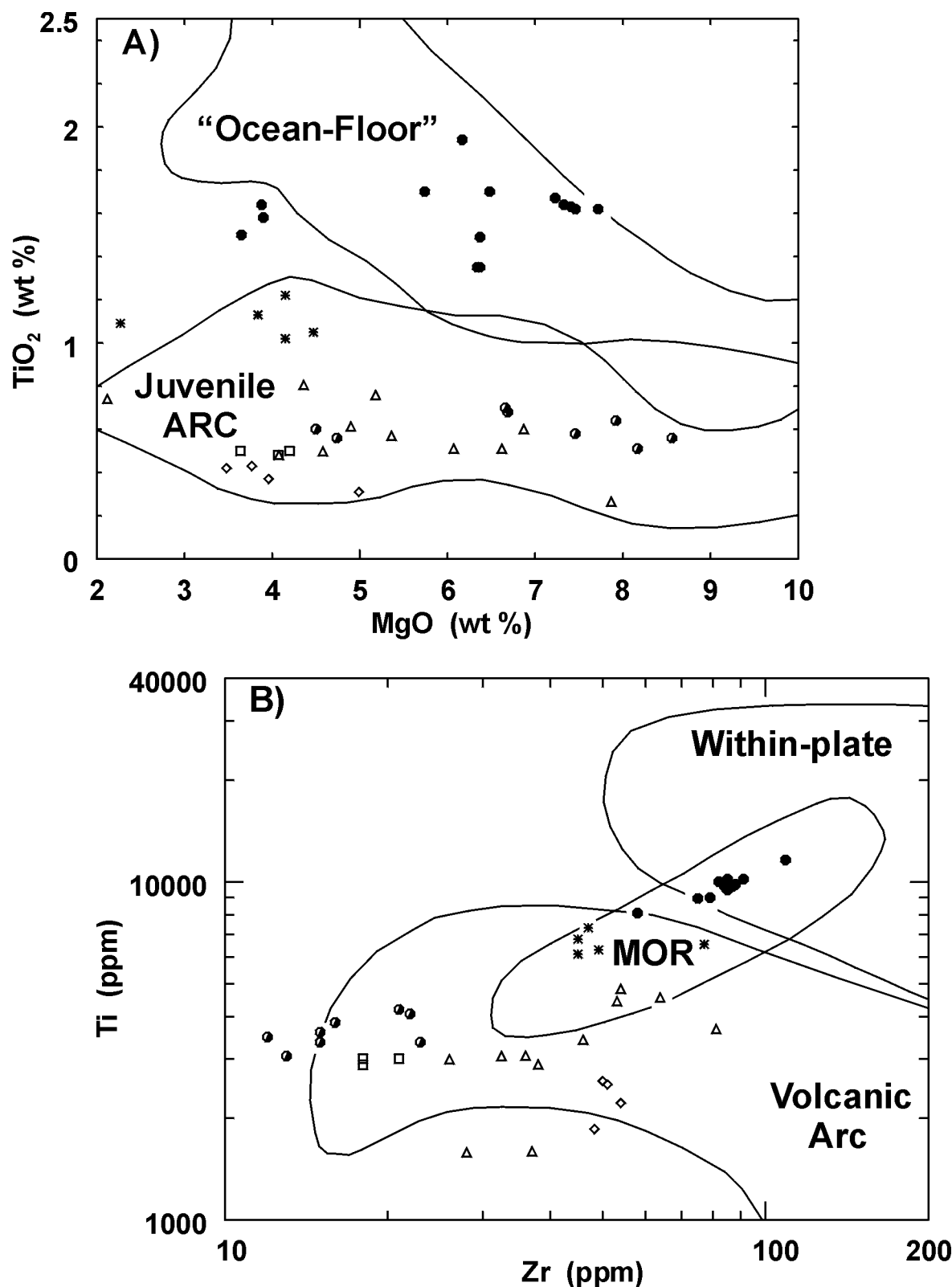


Figure 14: Geochemical plots of mafic and selected intermediate volcanic rocks in the Lac Aimée-Naosap Lake area. A) TiO_2 vs. MgO . Juvenile arc and "ocean floor" fields of Flin Flon Belt rocks are after Lucas et al. (1996), based on data from Stern et al. (1995a, b). N-type MORB Animus Lake rocks are HFSE-depleted compared to analogues elsewhere in the Flin Flon Belt, and plot in the arc volcanic field rather than the "ocean floor" field of Lucas et al. (1996). B) Ti vs. Zr. Compositional fields of modern volcanic rocks are from Pearce et al. (1981).

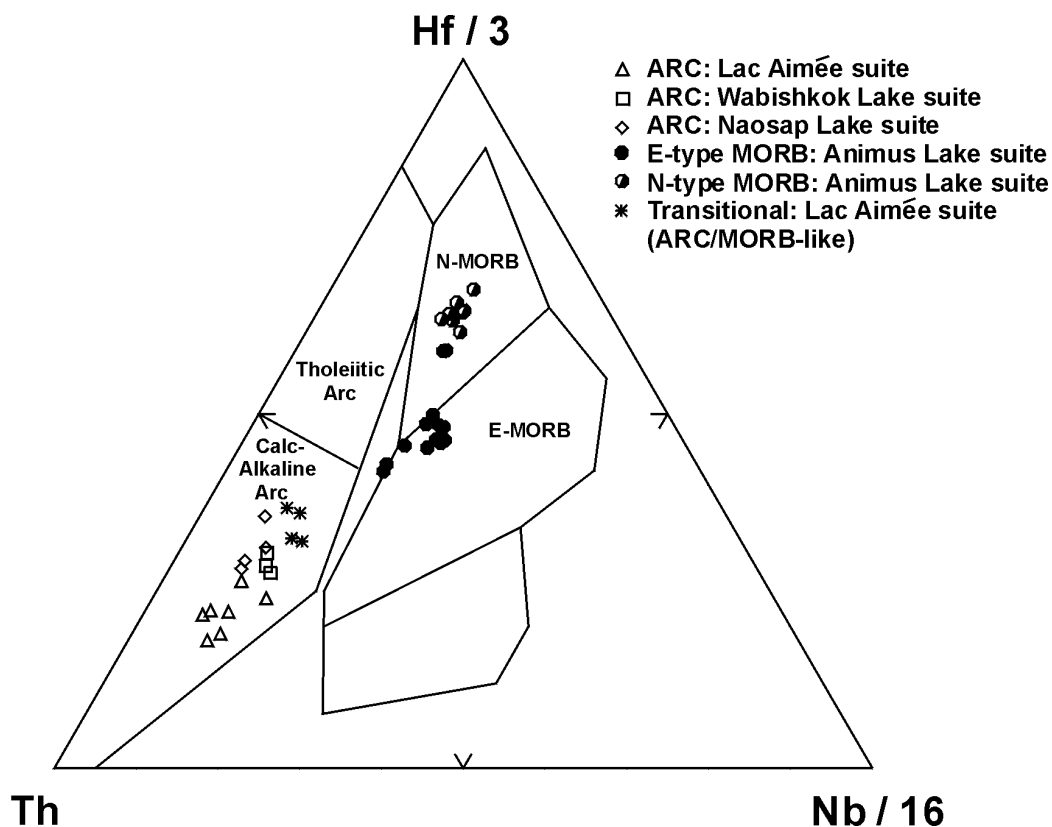


Figure 15: Th-Hf-Nb diagram showing the distinctive fields of arc and MORB-type volcanic rock suites in the Lac Aimée-Naosap Lake area. Compositional fields of modern volcanic rocks after Wood (1980).

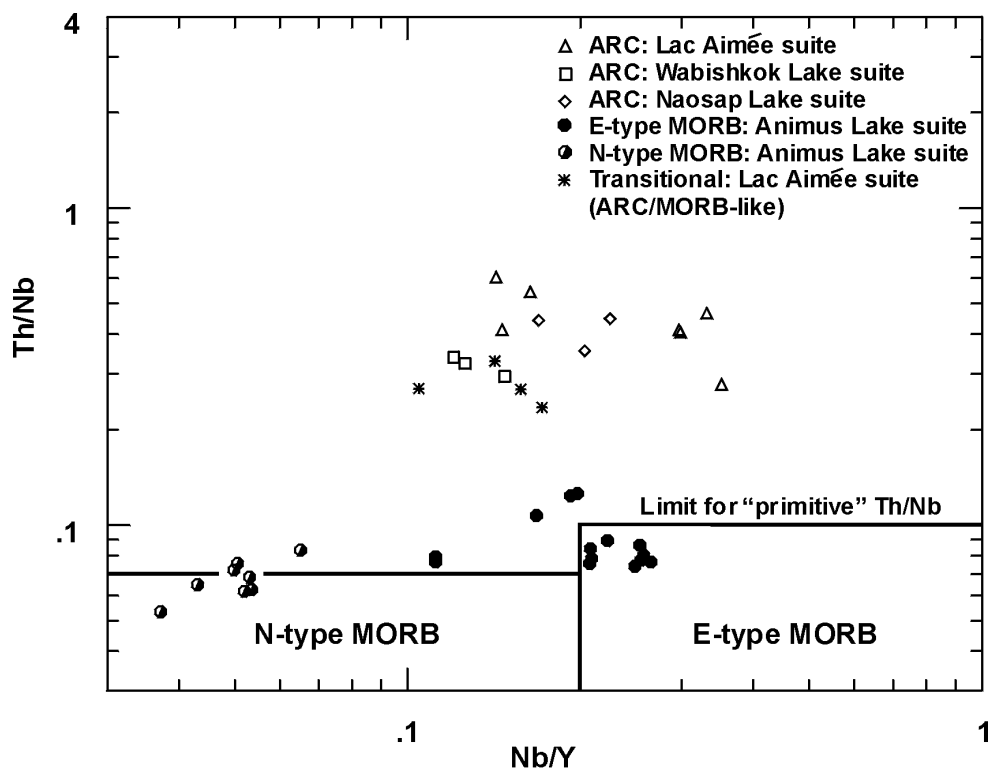


Figure 16: Th/Nb vs. Nb/Y plot of arc and MORB-type volcanic rock suites in the Lac Aimée-Naosap Lake area. Th/Nb ratios are higher in arc volcanic rocks than in primitive Animus Lake MORB-type basalts, due to subduction zone enrichment of Th and LILE (Table 2). Compositional fields are from Stern et al. (1995a), based on data in Saunders et al. (1988) and Sun and McDonough (1989).

prior to extrusion (Woodhead et al., 1993); strong depletion may be caused by repeated melt extraction from the sub-arc mantle source (Kerrick and Wyman, 1996). Transitional basalts are characterized by HFSE levels intermediate between arc and MORB (Fig. 12C).

Light rare earth elements (LREE) and Th are notably enriched in arc basalts (and moderately enriched in E-MORB type rocks) in the Lac Aimée-Naosap Lake area, resulting in LREE/HFSE 'decoupling' and negative-sloping REE profiles. Enrichment in LREE and Th (and, by association, large ion lithophile elements - LILE) is characteristic of magmas associated with subduction zones, and is variously attributed to contamination of MORB-type source magmas by subducted sediments (Stern et al., 1995b) or by residual sial in the crust ('intracrustal recycling'; Hawkesworth et al., 1994; White and Dupré, 1986); or mixing of the source magma with metasomatized sub-arc mantle wedge (Sinton and Fryer, 1987). REE patterns and ϵ_{Nd} values indicate contamination by sediments was the more significant process for Flin Flon arc volcanic rocks (Stern et al., 1995b).

Whereas conspicuous LILE and Th enrichment relative to N-MORB is a hallmark of arc basalts, moderate LILE and Th enrichment is also characteristic of some MORB-like rocks, such as Animus Lake E-type MORB (Figs. 12D, 12E). In contrast, Animus Lake N-type MORB (Fig. 12F) is distinguished by Th depletion (average Th = 0.08 ppm; Table 2) relative to N-MORB (average Th = 0.12 ppm; Sun and McDonough, 1989). Elsewhere in the Flin Flon Belt, depletion of Th in mafic volcanic rocks is displayed only by Moen Bay N-type MORB in the Elbow-Athapapuskow ocean floor assemblage (Stern et al., 1995a); all other MORB-like and arc mafic volcanic rocks show moderate to strong Th enrichment. Low levels of Th and REE, and low Th/Nb in Animus and Moen Bay N-type MORB suites suggest the source magmas were not subjected to either metasomatism or mixing/contamination by subduction-related magmas, consistent with an ocean floor setting remote from the influence of island

arc magmatism. Strong positive ϵ_{Nd} values for Moen Bay basalt support this interpretation (Stern et al., 1995a). Animus Lake N-type MORB is also distinguished by conspicuously low Zr, and lower HFSE than other MORB-like rock suites in the Flin Flon Belt. This pattern may be due to mantle heterogeneity and/or remelting, during which incompatible elements become depleted in the refractory source (Jenner, 1996).

FELSIC VOLCANIC ROCKS

Two geochemically distinct felsic volcanic types that are recognized in the Lac Aimée-Naosap Lake area correspond with arc- and extension-related types described elsewhere in the Flin Flon Belt (Syme, 1998). In the study area, these types are represented by:

- (1) sporadic 5 to 200 m wide felsic units intercalated with arc basalt in Lac Aimée block;
- (2) a felsic porphyry unit that extends discontinuously as several lensoid sills along the southeast margin of the Animus Lake MORB-like basalt section (Fig. 2; Open File Map OF99-1).

The felsic rock types are lithologically similar (e.g. plagioclase+quartzphyric textures are comparable) but display distinctive REE profiles that correspond, in part, to those of mafic volcanic rocks with which they are stratigraphically associated, suggesting a possible genetic association between the felsic and respective mafic volcanic rock types. Low Th contents (<10 ppm) of both Lac Aimée and Animus Lake rhyolites are consistent with their possible derivation by partial melting of the mafic sources from which stratigraphically associated basalts are derived (Lentz, 1996).

Lac Aimée arc-type rhyolite is tholeiitic, and is distinguished from stratigraphically associated tholeiitic arc basalt by higher overall REE content (Fig. 17); heavy rare earth elements (HREE) in the rhyolite are mostly $>10 \times$ chondrite, in contrast to the pattern for Lac Aimée basalts (HREE $<10 \times$ chondrite). Both Lac Aimée and

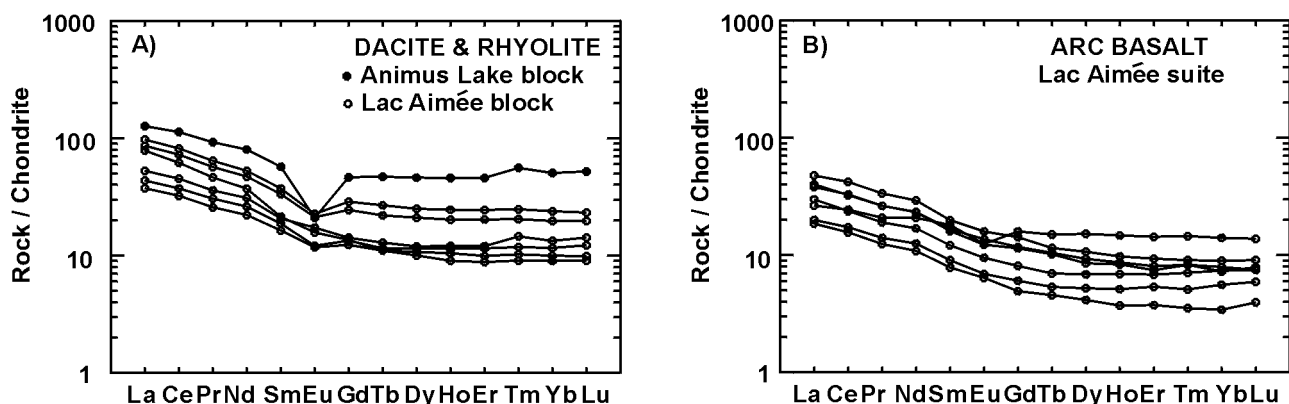


Figure 17: Chondrite-normalized rare earth element plots of felsic volcanic and related intrusive rocks, and arc basalt in the Lac Aimée-Naosap Lake area. Normalizing values from Sun and McDonough (1989).

Animus Lake rhyolites display moderate LREE/HREE enrichment, but overall REE contents are higher in extension-related Animus Lake rhyolite, which is also distinguished by a conspicuous negative Eu anomaly, in contrast to Lac Aimée rhyolite where the anomaly is slight to absent (Fig. 17; Appendix B). The REE profile of Animus Lake rhyolite is virtually identical to that of the extension-related Two Portage Lake rhyolite tuff within Bear Lake block in the TEM area (Fig. 3; Syme, 1998), although overall REE contents are slightly higher in Animus Lake rhyolite. Pronounced negative Eu anomalies, which are also characteristic of felsic volcanic rocks associated with base metal ore deposits in Flin Flon Mine (Syme, 1998), indicate fractionation and removal of plagioclase either during magmatic evolution in the mantle or at higher crustal levels (Leshner et al., 1986).

The geochemical distinction between arc- and extension-related rhyolites is also highlighted by HFSE content and element ratios, especially Zr/TiO₂ that reflects the divergent trends of these elements during fractional crystallization (Zr increase, TiO₂ decrease; Barrett and MacLean, 1994a, b). Average Zr/TiO₂, Y and Nb of extension-related Animus Lake rhyolite are 3 × average values for Lac Aimée arc-related rhyolite, in accordance with the differential between extension- and arc-related rhyolites elsewhere in the Flin Flon Belt (Table 3; Syme, 1998).

The origin and genetic association of felsic volcanic rocks are highly significant factors for the assessment of their potential for mineralization, given that almost all base metal ore deposits in the Flin Flon Belt are associated with rhyolitic host rocks. Although ore-related rhyolitic rocks in the Flin Flon Belt cannot be directly classified with either the arc- or extension-related types, they do display some compositional overlap with the latter type

(Syme, 1998). This partial correlation, together with the association of base metal mineralization with extension-related, rifted volcanic rock suites (Syme et al., 1996), suggests that the felsic porphyry unit at the margin of Animus Lake block is a potential target for base metal exploration.

DISCUSSION

Recognition of the tectonostratigraphic setting of volcanic rocks is important for mineral exploration, in view of the selective association of base metal ore deposits with juvenile arc assemblages in the Flin Flon Belt (Syme and Bailes, 1993). Arc rifting has also been identified as a significant characteristic of arc volcanic rock suites that host base metal ores (Syme et al., 1996; Bailes and Galley, in press; Syme et al., in press). Within the study area, Lac Aimée suite appears to offer the best potential for base metal mineralization, in view of the arc tholeiite affiliation of the volcanic rocks, and the presence of intercalated transitional (arc/MORB-like) basalts that may signify contemporaneous rifting.

Animus Lake block, which consists almost exclusively of MORB-type volcanic rocks and related gabbro, is considered to have low potential for base metal mineralization. Although Animus Lake E-type MORB is compositionally similar to basaltic rocks in Mikanagan Lake block that are interpreted as arc-rift in origin (Figs. 12, 13; Gilbert, in press), Animus Lake E-type MORB is conformable with primitive N-type MORB, indicative of an ocean floor or BABB setting. The N-type/E-type MORB volcanic association in Animus Lake block suggests this highly deformed tectonic wedge may be related to the Elbow-Athapapuskow ocean floor assemblage, which extends through the south-central part of the Flin Flon Belt 20 km south of Lac Aimée (NATMAP Shield Margin Project Working Group, 1998). Animus Lake block may represent a dismembered part of the ocean floor assemblage that was tectonically intercalated with arc components in the Amisk collage during tectonic accretion ca. 1.88-1.87 Ga (Lucas et al., 1996).

CONCLUSIONS

1. The Lac Aimée-Naosap Lake area is situated at a regional flexure in the Paleoproterozoic Flin Flon Belt, where a series of geochemically distinct arc and ocean floor components are structurally intercalated.

2. Animus Lake block contains a MORB-like volcanic assemblage that was deformed in a series of repeated folds, and subsequently juxtaposed against arc basalt (Lac Aimée block) along a crustal scale structure (Lac Aimée Fault Zone).

3. The occurrence of N-MORB type basalt in Animus Lake block, which is intercalated with E-type MORB, suggests an ocean floor or back-arc basin setting, and hence a low potential for base metal mineralization.

Table 3
Selected geochemical data for rhyolites in the Lac Aimée-Naosap Lake area, and for rhyolites elsewhere in the Flin Flon Belt (averages for Flin Flon Belt rhyolites based on data in Syme, 1998).

	Zr/TiO ₂	Y	Nb
Lac Aimée-Naosap Lake area:			
Lac Aimée	0.05	26	6.1
(range)	(0.04-0.10)	(15-36)	(4.5-6.4)
Animus Lake	0.15	76	17.8
Flin Flon Belt:			
Arc assemblage	0.03	20	3.7
(range)	(0.01-.05)	(8-29)	(1.1-7.2)
Extension-related	0.15	55	11.5
(range)	(0.10-0.18)	(26-82)	(1.8-18.6)

4. Lac Aimée arc basalt is part of the Flin Flon arc assemblage that hosts most of the base metal mines in the Flin Flon Belt. Transitional (arc/MORB-like) basalt within Lac Aimée arc volcanic suite may signify a partially rifted environment, indicating Lac Aimée fault block may offer a favourable prospect for base metal exploration.

5. Limited geochemical data suggest felsic volcanic rocks in Lac Aimée block are akin to arc-affiliated rhyolites elsewhere in the Flin Flon Belt, which are not associated with mineralization (Syme, 1998). A felsic porphyry unit at the southeast margin of Animus Lake block, however, is similar to extension-related rhyolites that may be related, in part, to felsic rocks that host base metal ore at Flin Flon Mine.

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Appendix A

Major, minor and trace element data for mafic to intermediate volcanic rocks in the Lac Aimée-Naosap Lake area.

Sample number	Rock type	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ [†]	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Ni	Cr	Sc
Juvenile arc basalt, andesite															
32-96-0065-1	Lac Aimée	52.11	0.53	15.05	12.66	0.22	6.87	8.95	2.73	0.79	0.09	2.60	25	160	
32-96-0044-1	Lac Aimée	52.17	0.88	13.97	15.17	0.23	4.76	8.95	3.39	0.31	0.17	8.55	21	18	39
32-96-0149-1	Lac Aimée*	53.62	0.94	12.40	12.61	0.19	8.80	7.70	2.90	0.70	0.14	1.80	52	407	53
32-96-0092-1	Lac Aimée	55.12	0.76	17.86	11.39	0.17	2.18	8.80	2.14	1.39	0.20	1.75	6	15	33
32-96-0033-1	Lac Aimée	55.47	0.27	9.04	11.54	0.19	11.85	8.29	3.05	0.21	0.07	1.70	50	700	
32-96-0092-2	Lac Aimée	55.74	0.78	14.76	12.28	0.23	5.35	7.57	2.33	0.79	0.17	2.30	24	155	47
32-96-0147-1	Lac Aimée	55.81	0.53	14.11	14.00	0.19	6.30	5.54	2.78	0.65	0.09	3.85	11	16	46
32-86-0319-1	Lac Aimée	57.06	0.61	14.44	9.20	0.16	7.04	7.45	2.97	0.91	0.15	2.50	91	512	
32-96-0230-1	Lac Aimée	57.26	0.49	14.09	13.98	0.21	4.13	6.94	2.48	0.31	0.10	0.60	<3	14	
32-96-0173-1	Lac Aimée	58.29	0.50	13.89	13.18	0.19	4.64	5.53	2.89	0.79	0.09	1.05	10	13	44
32-97-1106-1	Lac Aimée	58.30	0.60	13.53	12.38	0.16	5.60	7.13	2.03	0.14	0.15	4.97	12	120	35
32-96-0037-1	Lac Aimée	59.07	0.63	13.24	12.31	0.20	5.07	5.44	2.89	1.00	0.14	3.35	42	190	
32-96-0056-1	Lac Aimée	59.55	0.27	9.07	11.50	0.20	8.15	8.71	1.79	0.68	0.07	3.60	40	386	48
32-97-1399-1	Dyke in Animus E-MORB*	50.26	0.57	13.89	11.07	0.18	8.91	12.06	2.41	0.31	0.34	3.23	32	250	38
32-97-1061-1	Wabishkok Lake	55.52	0.48	16.10	12.09	0.17	4.06	6.71	3.09	1.57	0.21	0.76	4	7	35
32-97-1073-1	Wabishkok Lake	55.77	0.50	15.20	13.02	0.19	3.66	7.00	2.19	2.23	0.22	1.21	6	9	35
32-97-1229-1	Wabishkok Lake	56.45	0.50	15.54	12.10	0.14	4.20	6.83	2.90	1.12	0.23	0.71	3	6	35
Andesite, dacite, arc-affiliated															
32-97-1015-1	Naosap Lake	62.27	0.31	14.75	7.78	0.10	5.04	4.71	4.73	0.22	0.08	1.69	25	29	25
32-97-1550-1	Naosap Lake	65.41	0.37	13.84	8.13	0.09	3.94	5.61	2.37	0.16	0.09	0.35	7	20	24
32-97-1533-1	Naosap Lake	65.43	0.44	14.02	8.26	0.07	3.88	3.28	4.04	0.47	0.09	3.52	<3	<3	26
32-97-1531-1	Naosap Lake	66.39	0.43	13.54	7.34	0.07	3.54	3.84	4.58	0.19	0.09	2.46	<3	<3	25
E-MORB type ocean floor/BABB															
32-97-1253-1	Animus Lake**	47.37	1.36	14.65	13.46	0.20	9.24	11.49	1.87	0.25	0.10	1.89	67	45	42
32-97-1024-1	Animus Lake**	47.62	1.33	14.80	12.44	0.18	8.10	13.62	1.60	0.18	0.12	1.86	96	62	43
32-97-1228-1	Animus Lake	47.76	1.76	13.95	14.70	0.22	5.96	13.00	2.26	0.23	0.16	3.25	32	23	41
32-97-1201-1	Animus Lake**	48.14	1.42	14.96	12.85	0.18	7.97	11.98	2.18	0.21	0.11	1.06	20	27	42
32-97-1354-1	Animus Lake	48.16	1.70	14.51	14.60	0.19	7.38	10.93	2.14	0.23	0.15	2.26	49	66	44
32-97-1466-1	Animus Lake	48.84	1.55	13.98	12.34	0.19	6.62	12.87	3.27	0.20	0.15	3.99	46	63	43
32-97-1023-1	Animus Lake	49.22	1.65	14.50	12.66	0.18	7.61	10.95	2.86	0.20	0.16	2.56	29	51	45
32-97-1160-1	Animus Lake**	49.34	1.81	13.72	15.75	0.21	5.55	10.29	2.82	0.33	0.17	2.10	21	18	44
32-97-1267-1	Animus Lake	49.75	1.69	13.85	13.88	0.21	7.53	9.40	3.36	0.15	0.16	2.69	44	83	41
32-97-1277-1	Animus Lake	49.81	1.79	14.36	12.91	0.18	6.82	10.60	3.24	0.13	0.18	4.79	34	59	43
32-97-1170-1	Animus Lake	49.83	2.04	14.01	13.79	0.21	6.48	10.25	3.05	0.15	0.19	4.07	30	48	43
32-97-1384-1	Animus Lake	49.99	1.37	13.39	15.46	0.23	6.43	10.62	2.24	0.14	0.12	1.71	31	49	48
32-97-1402-1	Animus Lake	50.33	1.37	13.22	15.47	0.22	6.45	9.73	2.66	0.18	0.35	1.71	31	57	47
32-97-1301-1	Animus Lake	50.81	1.69	13.64	14.41	0.20	7.69	9.24	2.11	0.07	0.15	3.80	39	88	40
32-97-1291-1	Animus Lake	51.29	1.66	14.73	10.38	0.16	7.93	9.84	3.40	0.45	0.13	2.14	43	83	47
32-97-1465-1	Animus Lake	54.90	1.64	13.07	14.93	0.19	4.05	7.18	3.42	0.47	0.17	2.10	8	10	38
32-97-1315-1	Animus Lake	55.06	1.56	12.76	17.31	0.23	3.80	6.11	2.61	0.37	0.18	2.75	<3	4	38
32-97-1454-1	Animus Lake	57.10	1.66	13.64	13.82	0.15	3.94	6.23	2.72	0.55	0.19	2.40	3	3	41
N-MORB type ocean floor/BABB															
32-97-1395-1	Animus Lake	46.77	0.57	16.97	12.92	0.17	8.73	11.90	1.90	0.04	0.04	2.91	126	200	43
32-97-1326-1	Animus Lake	47.09	0.59	15.60	13.91	0.19	7.57	13.46	1.46	0.07	0.06	2.30	95	120	49
32-97-1421-1	Animus Lake	47.69	0.52	16.32	12.91	0.17	8.35	11.77	2.15	0.07	0.04	2.34	85	120	39
32-97-1319-1	Animus Lake	48.34	0.66	15.35	15.73	0.22	8.18	8.17	3.10	0.17	0.08	3.06	71	180	53
32-97-1179-1	Animus Lake	48.69	0.59	19.75	10.05	0.14	4.98	12.43	2.98	0.34	0.06	5.62	65	99	34
32-97-1286-1	Animus Lake	48.87	0.70	16.30	13.77	0.17	6.87	10.94	2.00	0.14	0.24	2.74	76	100	48
32-97-1176-1	Animus Lake	49.44	0.72	16.10	14.35	0.17	6.81	10.45	1.85	0.05	0.06	3.16	74	160	48
32-97-1374-1	Animus Lake	55.11	0.61	17.89	7.66	0.09	4.55	9.06	4.75	0.23	0.05	1.81	171	160	46
Transitional arc/MORB-like basalt, basaltic andesite															
32-96-0150-2	Lac Aimée*	51.17	0.96	17.54	13.18	0.19	4.49	9.71	2.37	0.24	0.16	2.90	26	26	36
32-96-0041-1	Lac Aimée	52.86	1.26	14.63	15.87	0.23	4.28	6.70	3.35	0.67	0.15	3.20	<3	10	
32-96-0106-1	Lac Aimée	53.72	1.19	14.09	15.56	0.23	4.04	7.54	2.58	0.87	0.19	5.00	4	5	
32-96-0016-1	Lac Aimée	54.91	1.08	14.78	15.09	0.19	4.59	5.20	3.07	0.89	0.21	2.50	11	8	40
32-96-0073-1	Lac Aimée	55.15	1.05	14.61	14.20	0.22	4.27	6.68	3.39	0.32	0.12	2.55	12	13	43
32-96-0095-1	Lac Aimée	57.51	1.13	13.62	15.08	0.21	2.36	5.28	3.44	1.06	0.30	4.00	3	3	

* Diabase, synvolcanic

** Gabbro, synvolcanic

Major elements (wt.%) calculated to 100% volatile free. Trace elements in ppm. Total Fe as Fe₂O₃[†].

Appendix A (continued)

Major, minor and trace element data for mafic to intermediate volcanic rocks in the Lac Aimée-Naosap Lake area.

Sample number	Rock type	V	Rb	Ba	Sr	Cs	Hf	Zr	Y	Ta	Th	U	Nb	La	Ce
Juvenile arc basalt, andesite															
32-96-0065-1	Lac Aimée		0	383	190			36	-10.0						
32-96-0044-1	Lac Aimée		2	117	98	0.00	1.54	54	20.5	0.12	1.24	0.65	3.00	6.26	14.89
32-96-0149-1	Lac Aimée*		13	342	210	0.12	1.98	68	10.0	0.16	1.48	0.37	4.75	10.63	25.19
32-96-0092-1	Lac Aimée		29	422	419	0.12	1.34	53	13.6	0.15	1.65	0.85	4.07	9.03	20.07
32-96-0033-1	Lac Aimée		13	121	135			37	-10.0						
32-96-0092-2	Lac Aimée		10	320	265	0.24	1.74	64	15.0	0.20	2.32	0.75	4.98	11.32	25.71
32-96-0147-1	Lac Aimée		9	261	142	0.17	0.87	32	11.0	0.05	0.95	0.30	1.57	7.08	14.48
32-86-0319-1	Lac Aimée		20	412	289										
32-96-0230-1	Lac Aimée		0	70	225			38	-10.0						
32-96-0173-1	Lac Aimée		12	341	200	0.79	0.71	26	8.3	0.05	0.74	0.42	1.36	4.73	10.55
32-97-1106-1	Lac Aimée	239	1	15	510	0.04	1.56	46	13.0	0.23	1.59	0.54	3.86	9.48	19.78
32-96-0037-1	Lac Aimée		10	298	186			81	12.0						
32-96-0056-1	Lac Aimée		10	301	198	0.00	0.72	28	6.3	0.06	0.62	0.23	2.23	4.39	9.56
32-97-1399-1	Dyke in Animus E-MORB*	232	3	57	141	0.06	1.17	32	14.0	0.13	1.46	0.86	2.20	9.33	20.66
32-97-1061-1	Wabishkok Lake	304	31	372	440	0.41	0.79	18	12.5	0.10	0.51	0.32	1.51	4.15	10.02
32-97-1073-1	Wabishkok Lake	299	38	365	616	0.37	0.76	18	13.0	0.10	0.53	0.29	1.64	5.20	11.42
32-97-1229-1	Wabishkok Lake	267	21	292	439	0.32	0.83	21	13.8	0.12	0.60	0.34	2.04	4.56	10.50
Andesite, dacite, arc-affiliated															
32-97-1015-1	Naosap Lake	195	4	13	120	0.53	1.36	48	9.6	0.12	0.72	0.29	1.63	2.58	6.48
32-97-1550-1	Naosap Lake	161	1	32	162	0.02	1.82	54	15.8	0.20	1.14	0.36	3.22	6.62	14.18
32-97-1533-1	Naosap Lake	194	7	44	127	0.30	1.77	50	12.4	0.18	1.25	0.44	2.79	5.93	13.13
32-97-1531-1	Naosap Lake	188	1	20	120	0.03	1.73	51	12.8	0.18	1.29	0.41	2.89	4.06	10.02
E-MORB type ocean floor/BABB															
32-97-1253-1	Animus Lake**	314	3	37	249	0.02	1.74	54	20.0	0.30	0.32	0.11	4.86	4.70	12.48
32-97-1024-1	Animus Lake**	308	3	43	211	0.08	2.09	62	23.2	0.34	0.44	0.13	5.04	5.36	13.97
32-97-1228-1	Animus Lake	361	1	36	195	0.02	2.63	85	27.6	0.43	0.57	0.19	7.11	6.20	16.62
32-97-1201-1	Animus Lake**	327	1	43	184	0.02	1.84	58	21.2	0.34	0.36	0.12	5.38	5.05	13.39
32-97-1354-1	Animus Lake	356	1	20	204	0.03	2.43	82	27.7	0.42	0.51	0.18	6.88	6.14	16.36
32-97-1466-1	Animus Lake	343	1	61	179	0.02	2.22	75	26.9	0.35	0.44	0.18	5.62	5.75	15.22
32-97-1023-1	Animus Lake	364	1	72	192	0.04	2.70	87	28.2	0.43	0.56	0.21	6.28	6.01	16.59
32-97-1160-1	Animus Lake**	403	3	70	208	0.08	2.83	108	33.6	0.46	0.69	0.23	7.41	7.36	19.15
32-97-1267-1	Animus Lake	357	1	43	118	0.02	2.72	84	29.3	0.46	0.58	0.18	7.48	6.79	17.66
32-97-1277-1	Animus Lake	376	1	69	165	0.02	2.80	91	30.8	0.38	0.54	0.32	6.41	6.67	17.87
32-97-1170-1	Animus Lake	401	1	32	160	0.04	3.42	109	36.5	0.57	0.80	0.28	9.27	8.17	21.82
32-97-1384-1	Animus Lake	376	1	36	142	0.05	1.88	58	28.1	0.20	0.24	0.10	3.14	3.50	9.72
32-97-1402-1	Animus Lake	374	2	55	138	0.07	1.92	58	28.1	0.20	0.25	0.10	3.15	3.53	9.81
32-97-1301-1	Animus Lake	354	1	27	158	0.03	2.64	84	28.1	0.46	0.57	0.18	7.46	6.65	17.36
32-97-1291-1	Animus Lake	384	6	170	133	0.04	2.29	84	28.7	0.36	0.45	0.31	5.96	6.05	15.98
32-97-1465-1	Animus Lake	403	6	121	183	0.32	2.54	85	31.5	0.36	0.75	0.46	6.06	6.16	15.31
32-97-1315-1	Animus Lake	331	4	85	113	0.16	2.70	79	37.9	0.39	0.68	0.33	6.35	6.91	17.40
32-97-1454-1	Animus Lake	417	11	195	181	0.55	2.69	88	33.4	0.38	0.83	0.47	6.61	7.32	18.30
N-MORB type ocean floor/BABB															
32-97-1395-1	Animus Lake	235	0	9	70	0.03	0.66	15	18.7	0.06	0.06	0.00	0.97	1.00	2.83
32-97-1326-1	Animus Lake	278	1	11	111	0.02	0.68	12	25.3	0.07	0.05	0.00	0.94	0.80	2.21
32-97-1421-1	Animus Lake	215	0	14	136	0.01	0.65	13	18.0	0.06	0.06	0.00	0.96	0.96	2.72
32-97-1319-1	Animus Lake	307	1	34	88	0.02	0.66	16	25.1	0.07	0.07	0.03	1.08	1.09	2.93
32-97-1179-1	Animus Lake	198	4	50	139	0.05	1.00	23	20.3	0.09	0.11	0.08	1.32	1.80	4.24
32-97-1286-1	Animus Lake	263	2	22	151	0.02	0.88	22	23.5	0.08	0.09	0.04	1.19	1.26	3.58
32-97-1176-1	Animus Lake	273	0	11	126	0.04	0.88	21	22.0	0.09	0.08	0.03	1.17	1.23	3.45
32-97-1374-1	Animus Lake	248	3	46	104	0.04	0.77	15	22.2	0.08	0.08	0.64	1.11	1.36	3.90
Transitional arc/MORB-like basalt, basaltic andesite															
32-96-0150-2	Lac Aimée*		4	77	361	0.12	1.14	43	16.6	0.09	0.63	0.37	2.76	5.07	11.87
32-96-0041-1	Lac Aimée		11	147	228	0.27	1.54	47	26.3	0.18	0.74	0.36	2.75	5.55	12.54
32-96-0106-1	Lac Aimée		19	287	382	2.23	1.35	45	19.8	0.20	0.72	0.35	3.02	5.48	13.09
32-96-0016-1	Lac Aimée		14	273	251	0.83	1.35	49	18.0	0.13	0.76	0.87	2.84	5.61	12.93
32-96-0073-1	Lac Aimée		5	116	113	0.07	1.45	45	15.0	0.08	0.70	0.50	2.13	4.99	11.86
32-96-0095-1	Lac Aimée		18	296	265	1.65	2.31	77	32.1	0.35	1.29	0.69	5.50	9.40	21.66

* Diabase, synvolcanic

** Gabbro, synvolcanic

Trace elements in ppm.

Appendix A (continued)

Major, minor and trace element data for mafic to intermediate volcanic rocks in the Lac Aimée-Naosap Lake area.

Sample number	Rock type	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	(La/Yb) _{ch}	Mg#
Juvenile arc basalt, andesite															
32-96-0065-1	Lac Aimée														55
32-96-0044-1	Lac Aimée	1.98	9.71	2.76	0.72	3.27	0.56	3.85	0.83	2.37	0.37	2.38	0.35	3.7	42
32-96-0149-1	Lac Aimée*	3.22	13.88	3.23	0.88	3.11	0.51	3.28	0.68	1.99	0.28	1.82	0.28	8.1	61
32-96-0092-1	Lac Aimée	2.50	10.89	2.54	0.79	2.41	0.39	2.36	0.49	1.33	0.21	1.34	0.19	9.4	30
32-96-0033-1	Lac Aimée														70
32-96-0092-2	Lac Aimée	3.18	13.62	3.04	0.92	2.92	0.43	2.71	0.55	1.54	0.23	1.52	0.23	10.4	50
32-96-0147-1	Lac Aimée	1.80	7.90	1.85	0.55	1.66	0.26	1.74	0.39	1.13	0.18	1.25	0.19	7.9	51
32-86-0319-1	Lac Aimée														64
32-96-0230-1	Lac Aimée														40
32-96-0173-1	Lac Aimée	1.33	5.84	1.38	0.40	1.24	0.20	1.32	0.29	0.89	0.13	0.95	0.15	6.9	45
32-97-1106-1	Lac Aimée	2.50	10.83	2.45	0.71	2.35	0.38	2.16	0.47	1.23	0.21	1.23	0.20	10.7	51
32-96-0037-1	Lac Aimée														48
32-96-0056-1	Lac Aimée	1.18	5.06	1.20	0.37	1.01	0.17	1.05	0.21	0.62	0.09	0.58	0.10	10.6	62
32-97-1399-1	Dyke in Animus E-MORB*	2.71	12.58	2.93	0.87	2.83	0.41	2.41	0.48	1.32	0.21	1.28	0.20	10.2	65
32-97-1061-1	Wabishkok Lake	1.32	6.41	1.61	0.55	1.74	0.29	2.03	0.44	1.19	0.22	1.33	0.21	4.4	43
32-97-1073-1	Wabishkok Lake	1.54	7.19	1.91	0.65	2.08	0.32	2.08	0.46	1.31	0.23	1.37	0.21	5.3	39
32-97-1229-1	Wabishkok Lake	1.48	7.12	1.82	0.61	2.07	0.34	2.20	0.50	1.45	0.25	1.48	0.24	4.3	44
Andesite, dacite, arc-affiliated															
32-97-1015-1	Naosap Lake	0.83	4.01	1.13	0.33	1.27	0.23	1.59	0.32	0.91	0.15	0.90	0.16	4.0	60
32-97-1550-1	Naosap Lake	1.78	8.00	2.02	0.61	2.27	0.38	2.51	0.54	1.49	0.26	1.63	0.26	5.7	53
32-97-1533-1	Naosap Lake	1.67	7.50	1.77	0.52	1.87	0.32	2.03	0.42	1.23	0.21	1.32	0.21	6.3	52
32-97-1531-1	Naosap Lake	1.30	5.94	1.59	0.47	1.81	0.32	2.01	0.45	1.27	0.23	1.34	0.22	4.2	52
E-MORB type ocean floor/BABB															
32-97-1253-1	Animus Lake**	1.91	9.73	2.89	1.04	3.20	0.53	3.39	0.71	1.89	0.31	1.83	0.27	3.6	61
32-97-1024-1	Animus Lake**	2.12	10.87	3.23	0.98	3.60	0.61	3.93	0.82	2.16	0.36	1.99	0.31	3.8	60
32-97-1228-1	Animus Lake	2.52	12.68	3.72	1.26	4.29	0.76	4.79	1.01	2.72	0.43	2.49	0.40	3.5	48
32-97-1201-1	Animus Lake**	2.11	10.61	3.02	1.09	3.43	0.59	3.62	0.78	2.08	0.34	1.92	0.30	3.7	59
32-97-1354-1	Animus Lake	2.44	12.62	3.84	1.31	4.36	0.75	4.71	0.97	2.66	0.44	2.51	0.38	3.4	54
32-97-1466-1	Animus Lake	2.33	12.09	3.66	1.23	4.10	0.69	4.44	0.94	2.55	0.41	2.41	0.35	3.3	55
32-97-1023-1	Animus Lake	2.47	12.57	3.76	1.21	4.25	0.75	4.86	1.01	2.70	0.44	2.40	0.38	3.5	58
32-97-1160-1	Animus Lake**	2.89	14.66	4.30	1.37	5.06	0.90	5.73	1.24	3.34	0.56	3.21	0.49	3.2	45
32-97-1267-1	Animus Lake	2.67	13.90	4.08	1.25	4.60	0.78	5.02	1.03	2.78	0.45	2.60	0.41	3.6	55
32-97-1277-1	Animus Lake	2.76	13.82	4.08	1.25	4.72	0.79	5.12	1.08	3.02	0.50	2.91	0.44	3.2	55
32-97-1170-1	Animus Lake	3.35	16.65	4.78	1.48	5.47	0.96	6.14	1.30	3.57	0.60	3.49	0.55	3.3	52
32-97-1384-1	Animus Lake	1.55	8.72	3.00	1.02	3.50	0.64	4.46	0.96	2.73	0.46	2.63	0.41	1.9	49
32-97-1402-1	Animus Lake	1.56	8.58	2.83	0.98	3.52	0.65	4.43	0.96	2.70	0.46	2.66	0.42	1.9	49
32-97-1301-1	Animus Lake	2.60	13.15	3.86	1.32	4.35	0.75	4.80	1.00	2.66	0.47	2.59	0.39	3.6	55
32-97-1291-1	Animus Lake	2.45	12.81	3.90	1.24	4.36	0.76	4.83	1.04	2.78	0.45	2.50	0.36	3.4	64
32-97-1465-1	Animus Lake	2.15	10.80	3.23	1.04	3.73	0.71	4.96	1.07	3.07	0.56	3.30	0.53	2.6	38
32-97-1315-1	Animus Lake	2.55	12.99	3.85	1.16	4.76	0.86	5.87	1.31	3.83	0.67	3.90	0.62	2.5	33
32-97-1454-1	Animus Lake	2.62	12.81	3.73	1.24	4.30	0.76	5.15	1.12	3.17	0.56	3.24	0.51	3.1	39
N-MORB type ocean floor/BABB															
32-97-1395-1	Animus Lake	0.49	2.90	1.18	0.44	1.73	0.35	2.60	0.63	1.86	0.34	2.07	0.32	0.7	61
32-97-1326-1	Animus Lake	0.38	2.48	1.19	0.46	2.02	0.44	3.44	0.87	2.60	0.46	2.90	0.47	0.4	55
32-97-1421-1	Animus Lake	0.47	2.76	1.09	0.44	1.59	0.34	2.57	0.59	1.78	0.32	2.01	0.32	0.7	60
32-97-1319-1	Animus Lake	0.47	2.73	1.25	0.44	2.02	0.44	3.58	0.88	2.64	0.48	2.90	0.48	0.5	54
32-97-1179-1	Animus Lake	0.69	4.11	1.48	0.56	2.09	0.41	2.97	0.69	2.11	0.36	2.24	0.34	1.1	53
32-97-1286-1	Animus Lake	0.63	3.75	1.56	0.54	2.22	0.45	3.34	0.79	2.33	0.43	2.69	0.42	0.7	53
32-97-1176-1	Animus Lake	0.63	3.77	1.50	0.54	2.28	0.44	3.36	0.78	2.36	0.42	2.51	0.40	0.7	52
32-97-1374-1	Animus Lake	0.68	3.90	1.43	0.44	2.14	0.42	3.21	0.72	2.14	0.39	2.20	0.36	0.9	58
Transitional arc/MORB-like basalt, basaltic andesite															
32-96-0150-2	Lac Aimée*	1.59	7.56	2.12	0.75	2.45	0.42	2.72	0.57	1.68	0.25	1.65	0.24	4.3	44
32-96-0041-1	Lac Aimée	1.79	9.07	2.79	0.97	3.43	0.60	4.20	0.91	2.63	0.46	2.68	0.42	2.9	38
32-96-0106-1	Lac Aimée	1.89	9.04	2.53	0.85	2.90	0.48	3.16	0.69	1.92	0.33	1.98	0.30	3.9	37
32-96-0016-1	Lac Aimée	1.71	8.31	2.39	0.73	2.57	0.45	3.02	0.66	1.89	0.28	1.79	0.27	4.4	41
32-96-0073-1	Lac Aimée	1.68	8.24	2.58	0.91	3.33	0.60	4.07	0.89	2.61	0.41	2.61	0.38	2.7	41
32-96-0095-1	Lac Aimée	3.04	14.52	4.07	1.19	4.54	0.75	5.04	1.11	3.08	0.54	3.18	0.50	4.1	26

* Diabase, synvolcanic

** Gabbro, synvolcanic

Trace elements in ppm.

Mg# calculated assuming $\text{Fe}^{2+}/(\text{Fe}^{2+} + \text{Fe}^{3+}) = 0.9$.

Chondrite normalizing values from Sun and McDonough (1989).

Appendix B
Major, minor and trace element data for felsic volcanic rocks in the Lac Aimée-Naosap Lake area.

Sample number	Rock suite	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ ^t	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Ni	Cr	Rb
32-96-0123-1	Lac Aimée	67.32	0.57	13.38	8.73	0.11	1.45	5.11	3.06	0.14	0.12	1.60			
32-96-0215-3	Lac Aimée	67.63	0.56	15.25	7.56	0.08	1.51	2.38	3.85	1.05	0.13	1.30			
32-96-0013-1	Lac Aimée	68.19	0.43	12.62	8.66	0.19	2.70	1.21	4.13	1.71	0.16	1.95	1	2	36
32-96-0223-1	Lac Aimée	68.31	0.39	13.74	7.22	0.11	1.65	5.46	2.67	0.36	0.09	0.55	6	20	10
32-96-0030-1	Lac Aimée	68.74	0.41	12.71	7.73	0.14	2.02	2.07	4.54	1.47	0.16	1.85			17
32-96-0079-1	Lac Aimée	69.54	0.41	14.13	6.06	0.08	1.08	1.37	5.34	1.90	0.09	1.55			26
32-97-1084-1	Lac Aimée	70.44	0.29	13.35	6.29	0.09	1.68	2.88	2.34	2.52	0.11	3.90			36
32-96-0113-2	Lac Aimée	72.31	0.37	12.74	5.58	0.08	0.68	2.67	3.94	1.54	0.09	2.65			24
32-96-0061-1	Lac Aimée	72.53	0.38	12.43	6.00	0.06	0.80	1.40	5.06	1.24	0.09	1.90	2	12	19
32-96-0176-1	Lac Aimée	73.25	0.38	12.64	5.40	0.06	0.72	1.92	4.24	1.29	0.09	0.45	2	11	26
32-96-0265-1	Lac Aimée	74.53	0.25	12.78	3.82	0.05	0.54	2.93	4.19	0.85	0.06	0.80	1	12	19
32-96-0233-2	Lac Aimée	75.32	0.25	12.05	4.45	0.05	0.79	2.07	4.08	0.90	0.04	0.55			
32-97-1149-1	Animus Lake	79.72	0.12	11.17	1.06	-0.01	0.39	0.46	2.92	4.14	0.03	1.13			58

Sample number	Rock suite	Ba	Sr	Cs	Hf	Zr (xrf)	Zr (icp-ms)	Y (xrf)	Y (icp-ms)	Ta	Th	U	Nb
32-96-0123-1	Lac Aimée	79	175			100		12					
32-96-0215-3	Lac Aimée	884	141			122		-10					
32-96-0013-1	Lac Aimée	577	102	0.49	1.67	88	64	11	16.6	0.12	1.77	0.68	2.55
32-96-0223-1	Lac Aimée	89	222	1.56	2.35	106	89	-10	15.5	0.16	2.25	0.79	3.81
32-96-0030-1	Lac Aimée	487	165			92		11					
32-96-0079-1	Lac Aimée	492	111			151		25					
32-97-1084-1	Lac Aimée	1261	65	0.59	2.06	58	74	16	19.2	0.23	2.08	0.70	3.72
32-96-0113-2	Lac Aimée	574	89			149		23					
32-96-0061-1	Lac Aimée	522	108	0.11	3.5	147	122	24	29.1	0.35	5.26	1.63	6.41
32-96-0176-1	Lac Aimée	513	172	0.43	4.03	152	142	23	35.6	0.42	6.12	1.47	7.35
32-96-0265-1	Lac Aimée	799	194	0.20	2.44	134	103	11	14.6	0.22	4.66	1.12	4.54
32-96-0233-2	Lac Aimée	326	113			241		28					
32-97-1149-1	Animus Lake	971	48	0.43	6.85	185	>2000	69	75.8	1.16	5.90	2.17	17.82

Sample number	Rock suite	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
32-96-0123-1	Lac Aimée														
32-96-0215-3	Lac Aimée														
32-96-0013-1	Lac Aimée	10.31	22.76	2.89	12.16	2.86	0.70	2.74	0.43	2.89	0.65	1.90	0.30	1.97	0.31
32-96-0223-1	Lac Aimée	8.87	19.70	2.44	10.32	2.50	0.68	2.53	0.41	2.72	0.59	1.64	0.26	1.69	0.25
32-96-0030-1	Lac Aimée														
32-96-0079-1	Lac Aimée														
32-97-1084-1	Lac Aimée	12.49	27.58	3.40	14.40	3.16	1.00	2.91	0.48	3.03	0.68	1.98	0.37	2.26	0.36
32-96-0113-2	Lac Aimée														
32-96-0061-1	Lac Aimée	20.35	44.32	5.39	21.97	5.09	1.23	5.01	0.82	5.32	1.14	3.36	0.52	3.34	0.50
32-96-0176-1	Lac Aimée	22.99	49.97	6.09	24.64	5.70	1.31	5.89	1.00	6.35	1.39	4.04	0.63	4.04	0.59
32-96-0265-1	Lac Aimée	18.53	37.72	4.39	17.27	3.27	0.91	2.78	0.41	2.54	0.51	1.45	0.23	1.52	0.23
32-96-0233-2	Lac Aimée														
32-97-1149-1	Animus Lake	30.07	68.77	8.77	37.37	8.73	1.21	9.54	1.75	11.68	2.60	7.59	1.42	8.59	1.32

Major elements (wt.%) calculated to 100% volatile free. Trace elements in ppm. Total Fe as Fe₂O₃^t.