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Ore-Associated and Barren Rhyolites in the Central Flin Flon Belt: Case Study of the Flin Flon Mine Sequence

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Ore-Associated and Barren Rhyolites in the Central Flin Flon Belt: Case Study of the Flin Flon Mine Sequence

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Winnipeg, 1998

GEOREF

NTS AREA: parts of 63K/12 and 13

Keywords:

arc rift	rare earth elements
calc-alkaline	rhyolite
Flin Flon	tholeiitic
geochemistry	volcanic-hosted massive sulphide deposits
Paleoproterozoic	volcanic stratigraphy

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SUMMARY

This preliminary report summarizes the stratigraphic setting and geochemistry of rhyolites in the central Flin Flon Belt, with particular emphasis on the felsic rocks hosting the Flin Flon massive sulphide deposit.

A compilation of new rhyolite trace element geochemistry demonstrates that felsic volcanic rocks in the central Flin Flon Belt can be subdivided in a first-order manner into: 1) slightly light rare earth element (LREE)-enriched calc-alkaline and tholeiitic arc assemblage rhyolites with small negative Eu anomalies; and 2) extension-related (arc-rift) rhyolites with higher total rare earth element contents, higher light rare earth element contents, negative Eu anomalies, and high field strength element (HFSE) contents greater than the arc assemblage rhyolites.

Rhyolites associated with the Flin Flon massive sulphide deposit can be distinguished geochemically from barren rhyolites of either arc or arc-rift origin. They have flat REE patterns with pronounced negative Eu anomalies, similar in some respects to the extension-related rhyolite group.

INTRODUCTION

Volcanic-hosted massive sulphide (VMS) deposits in the Paleoproterozoic Flin Flon Belt (Fig. 1) occur in basalt-dominated, juvenile arc assemblages in which rhyolite flows are a minor component (Bailes and Syme, 1989; Thomas, 1990; Syme and Bailes, 1993; Bailes and Galley, 1996; Syme et al., in press). From a study of the mafic volcanic rocks in the Flin Flon Belt, Stern et al. (1995) defined tholeiitic, calc-alkaline, shoshonitic and boninitic magma series; only tholeiitic and calc-alkaline sequences contain rhyolites. Recent work has focused on the importance of an extension-related (arc rift) subgroup within the arc assemblage (Syme et al., 1996; Syme et al., in press; Bailes and Galley, in review; Gilbert, in review), a subgroup that also has been defined primarily by basalt geochemistry. The first objective of this study is to define the distinguishing geochemical characteristics of rhyolites that occur in tholeiitic, calc-alkaline and extension-related sequences, so that the geochemistry of rhyolites that host massive sulphide deposits can be placed in context.

The close association of economic volcanic-associated massive sulphide (VMS) deposits and felsic volcanism is common within the Flin Flon Belt, similar to many other VMS camps (e.g., review in Franklin, 1996). However, as in other VMS camps, not all rhyolites are associated with massive sulphide deposits. The comparatively immobile trace elements (rare earth elements (REE), high field strength elements (HFSE: Ti, Zr, Hf, Nb, Ta, P, Y) and Th; Campbell et al., 1983; Jenner, 1996) have been used to distinguish felsic metavolcanic rocks associated with VMS deposits from 'barren' felsic metavolcanic rocks (e.g., Lesher et al., 1986). The second objective of this study is to define the trace element characteristics of 'barren' and 'ore-associated' Flin Flon Belt rhyolites, using as a case study the felsic rocks in the Flin Flon Mine section.

The third objective of this study is to use geochemistry to construct stratigraphic correlations within the diverse sequence of rhyolites in the Flin Flon Mine package. An understanding of map relations between rhyolites allows the geochemistry to be placed in context and used to define stratigraphy.

RHYOLITES IN THE FLIN FLON BELT

1.90-1.87 Ga tectonostratigraphic assemblages in the Flin Flon Belt (Fig. 1) include juvenile arc rocks (~68% of exposed Flin Flon Belt), juvenile ocean-floor/ back-arc rocks (~20%), and minor (~3% total) oceanic plateau, ocean island basalt and 'evolved' plutonic arc rocks (~9% are undivided; Syme et al., in press). Felsic metavolcanic rocks occur overwhelmingly in the arc assemblages, and are subdivided below according to their stratigraphic associations.

Based on the geochemistry of contained mafic rocks, arc sequences include tholeiitic, calc-alkaline, and subordinate alkaline (shoshonitic) magma series (Stern et al., 1995), as well as recently defined 'arc rift' sequences (Syme et al., in press). For the purposes of classification in this report, rhyolites are termed 'calc-alkaline' if they occur in calc-alkaline or transitional tholeiitic - calc-alkaline suites, 'tholeiitic' if they occur in tholeiitic suites, and 'extension-related' if they occur in suites that contain the magmatic products of intra-arc extension and rift basin development. Most are high-silica rhyolites with 73-88 wt.% SiO_2, but some have clearly been silicified; associated hyaloclastites and microbreccias contain 67-70 wt.% SiO_2 by virtue of post-emplacement alteration of the fine grained, originally glassy hyaloclastite granules.

Tholeiitic and calc-alkaline arc rhyolites

Subaqueous rhyolite flows, domes, and volcaniclastic rocks in basalt/basaltic andesite-dominated tholeiitic sequences generally form relatively thin (tens of metres) units sharply interlayered with the mafic volcanic rocks. These tholeiitic sequences tend to be strikingly bimodal, with rhyolite only ca. 5% of the sequence. Calc-alkaline suites typically include a small proportion of intermediate (andesitic) material and the contained rhyolite complexes tend to be larger (hundreds of metres) than in tholeiitic suites. Regardless of magmatic affinity, rhyolite flow types

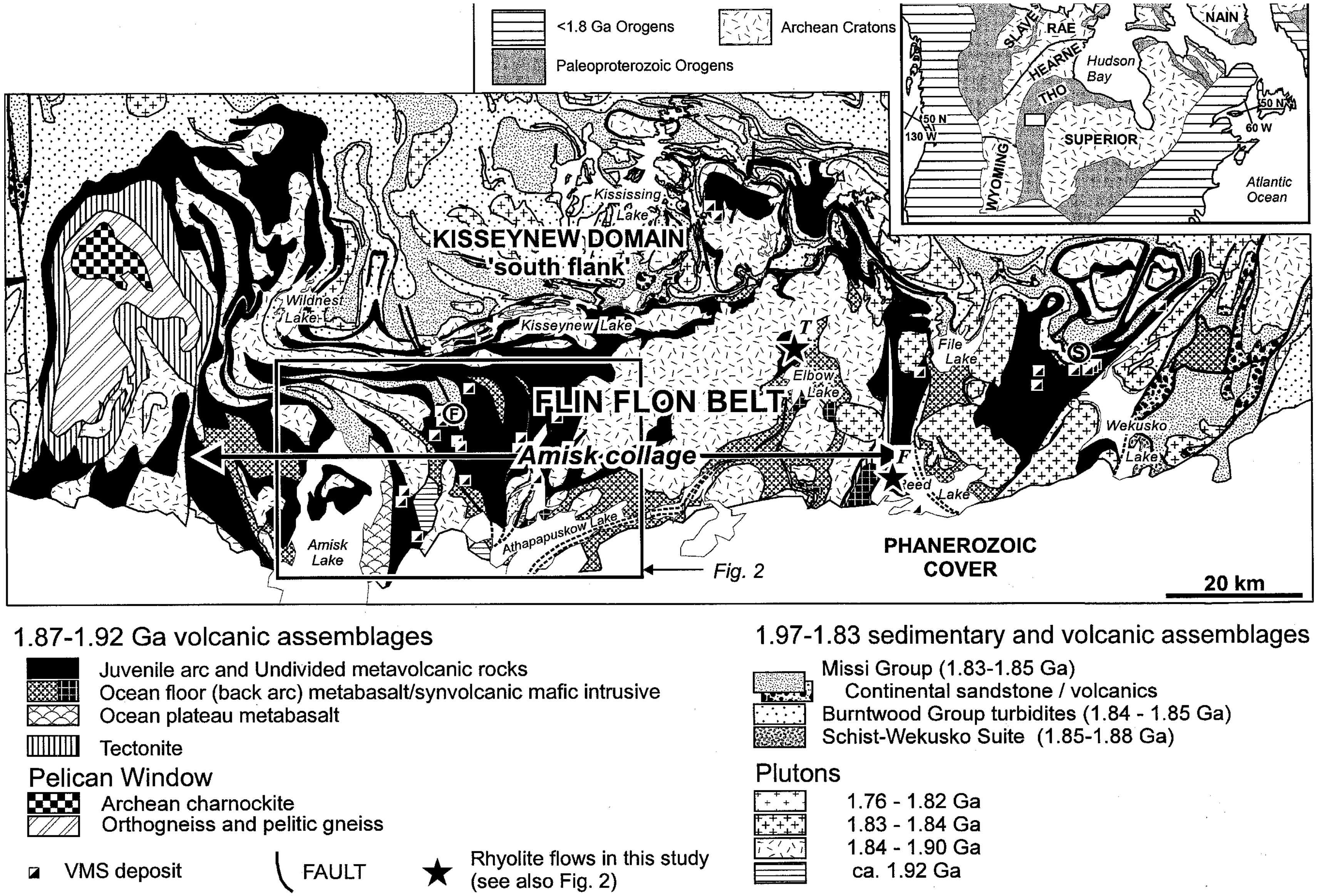


Figure 1 *Tectonic assemblage map of the exposed portion of the Flin Flon Belt, based on NATMAP Shield Margin compilation maps (NATMAP Shield Margin Working Group 1998). Inset: location of Flin Flon Belt (box) in Trans-Hudson Orogen (THO). T: Tee Lake rhyolite, Elbow Lake area; F: rhyolite in the Fourmile Island assemblage, Reed Lake.*

include massive (± flow-top breccia) and lobe-hyaloclastite complexes, and are aphyric, quartz phyric or quartz-plagioclase phyric. Despite the range in flow morphology, all rhyolite flows were emplaced in a subaqueous environment.

Rhyolites were sampled in the tholeiitic Flin Flon and Hook Lake sections (Stern et al., 1995), the calc-alkaline lower Bear Lake and Bakers Narrows sections (Stern et al., 1995), and the extension-related upper Bear Lake and Grassy Narrows sections (Syme et al., in press) (Fig. 2; Table 1). Location of rhyolites from the tholeiitic Elbow Lake section (Syme, 1991) and the tholeiitic Fourmile Island assemblage (Reed Lake; Syme and Bailes, 1995) are shown on Figure 1.

Extension-related rhyolites

Two rhyolites in the Flin Flon area are stratigraphically distinct from 'typical' arc assemblage rhyolites (Syme, 1998) in that they are associated with MORB-like basalts. Two Portage Lake (TPL) rhyolite crystal tuff (Table 2; Fig. 2) occurs as interflow beds within a 150-200 m thick unit MORB-like ferrobasalt in the upper part of the Bear Lake section. This 5.5 km thick section records the rifting of a transitional tholeiitic-calc-alkaline arc, production of an extensional basin floored by the MORB-like ferrobasalt and intercalated rhyolite tuff, and infilling of the basin by shoshonitic tuff (Syme et al., in press). The stratigraphic relationships and geochemical

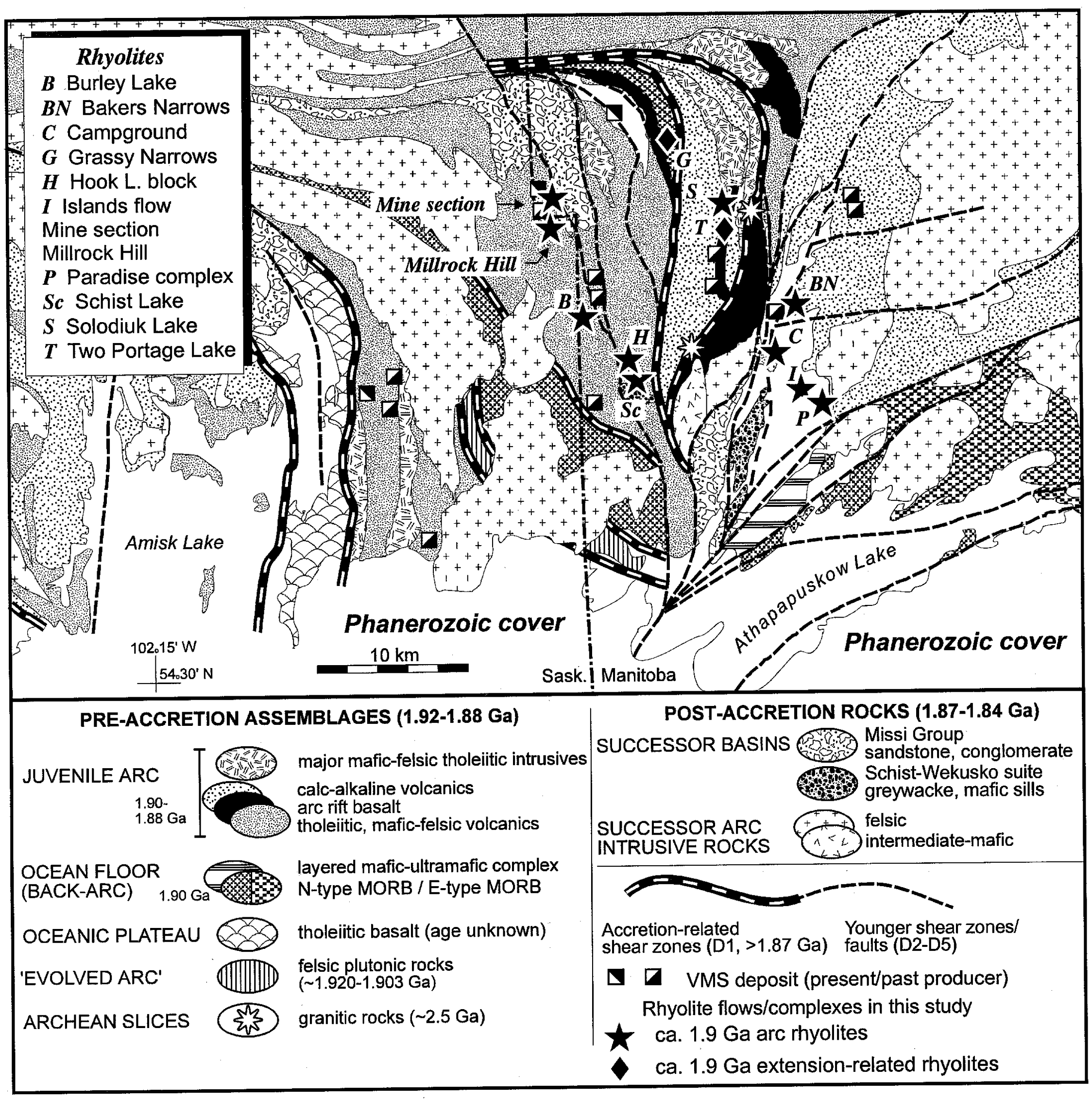


Figure 2 Simplified geological map of the Flin Flon area, Manitoba and Saskatchewan, with location of rhyolites in this study.

Table 1
Characteristics of juvenile arc rhyolites in the central Flin Flon Belt discussed in this study

JUVENILE ARC RHYOLITES		
In tholeiitic sequences:		
Burley Lake rhyolite	Flow banded massive rhyolite ≤30 m thick. Locally brecciated basal portion. Porphyritic: quartz (1%, 0.2-1 mm); plagioclase (3%, 0.4-2 mm).	Bailes and Syme, 1989
Hook Lake block rhyolite	Massive rhyolite and breccia, aphyric to weakly quartz phyric (2%, 1 mm), >370 m thick.	Syme, 1988
Schist Lake rhyolite	Fault-bounded, variably tectonized (foliated, brecciated) segments of a large, aphyric and quartz-phyric rhyolite body.	Syme, 1988
Bear Lake block dacite	ca. 100 m of dacite flows and poorly exposed intermediate and felsic tuff. Rare flow laminations (<1-3 mm wide) and spherulites (to 2 mm). Overlies Vick Lake shoshonite tuff.	Bailes and Syme, 1989
Tee Lake rhyolite	Largest felsic volcanic complex in the Elbow Lake area (Fig. 1), at least 600 m thick. Dominantly massive aphyric, quartz-phyric and plagioclase-phyric felsic rocks; there are few occurrences of felsic tuff and breccia.	Syme, 1991
Fourmile Island assemblage rhyolite	Thick (150 m) unit of coarsely quartz-feldspar phyric rhyolite, Reed Lake (Fig. 1). Interpreted as an exogenous felsic dome, on the basis of its low strike-length to thickness ratio and fragmental nature.	Syme and Bailes, 1996
In calc-alkaline sequences:		
Bakers Narrows block rhyolite	6 m thick flow, massive with flow-brecciated top. Part of a felsic unit approximately 360 m thick, composed of similar thin (6-12 m) massive flows. All flows are plagioclase (1-10%, 0.2-1.4 mm) +/- quartz (2%, 0.1-0.8 mm) phyric.	Bailes and Syme, 1989
Campground rhyolite	Flow complex >460 m thick. Aphyric. Central part of complex is massive rhyolite, with basal and upper zones containing rhyolite lobes in rhyolite microbreccia matrix.	Syme, 1987
Islands flow	Massive aphyric flow approximately 210 m thick, exposed for a strike length of 3.3 km. Feeding fissures represented by massive rhyolite dykes up to 30 m thick form a stockwork in the stratigraphic footwall, continuous with the massive part of the flow. The basal part of the flow is spherulitic and contains polygonal cooling joints. The upper third of the flow consists of massive rhyolite, flow-folded flow-banded rhyolite, and rhyolite breccia containing large tabular slabs of flow-banded material.	Syme, 1987
Paradise complex	Composed predominantly of aphyric massive rhyolite lobes and rhyolite hyaloclastite, microbreccia and breccia. Entire complex is at least 900 m thick. Like the Campground rhyolite, some of the clastic material in the microbreccia is pumiceous.	Syme, 1987
Solodiuk Lake rhyolite	Subaqueous rhyolite flow complex in the transitional tholeiitic-calc-alkaline Bear Lake section. Maximum thickness 250 m, comprising massive rhyolite lobes, pods and narrow tongues enveloped by breccia and microbreccia/hyaloclastite. Weakly porphyritic: quartz (<1%-4%, 0.1-0.5 mm); plagioclase (1-3%, 0.5-1.5 mm). Spherulitic groundmass.	Bailes and Syme, 1989

characteristics of the tectonic units in the section are well defined, making TPL rhyolite a prototypical example of felsic rocks emplaced in an extensional arc setting.

Grassy Narrows rhyolite (Table 2; Fig. 2) comprises a major felsic complex with massive and lobe/hyaloclastite facies (Peloquin, 1981; Peloquin et al., 1982; Bailes and Syme, 1989). Although fault bounded, this rhyolite is contained within a panel containing MORB-like basalts that are inferred to be extension-related, and are overlain by conglomerates and arc volcanic units (Bailes and Syme, 1989; Syme et al., in press). Thus, although the stratigraphic relationships are not as clear as for TPL rhyolite tuff, the tectonostratigraphic association of Grassy Narrows rhyolite suggests that it too was emplaced in an extensional environment.

Table 2
Characteristics of extension-related rhyolites discussed in this study.

EXTENSION-RELATED RHYOLITES		
Grassy Narrows rhyolite	Comprises two separate facies 1) a massive, sparsely plagioclase-phyric flow, and 2) a rhyolite complex comprising massive lobes in a microbreccia. The massive facies is exposed for a strike length of 1.2 km with a maximum width of 180 m. Basal unit of massive, columnar-jointed rhyolite, a central unit of brecciated rhyolite in which columnar jointing is less distinct, and an upper unit of brecciated rhyolite in which columnar jointing is rarely preserved. Sparsely plagioclasephyric (tr-2%, 0.4-1.5 mm), abundant spherulites. The lobe/microbreccia facies consists of lensoid podiform bodies of massive, white-weathering rhyolite enclosed by light yellow-green weathering microbreccia. Massive rhyolite lobes comprise 20% of the rhyolite complex and range in thickness from 0.15 to 6 m and in length from 0.5 to 30 m. They are enclosed in a crudely layered tuff to tuff breccia matrix. Lobes range from aphyric to porphyritic with up to 10% quartz and 5% plagioclase phenocrysts (0.2-0.8 mm). Texturally similar lobes occur in discrete zones several tens of metres thick.	Bailes and Syme, 1989; Peloquin, 1981; Peloquin et al., 1982; Ayres, pers. comm., 1981
Two Portage Lake rhyolite crystal tuff	Graded rhyolite crystal tuff beds, 30 cm to 8.5 m thick, occur as interflow markers in Two Portage Lake ferrobasalt. Rhyolite crystal tuff beds have turbidite sedimentary structures (graded and laminated) and contain varying amounts of crystals and crystal fragments (quartz maximum 3-4 mm, plagioclase typical maximum 2 mm) and a heterolithologic suite of rock fragments including ferrobasalt, porphyritic rhyolite, and minor "plagioclasite", tonalite and slabby mudstone. Fine grained tops of beds commonly contain disseminated very fine grained pyrite.	Bailes and Syme, 1989; Syme and Bailes, 1993

FLIN FLON MINE STRATIGRAPHY

Overview

The Flin Flon (62.4 m.t.), Callinan (3.5 m.t.), and newly discovered Triple 7 (13.3 m.t.) deposits occur within a single felsic volcanic interval (J.J. O'Donnell, Hudson Bay Mining and Smelting Co. Ltd. (HBMS), pers. comm., 1998) in a 4 km thick, tholeiitic basalt-dominated sequence within the Flin Flon arc assemblage (Bailes and Syme, 1989; Thomas, 1992; Stern et al., 1995; Syme et al., in press). The sulphide-hosting rhyolitic interval (1903 +7/-5 Ma; Stern et al., in review) is up to 150 m thick, at the stratigraphic contact between footwall ('South Main') and hanging wall ('Hidden Lake') basalts (Bailes and Syme, 1989; Syme and Bailes, 1993; Fig. 3). The basalts are prototypical juvenile arc rocks, characterized by flat to slightly enriched chondrite-normalized REE patterns, depletions at Nb, Zr-Hf and Ti relative to adjacent REEs on MORB-normalized plots, and initial ε_{Nd} values ranging from +3.1 to +4.1 (Stern et al., 1995).

Variation in regional mine stratigraphy can be summarized by considering three contrasting along-strike sections (depicted schematically on Fig. 3): 1) northwest of the Flin Flon smelter, 2) at South Main Shaft (both from Bailes and Syme, 1989, Syme and Bailes, 1993), and 3) at Millrock Hill (Syme, 1997). These sections clearly demonstrate a profound lateral variation within both the footwall and rhyolite stratigraphy. The footwall displays an abrupt northward transition from 'proximal' pillowed basalt flows and related amoeboid pillow breccia in the Millrock Hill and South Main Shaft areas, to a thick succession of 'distal' mafic volcaniclastic rocks, including pillow fragment breccias in the immediate footwall of the Flin Flon orebody. Northwest of the smelter the footwall sequence also contains a package of redeposited mafic pyroclastic rocks, cut by South Main-type basalt dykes, both of which are truncated and unconformably overlain by the pillow fragment breccias (Bailes and Syme, 1989, Syme and Bailes, 1993). The volcaniclastic rocks are locally overprinted by a disconformable, chlorite-dominated hydrothermal alteration zone (Koo and Mossman, 1975).

A heterogeneous package of rhyolite flows and breccias at the South Main basalt-Hidden Lake basalt contact hosts the Flin Flon, Callinan and Triple 7 massive sulphide deposits (J.J. O'Donnell, HBMS, pers. comm., 1998; Fig. 3). Significant lateral variation exists in both the components and thickness of this package: it is thickest

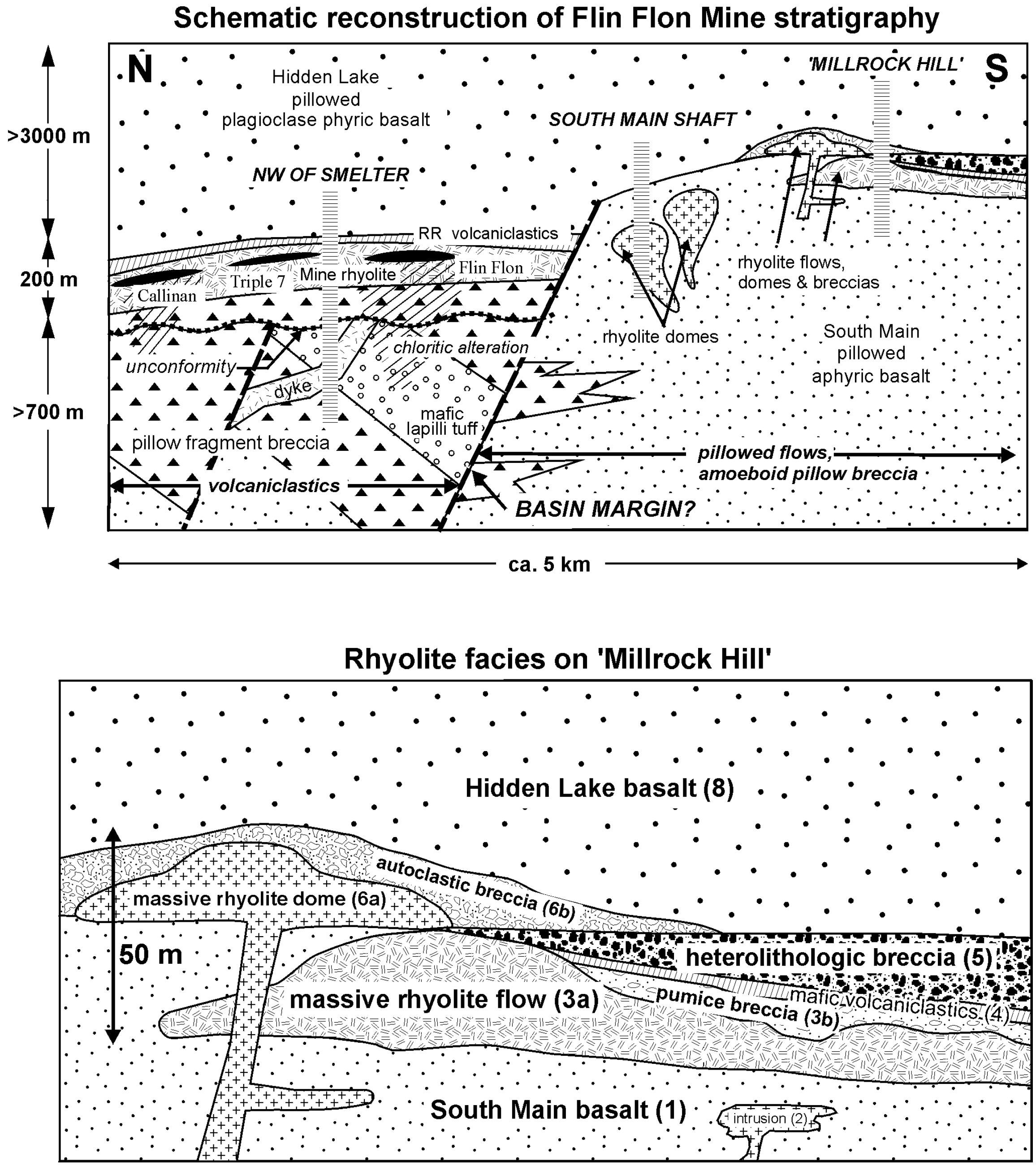


Figure 3 Top: Simplified stratigraphic relationships in the Flin Flon Mine sequence (from Syme et al., in press). Bottom: Schematic cross section showing the various rhyolite facies on Millrock Hill. Unit numbers correspond to Figure 4.

in the footwall volcaniclastic basin, where it ranges from only a few metres to several 10's of metres thick (J.J. O'Donnell, HBMS, pers. comm., 1998). Mine rhyolite, a composite rhyolite flow complex approximately 150 m thick where it is exposed northwest of the HBMS smelter, is a specific term (Bailes and Syme, 1989) for the host rock of the Flin Flon massive sulphide deposit (Stockwell, 1960; Price, 1977). This rhyolite disappears to the south such that at South Main Shaft the footwall and hanging wall basalts are in stratigraphic contact. To the north, the Callinan and Triple 7 deposits are hosted by rhyolites that, although stratigraphically contiguous with Mine rhyolite, may not necessarily be the same flow(s). Rhyolitic bodies at South Main Shaft are high-level domes with intrusive contacts (South Main domes, Bailes and Syme, 1989; below). At Millrock Hill the rhyolite package is 10-50 m thick and comprises flows, small domes and breccias (Syme, 1997; below). These stratigraphic relations indicate that felsic volcanism in the interval containing the Flin Flon/Callinan/Triple 7 massive sulphide deposits was concentrated in the footwall volcaniclastic basin but extended into the more proximal areas of the South Main basalt.

The presence of a thick volcaniclastic sequence in the footwall basalt sequence, in an otherwise proximal volcanic domain, the presence of an unconformity and lithologically anomalous units in the footwall sequence, and variation in thickness of the 'Mine' rhyolite package have been explained in terms of an intra-arc basin (Syme and Bailes, 1993), which likely developed as a result of extension within an oceanic arc (Syme et al., in press). The basin formed a depocentre for fragmental rocks derived from rift scarps. Back-rotated fault blocks within the footwall sequence would be subsequently covered by younger volcaniclastic deposits, forming the intravolcanic angular unconformity documented in the footwall (Bailes and Syme, 1989; Syme and Bailes, 1993; Fig. 3).

Mine rhyolite

The rhyolite flow complex which hosts the Flin Flon massive sulphide deposit is termed Mine rhyolite (Bailes and Syme, 1989; Syme and Bailes, 1993). This complex is approximately 150 m thick northwest of the HBMS smelter and thins to both the north and south. The complex is composed of two distinct phases, interpreted as different flows:

1. Basal phase: This 30 m thick rhyolite breccia with local massive lobes is porphyritic, containing 1-2% euhedral quartz (0.4-1.2 mm) and 4% euhedral plagioclase (0.4-2 mm). Quartz and plagioclase phenocrysts are locally glomerocrystic and there are rare oval phenocrysts of a micrographic quartz-feldspar intergrowth.

2. Main phase: The thicker rhyolite component of Mine rhyolite is distinguished in the field from the basal phase by the presence of quartz phenocrysts 2 mm or more in diameter. Phenocrysts include euhedral quartz (3-4%, 0.2-2.5 mm) and euhedral plagioclase (7%, 0.2-1.2 mm). This phase has two components: a lower zone (40 m) of flow banded massive rhyolite and an upper unit of rhyolite flow breccia containing tabular slabs of flow-banded rhyolite ranging up to 1.9 m long by 20 cm wide.

Zircons separated from the massive portion of the main phase yield a U-Pb age of 1903 +7/-5 Ma (David et al., 1993; Stern et al., in review). This is interpreted as the crystallization age of the rhyolite and by extension the age of the coeval Flin Flon massive sulphide deposit.

South Main rhyolite domes

South Main rhyolite domes (Bailes and Syme, 1989; Syme and Bailes, 1993) are composite high-level endogenous domes in the stratigraphic footwall of the Flin Flon VMS deposit (Fig. 3). The domes are composed of a number of phases that can be identified in the field by variations in phenocryst population. They have intrusive contacts with the footwall (South Main) basalt, bulbous upper portions (up to 150 m across) connected to narrower feeder dykes containing xenoliths of South Main basalt, well defined margin-parallel flow banding, pumice breccia tops, and local interbanded rhyolite breccia and flow banded rhyolite. These rhyolitic bodies, together with rhyolites in the mine workings, were traditionally considered to be host rocks of the massive sulphide deposit. However, previous mapping (Bailes and Syme, 1989) and a current close re-examination of field relationships and geochemistry demonstrates that the rhyolite domes and the sulphide-hosting Mine rhyolite flow are in fact separate entities.

Zircons separated from the southeast dome have suffered non-zero Pb loss and the U-Pb isotope data are thus difficult to interpret (Syme et al., 1991; David et al., 1993; Stern et al., in review). The best estimate for the crystallization age of the dated phase of the southeast dome is 1903 +15/-12 Ma (Stern et al., in review), consistent with stratigraphic and geochemical evidence (below) that the South Main domes are part of the felsic magmatism in the interval hosting the Cu-Zn orebody.

Millrock Hill stratigraphy

The host stratigraphy of Flin Flon Mine is exposed on a large outcrop informally known as Millrock Hill, south of South Main Shaft, near Creighton, Saskatchewan (Fig. 2). Together with the exposed portion of Mine rhyolite, the rhyolites on Millrock Hill provide an important glimpse at the diversity in rhyolite facies present in the interval hosting the Flin Flon, Callinan and Triple 7 massive sulphide deposits. It is worthwhile to understand these rocks in detail, as the host rhyolites of the Callinan and Triple 7 deposits are not well exposed on surface. Accordingly, the sequence was mapped at a scale of 3 cm = 10 m (Syme, 1997). Units are described below in ascending stratigraphic order as shown schematically in Figure 3. The stratigraphic sequence is folded in north-northwest-trending, tight, asymmetric Z folds and dissected by northwest-trending oblique-slip faults, resulting in a complicated outcrop pattern (Fig. 4).

South Main basalt (unit 1, Figs. 3, 4) was mapped 100 m into the stratigraphic footwall, underlying the area depicted in Figure 4. This basalt comprises intercalated dark green to brownish green, thin (2-3 m), aphyric, pillowed flows and amoeboid pillow breccia with abundant rusty brown inter-pillow hyaloclastite. Pillowed flows are typically laterally discontinuous (lensoid) and highly amygdaloidal, with a bimodal amygdale population (abundant 1-2 mm amygdales, sporadic 10 mm amygdales). Radial pipe amygdales up to several cm long occur in pillow margins.

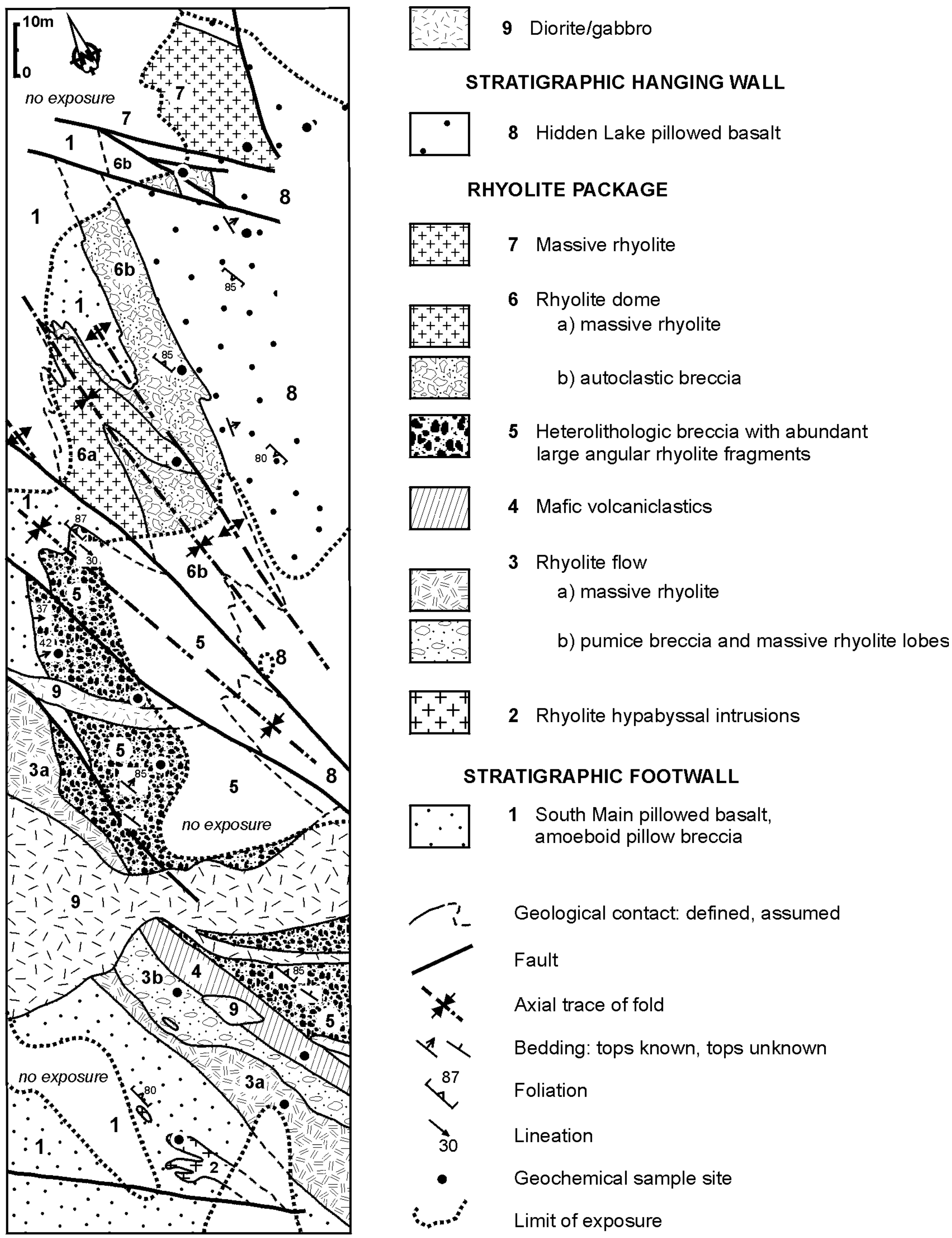


Figure 4 Geological map of the Millrock Hill outcrop, containing felsic rocks correlated with those hosting the Flin Flon massive sulphide deposit. The sequence has been folded in tight, northwest-trending, Z-asymmetric minor folds; the overall younging is to the northeast. See Figure 2 for general location. From Syme (1997).

The basalts display locally intense epidote-chlorite alteration.

South Main basalt is intruded by irregular to lensoid, high level aphyric rhyolite bodies (unit 2). These intrusions are sill-like in form with long axes broadly parallel to stratigraphy. They have sharp contacts with South Main amoeboid pillow breccia and are very fine grained, massive to locally flow banded, and locally spherulitic.

The South Main basalt section is overlain by a 11-18 m thick, weakly quartz phyric rhyolite (unit 3), the only true rhyolite 'flow' in the Millrock Hill sequence. This flow has a sharp, planar, slightly sheared, conformable lower contact with South Main basalt amoeboid pillow breccia and is overlain, at least locally, by 6 m of mafic volcaniclastic rocks. Massive rhyolite (unit 3a) forms the base of the flow and varies in thickness laterally from 2 m to >10 m. The top of the massive portion is slightly brecciated, then passes abruptly into a pumice breccia (unit 3b) composed of round to oval, brownish-weathering pumice clasts (1-20 cm) supported in a pale yellow, fine grained, recrystallized rhyolite hyaloclastite matrix. Lobes of massive rhyolite occur within the pumice breccia. The presence of pumice suggests that this flow was erupted into relatively shallow water.

A thin (6 m) unit of mafic volcaniclastic rocks (unit 4) overlies the pumice breccia portion of the rhyolite flow, and is overlain by heterolithologic breccias. Both contacts are sharp. This unit contains irregular, poorly defined clasts in a foliated matrix.

Heterolithologic breccias (unit 5) 30-35 m thick are conformably emplaced on South Main amoeboid pillow breccia, the mafic volcaniclastic rocks, and locally on the massive portion of the rhyolite flow (Fig. 4). The sharp, unfaulted contact with amoeboid pillow breccia is exposed continuously around the nose of a fold in the central part of the area, where it dips 37-42° east. The top of the breccia unit is not exposed within the area mapped, but structural relationships require that it be overlain by Hidden Lake basalt. The breccia is clast-supported, very poorly sorted and contains a heterolithologic clast population. Block-sized (to 1.5 m), white-weathering, quartz phyric (to 3 mm) rhyolite fragments dominate and are typically slab-like and highly angular. Subordinate brown-weathering aphyric mafic-intermediate fragments (1-20 cm) are angular and generally non-vesicular; the fine-grained matrix is a similar mafic-intermediate composition. Variations in the proportion and size of rhyolite fragments defines crude layering and grading. Re-entrant fractures displayed by some rhyolite fragments suggest the unit may be the product of episodic phreatic explosions (by analogy with features in the Joliette breccia, Noranda; Dimroth and Rocheleau, 1979). The fragmental material was likely emplaced on the sea floor as high density debris flows.

A prominent fault separates heterolithologic breccia (unit 5) in the southwest from a massive rhyolite - autoclastic breccia complex (unit 6) in the northeast (Fig. 4). Both units lie directly upon South Main amoeboid pillow breccia and are conformably overlain by Hidden Lake basalt. Massive quartz phyric (2-4 mm) rhyolite (unit 6a) weathers a distinct yellow colour and is light greenish yellow on fresh surfaces, contrasting with other rhyolites in the sequence. The massive material is up to 12 m thick and has an irregular, abruptly gradational contact with monolithologic, clast-supported rhyolite breccia (unit 6b), suggesting the breccia is autoclastic in origin. Unlike the heterolithologic breccia, autoclastic breccia contains no mafic fragments, is not layered and contains relatively small (5-50 cm) fragments. Despite tight folding of the massive rhyolite and breccia, map relations suggest that the units comprise a felsic dome, thinning to the north, emplaced on South Main basalt (Fig. 3). The massive core of the dome has a carapace of breccia (up to 35 m thick in the hinge area of a syncline) that thins laterally, where it contains more matrix. Locally, only 10 m of this breccia separates South Main and Hidden Lake basalts; this relation is important because it is consistent with the absence of rhyolites at this contact near the South Main shaft (Bailes and Syme, 1989).

Massive, creamy yellow weathering rhyolite at the north end of the mapped area (unit 7) is in fault contact on the south and east with Hidden Lake basalt (Fig. 4). Its stratigraphic relationships with other rhyolites in the felsic package are unknown. The rhyolite is weakly quartz phyric and is locally flow banded. Based on its morphologic and geochemical similarity to the dome described above, this incompletely exposed massive rhyolite is interpreted as a dome.

Hidden Lake basalt (unit 8) forms the stratigraphic hanging wall of the rhyolitic sequence at Millrock Hill as well as at the South Main and North Main shafts (Bailes and Syme, 1989; Syme and Bailes, 1993). Hidden Lake basalt is readily distinguished from South Main basalt by its distinctive buff weathering colour, abundant plagioclase phenocrysts, absence of radial pipe vesicles, absence of hydrothermal alteration, and lower specific gravity (Bailes and Syme, 1989). Flows are dominantly pillowed, although they do include local interflow amoeboid pillow breccia. Flows trend southeast and top northeast. The exposed contact between Hidden Lake basalt and rhyolite autoclastic breccia is conformable as it is neither sheared nor faulted and flow contacts within Hidden Lake basalt are parallel to the contact.

TRACE- AND RARE EARTH ELEMENT GEOCHEMISTRY

Although emphasis in this study was on the Flin Flon Mine rhyolites, it is clear from the trace element data that each of the major rhyolite associations in the central Flin Flon Belt have geochemical characteristics which serve to identify them. The following sections outline some of the geochemical characteristics of calc-alkaline arc, tholeiitic arc and extension-related rhyolites in the central Flin Flon Belt, with special reference to the Flin Flon Mine data set. A more comprehensive review is in preparation.

In this study, only the rhyolites in the Flin Flon Mine section are stratigraphically associated with massive sulphide mineralization; all of the rhyolites in tholeiitic and calc-alkaline arc sequences (Table 3) are apparently

Table 3
Summary of trace-element geochemistry of rhyolites in the central Flin Flon Belt, including stratigraphic components of the Flin Flon Mine sequence

	$[La/Yb]_N$	Eu/Eu*	Yb	Zr/Y	Zr	Y	Th	Hf	Sr	Sc	n
Arc assemblage rhyolites											
Calc-alkaline (CA)	2.6-5.1	0.58-0.88	1.6-3.0	3.7-5.4	58-144	16-27	1.3-5.7	1.5-4.0	51-375	12-23	12
Solodiuk (CA)	8.3	0.64	0.8	3.9	30	8	1.0	0.9	107		1
Tholeiitic (TH)	1.1-2.8	0.50-0.89	1.9-3.5	2.5-5.5	46-99	15-29	0.7-1.6	1.1-3.0	58-145	9-23	6
Extension-related rhyolites											
Grassy N.	3.5-7.1	0.38-0.53	2.4-6.9	3.7-5.0	115-240	27-59	7.8-11.2	3.2-6.8	11-133	3-5	6
TPL	2.0	0.41	8.3	3.2-3.6	244-263	67-82	7.0	3.6	125-151		2
Flin Flon Mine rhyolites											
Millrock flow	1.4-2.3	0.72-0.74	3.6-5.4	2.3-2.4	78-94	33-41	1.6-1.8	2.3-2.6	65-70	10-12	2
Millrock breccia	1.4-1.5	0.27-0.31	4.1-5.9	2.5-4.9	107-153	26-42	2.7-2.9	3.5-4.1	55-78	3-7	3
Millrock domes	1.3-1.9	0.25-0.29	5.9-7.5	2.6-4.0	123-187	38-56	2.9-3.5	3.8-5.2	32-55	4-6	4
Millrock dykes	1.6-2.1	0.23-0.47	5.5-5.8	2.8-4.8	135-175	36-49	3.3-3.7	3.8-5.1	53-60	3-5	2
Mine basal phase	1.3-1.5	0.47-0.66	2.9-5.5	2.5-2.6	61-91	23-36	1.2-1.7	1.5-2.6	37-58	8-14	3
Mine main phase	1.6-2.1	0.65-0.71	4.2-4.7	3.6-4.1	109-118	27-33	1.8-1.9	3.6-3.7	33-58	9-10	3
Mine flow top bx	0.3	0.58	5.3	3.6	115	32	1.8	3.2	29	10	1
S.M. dome (NW)	1.4-2.1	0.26-0.42	3.5-7.8	3.0-4.0	88-161	27-53	1.5-3.6	2.5-4.8	51-58	4-13	3
S.M. dome (SE)	1.4-1.8	0.25-0.49	5.4-8.4	2.2-3.7	128-138	37-61	2.6-3.4	4.0-4.3	78-95	4-5	3
Archean Superior Province (Lesher et al. 1986)											
FI	6-34	0.87-2.0	0.4-3.8	9-31	86-273	4-12	0.6-8.6	2.3-6.0	81-616	2-12	
FII	2-6	0.35-1.4	1.7-6.0	6-11	96-412	17-48	1.3-9.5	2.3-11	43-264	4-25	
FIIIa	1-4	0.37-0.94	3.4-9.3	4-7	170-370	25-70	1.5-7.3	3.9-8.6	5-101	8-20	
FIIIb	1-4	0.20-0.61	7.3-32	2-6	194-708	72-238	3.1-16	5.8-24	7-210	2-11	

n = number of samples

barren. The extension-related Grassy Narrows rhyolite is also apparently barren. Two Portage Lake (TPL) rhyolite crystal tuff is intercalated with N-MORB ferrobasalts which in turn directly overlie the Cuprus and White Lake VMS deposits; the rhyolites postdate mineralization.

Samples from older sample sets (Bailes and Syme, 1989; Syme, 1988; Syme, 1991; Syme and Bailes, 1996) were originally crushed in a tungsten carbide mill and were re-analysed in 1997 for trace and rare earth elements by ICP-MS at the University of Saskatchewan. Samples collected in 1997 from the Flin Flon Mine sequence and Millrock Hill were crushed in an agate mill and similarly analysed by ICP-MS at the University of Saskatchewan. Analyses are listed in Appendix A.

Selected HFSE

Tholeiitic and calc-alkaline arc rhyolites from the central Flin Flon Belt plot in the 'volcanic arc' field on an Y vs. Nb diagram (Fig. 5a), whereas the Grassy Narrows and TPL rhyolites plot mainly in the 'ocean ridge granite' field. This clear geochemical distinction is a result of higher Y contents in the extension-related rhyolites (Fig. 5c), and is consistent with the stratigraphic association of tholeiitic and calc-alkaline rhyolites with juvenile arc basalts and basaltic andesites, and of Grassy Narrows and TPL rhyolites with MORB-like basalts.

Rhyolites in the Flin Flon Mine package plot mainly in the 'volcanic arc' field (Fig. 5b) but clearly extend to the higher Y contents characteristic of the extension-related rhyolites (Fig. 5d).

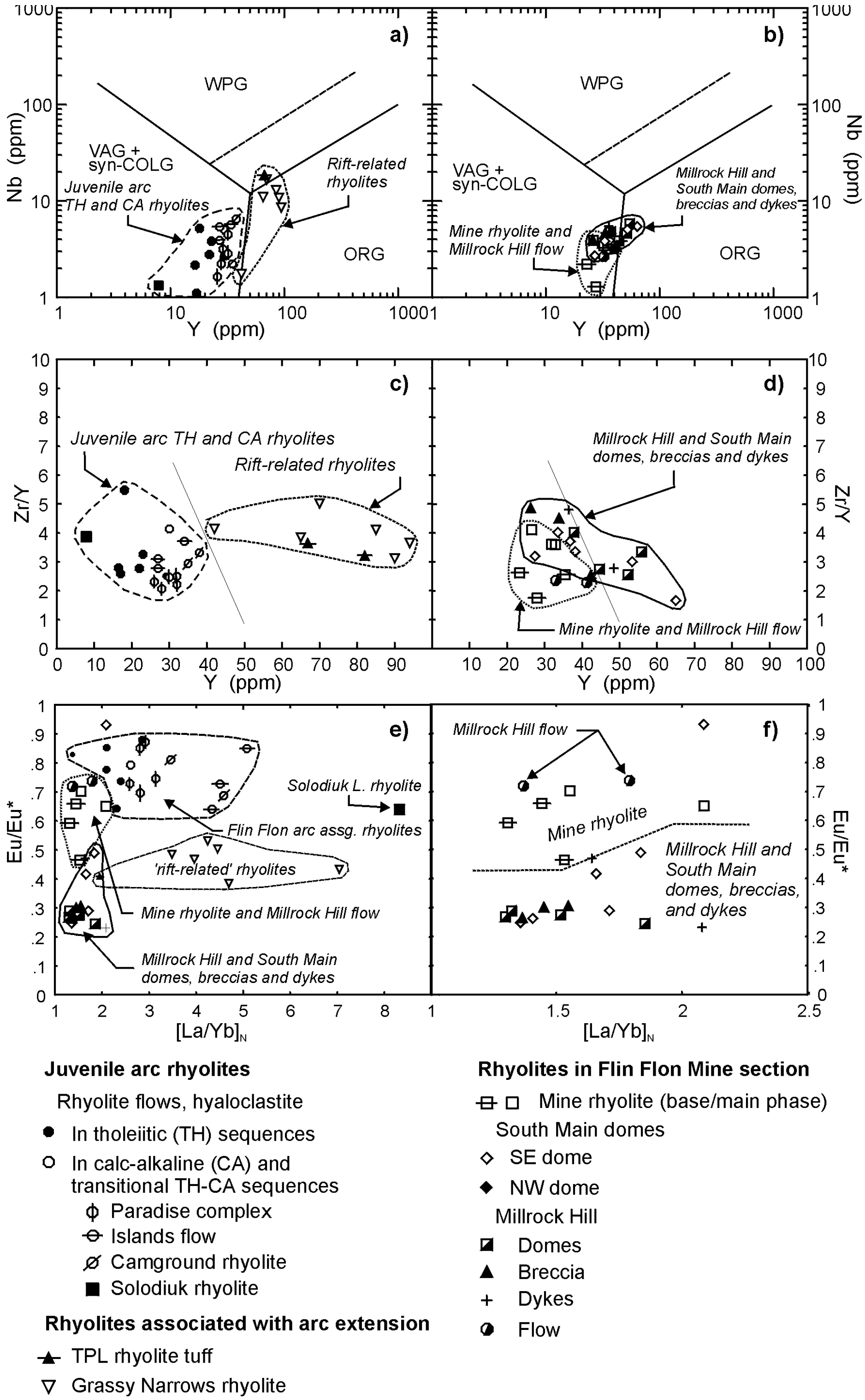


Figure 5 a, b) Discrimination diagrams (Pearce et al., 1984) for felsic rocks. Flin Flon Belt tholeiitic and calc-alkaline rhyolites plot in the 'volcanic arc' field. Grassy Narrows and TPL rhyolites plot mainly in the 'ocean ridge granite' fields. c) Y vs. Zr/Y. Virtually all rhyolites in the central Flin Flon Belt have Zr/Y ratios between 2 and 5.5. Tholeiitic and calc-alkaline rhyolites have lower Zr/Y ratios than Grassy Narrows and TPL rhyolites. d) Millrock Hill domes, breccias and dykes have Zr/Y ratios that extend into the range displayed by extension-related rhyolites. e) $[La/Yb]_N$ vs. Eu/Eu for all rhyolites in this study. f) Detail ($[La/Yb]_N$ = 1 to 2.5) showing distinction between Mine rhyolite + Millrock Hill flow and Millrock Hill domes, breccias and dykes.*

Zr/TiO_2 ratio

The Zr/TiO_2 ratio is an excellent index of compositional evolution in intermediate and felsic rocks (reviewed in Lentz, 1996). During fractional crystallization, Zr and Ti display divergent geochemical behaviour: Zr increases as TiO_2 decreases (Barrett and MacLean, 1994a, 1994b). All Flin Flon Belt rhyolite suites in this study, however, show a positive covariation between Zr and TiO_2: Zr and TiO_2 increase together (Fig. 6). Similar relationships have been documented in other rhyolites in the Flin Flon Belt (Gale et al., 1997). This type of covariation has also been observed elsewhere (e.g., Bathurst Camp, New Brunswick: Lentz, 1996; Rogers and van Stall, 1996), where the effect is attributed to crustal fusion processes involving different solubilities and melting behaviours of zircon, rutile and/or ilmenite in crustal partial melts or different crustal sources (Lentz, 1996).

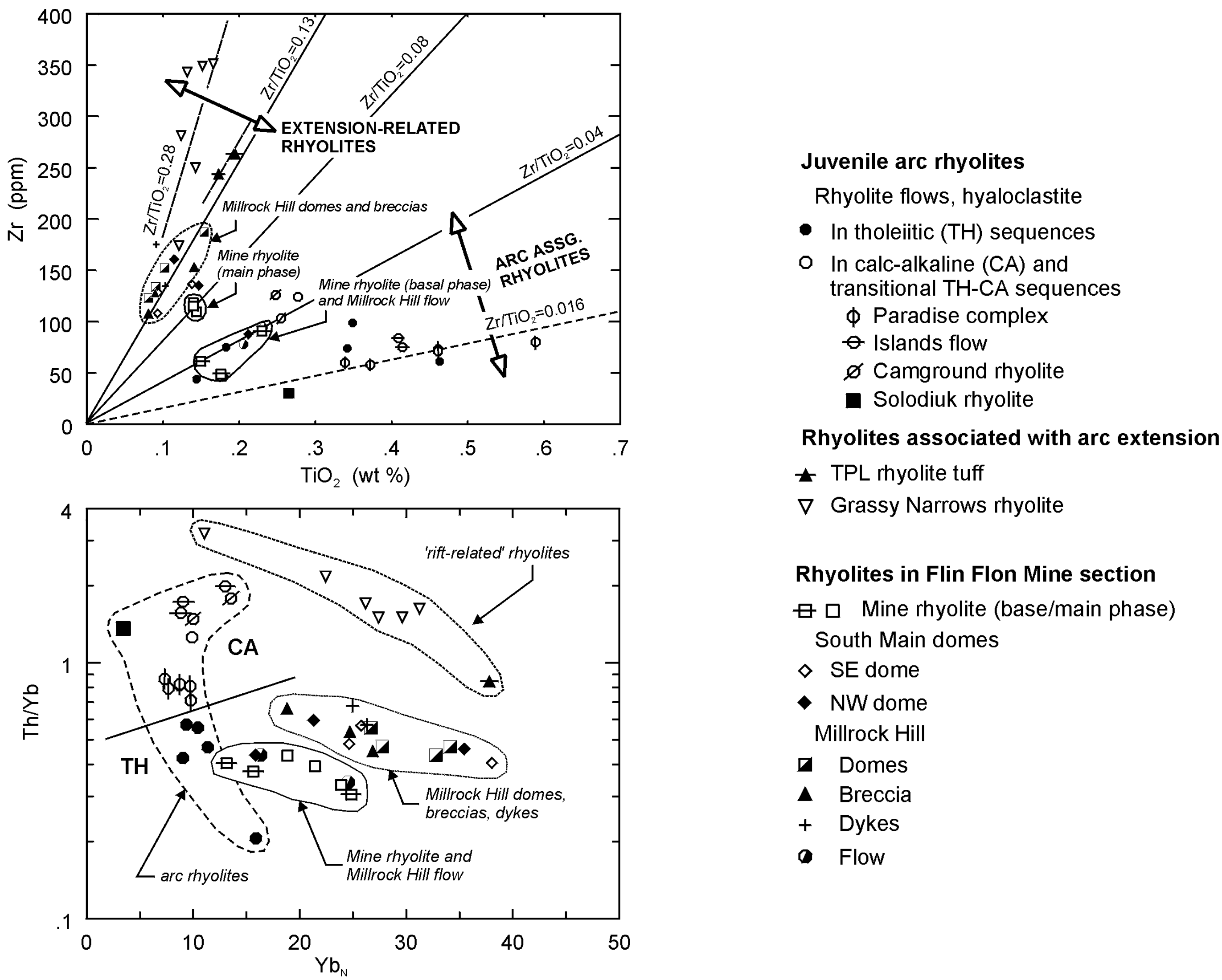


Figure 6 Top: Zr vs. TiO_2 for rhyolites in this study. Arc assemblage rhyolites and extension-related rhyolites display distinct Zr/TiO_2 ratios. See text for discussion. Bottom: Th/Yb vs. Yb_N for rhyolites in this study. Rhyolites in tholeiitic (TH) and calc-alkaline (CA) assemblages can be distinguished by their Th/Yb ratio. Extension-related rhyolites tend to have higher Yb_N than arc assemblage rhyolites. Rhyolites in the Flin Flon Mine sequence have relatively low Th/Yb but high Yb_N, distinguishing them from barren arc assemblage rhyolites. Geochemical similarity between Mine rhyolite and the Millrock Hill flow is one factor suggesting these flows are stratigraphically equivalent.

The Zr/TiO_2 ratio for rhyolites in this study vary systematically with the tectonic environment as defined by stratigraphic relationships. Rhyolites in tholeiitic and calc-alkaline arc suites have Zr/TiO_2 ratios ranging between about 0.016 and 0.04, whereas the extension-related rhyolites have much higher Zr/TiO_2 ratios, between about 0.13 and 0.28 (Fig. 6). Note that compositional variation displayed by single stratigraphic units within these suites (e.g., Paradise rhyolite, Grassy Narrows rhyolite) parallels the trends defined by the entire suites.

Interestingly, the diverse rhyolites within the Flin Flon Mine stratigraphy cluster in three different groups (Fig. 6): 1) the basal phase of Mine rhyolite, and the Millrock Hill flow, have Zr/TiO_2 ratios similar to arc assemblage rhyolites (ca. 0.04); 2) Millrock Hill domes and breccias have a Zr/TiO_2 ratio of approximately 0.13, similar to the extension-related rhyolites; and 3) the main phase of Mine rhyolite has a Zr/TiO_2 ratio of ca. 0.08, intermediate between the low ratios displayed by arc rhyolites and the higher ratios displayed by extension-related rhyolites. In stratigraphic terms, there is a clear evolution of increasing Zr/TiO_2 ratio with time within the Flin Flon Mine rhyolite package, appearing to define an increasing 'extensional' character upwards through the package.

Th

Thorium serves as an effective discriminant between various rhyolite types in the central Flin Flon Belt. Rhyolites in calc-alkaline or transitional arc sequences have Th contents which range from 1.3-5.7 ppm, while rhyolites in tholeiitic sequences have only 0.7-1.6 ppm Th (Table 3). Extension-related Grassy Narrows and TPL rhyolites have distinctly higher Th contents (7.0-11.2 ppm). Within the Flin Flon Mine rhyolite package, lowest Th contents (1.2-1.9 ppm) are recorded in Mine rhyolite and the Millrock Hill flow, reinforcing the interpretation that these flows are stratigraphically equivalent. The rhyolite breccias, domes and dykes on Millrock Hill have slightly but consistently higher Th contents than Mine rhyolite, ranging from 2.7-3.7 ppm (Table 3). South Main rhyolite domes chiefly have Th contents similar to the breccias, domes and dykes on Millrock Hill, but also some lower Th contents characteristic of Mine rhyolite (Table 3). A plot of Yb_N vs. Th/Yb (Fig. 6) similarly shows that the various rhyolitic suites are compositionally distinct.

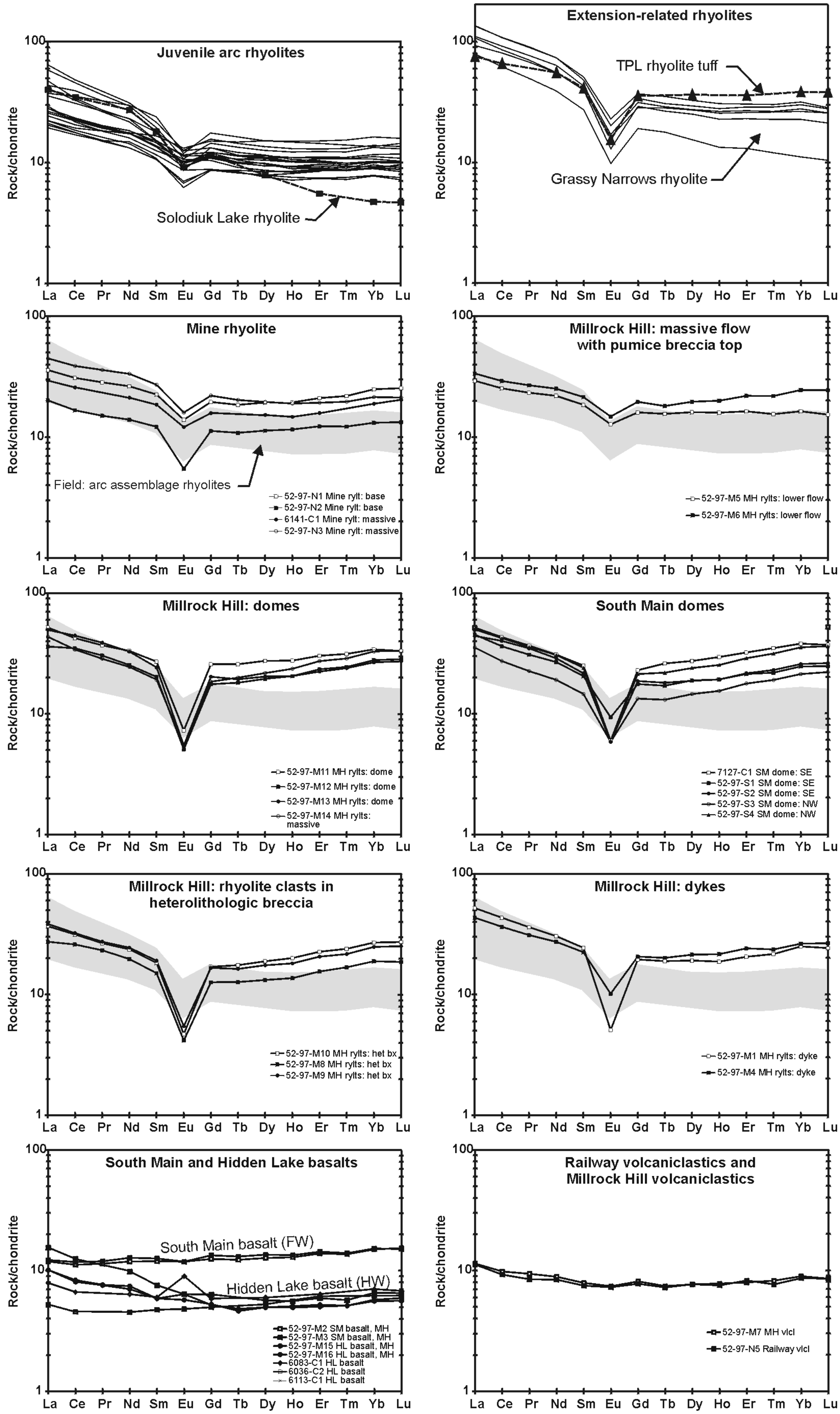
Th is an incompatible element with a large ionic radius and a very low mineral-melt partition coefficient for most rock-forming minerals (Lentz, 1996 and references therein), and has a relatively low but positive partition coefficient for many trace minerals. In view of the ionic similarity between Th and Rb, Th may be used in place of the much more mobile Rb as an index of compositional evolution in altered rocks. Th (and Rb) is usually low (<10 ppm) in mantle-derived and metabasaltic crustal-derived partial melts (Lentz, 1996), suggesting that all of the rhyolites in this study could be derived in a similar manner.

Rare earth elements

Rhyolites in the juvenile arc assemblage have REE profiles falling within a narrow range on a chondrite-normalized diagram (Fig. 7). The $[La/Yb]_N$ ratios range from 1.1-8.3 (Table 3), reflecting only slight to moderate light rare earth element (LREE) enrichment. Rhyolites in calc-alkaline and transitional sequences tend to have higher $[La/Yb]_N$ ratios (2.6-8.3) than rhyolites in tholeiitic sequences (1.1-2.8). Virtually all of the arc rhyolites have small negative Eu anomalies (Eu/Eu*), ranging from 0.58-0.89 (Table 3). By contrast, the extension-related TPL and Grassy Narrows rhyolites have higher ΣREE, similar $[La/Yb]_N$ ratios (2.0-7.1), and larger Eu anomalies (Eu/Eu* = 0.38-0.53) than typical arc rhyolites. Thus, arc- and extension-related rhyolites are readily distinguished by their $[La/Yb]_N$ and Eu/Eu* characteristics (Fig. 5e).

High $[La/Yb]_N$ and Zr/Y ratios are characteristic of calc-alkaline lavas (Lentz, 1996, and references therein). Low HREE and Y contents in calc-alkaline systems commonly results from extensive fractional crystallization of hornblende (± clinopyroxene), which favourably hosts Y and HREE relative to incompatible elements such as LREE, Zr, and Th. Solodiuk Lake rhyolite, part of the calc-alkaline Bear Lake arc section (basaltic andesite - andesite - rhyolite), displays typical calc-alkaline characteristics with the highest $[La/Yb]_N$ ratio (8.3) and lowest Y content (8 ppm) of all rhyolites in the sample set (Table 3). Rhyolites in the calc-alkaline Bakers Narrows suite have significantly lower $[La/Yb]_N$ ratios (<5) and higher Y contents (25-40 ppm) than Solodiuk Lake rhyolite and thus do not display strong calc-alkaline REE or HFSE characteristics.

REE characteristics of rhyolites from the Flin Flon Mine section and Millrock Hill are distinct from those of both arc and extension-related rhyolites: as a group they tend to have flat chondrite-normalized patterns ($[La/Yb]_N$ < 2), with distinctly negative Eu anomalies (Fig. 7). Millrock Hill domes, breccias and dykes have the largest negative Eu anomalies of all rhyolites in the central Flin Flon Belt (Eu/Eu* = 0.25-0.31; Fig. 5f). The basal phase of Mine rhyolite and the rhyolite flow on Millrock Hill have similar REE profiles (Fig. 7), distinguished by less pronounced negative Eu anomalies from the domes, breccias and dykes on Millrock Hill and South Main Shaft (Fig. 5f).



Juvenile arc rhyolites
Solodiuk Lake rhyolite
Extension-related rhyolites
TPL rhyolite tuff
Grassy Narrows rhyolite
Mine rhyolite
Field: arc assemblage rhyolites
52-97-N1 Mine rylt: base
52-97-N2 Mine rylt: base
6141-C1 Mine rylt: massive
52-97-N3 Mine rylt: massive
Millrock Hill: massive flow with pumice breccia top
52-97-M5 MH rylts: lower flow
52-97-M6 MH rylts: lower flow
Millrock Hill: domes
52-97-M11 MH rylts: dome
52-97-M12 MH rylts: dome
52-97-M13 MH rylts: dome
52-97-M14 MH rylts: massive
South Main domes
7127-C1 SM dome: SE
52-97-S1 SM dome: SE
52-97-S2 SM dome: SE
52-97-S3 SM dome: NW
52-97-S4 SM dome: NW
Millrock Hill: rhyolite clasts in heterolithologic breccia
52-97-M10 MH rylts: het bx
52-97-M8 MH rylts: het bx
52-97-M9 MH rylts: het bx
Millrock Hill: dykes
52-97-M1 MH rylts: dyke
52-97-M4 MH rylts: dyke
South Main and Hidden Lake basalts
South Main basalt (FW)
Hidden Lake basalt (HW)
52-97-M2 SM basalt, MH
52-97-M3 SM basalt, MH
52-97-M15 HL basalt, MH
52-97-M16 HL basalt, MH
6083-C1 HL basalt
6036-C2 HL basalt
6113-C1 HL basalt
Railway volcaniclastics and Millrock Hill volcaniclastics
52-97-M7 MH vlcl
52-97-N5 Railway vlcl
Rock/chondrite
100
10
1
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

The relatively flat REE patterns of Mine sequence rhyolites suggests that garnet was not involved as either a residual phase or fractionation product, while the pronounced negative Eu anomalies, and low Sr contents (Table 3), indicate either retention of plagioclase in the source residuum or fractional crystallization of plagioclase (after Lesher et al., 1986). Together, these characteristics have been taken by Lesher et al. (1986) to indicate that compositionally similar Archean felsic magmas fractionated plagioclase in high-level magma chambers.

Nd isotopes

Nd isotopic data for rhyolites in the central Flin Flon Belt include ε_{Nd} (at 1.9 Ga) for Mine rhyolite (+4.2), Solodiuk Lake rhyolite (+4.2), and Two Portage Lake (TPL) rhyolite (+4.6) (Stern et al., 1992). All three rhyolites are in some fashion stratigraphically associated with massive sulphides: as described above, Mine rhyolite hosts the Flin Flon VMS deposit; Solodiuk Lake rhyolite is approximately correlative with the Cuprus and White Lake deposits (Bailes and Syme, 1989); and the TPL rhyolite is intercalated with ferrobasalts which directly overlie the Cuprus-White Lake horizon. Stern et al. (1992) show that at both Flin Flon and Snow Lake the rhyolitic magmas associated with massive sulphide deposits are always among the most isotopically juvenile (highest ε_{Nd}) within their respective sections, and were most likely on the liquid line of descent of mantle-derived magmas. This suggests a coupling between ore deposition and input of mantle-derived heat or fluids (Stern et al., 1992), consistent with the interpretation that both the Flin Flon Mine sequence and Bear Lake sequence (containing Solodiuk and TPL rhyolites) are the products of intra-arc extension and rift basin development (Syme et al., in press).

STRATIGRAPHIC CORRELATION IN THE FLIN FLON MINE SEQUENCE

Previously mapped stratigraphic relationships in the Flin Flon Mine sequence (Bailes and Syme, 1989), augmented by recent detailed mapping on Millrock Hill (Syme, 1997) and geochemistry (above) confirm the following important stratigraphic constraints:

1. The Flin Flon massive sulphide deposit occurs between two thick basalt sequences, South Main basalt in the stratigraphic footwall and Hidden Lake basalt in the stratigraphic hanging wall (Fig. 4). These basalts are sufficiently distinct to map them confidently in the field and are also geochemically distinct (Bailes and Syme, 1989; Syme and Bailes, 1993). For example, chondrite-normalized REE patterns for these two basalt formations display no overlap whatever (e.g., Fig. 7).

2. Rhyolite geochemistry suggests that all rhyolites in the Flin Flon Mine interval are of a single lineage. However, subtle trace- and rare earth element differences between different bodies (Figs. 5, 6) allows the following geochemical correlations: a) the basal phase of Mine rhyolite correlates closely with the rhyolite flow exposed on Millrock Hill; b) hypabyssal rhyolite intrusions on Millrock Hill correlate with the domes and breccias which occur up-section, but are distinct from the rhyolite flow on Millrock Hill; c) South Main domes are composite bodies that contain geochemical types identical to Millrock Hill domes and breccias, and some with similarities to Mine rhyolite (e.g., Fig. 6). The petrogenetic link between Mine rhyolite and South Main domes is consistent with their identical initial ε_{Nd} values of +4.2 at 1.9 Ga (Stern et al., 1992).

3. The 6 m thick mafic volcaniclastic formation mapped on Millrock Hill (unit 4, Fig. 4) is geochemically identical to the sandy matrix fraction of Railway volcaniclastics, and is distinct from both footwall and hanging wall basalts (e.g., Fig. 7). The implied correlation is significant. Railway volcaniclastics directly overlie Mine rhyolite (and thus the massive sulphide orebody) north-west of the HBMS smelter (Bailes and Syme, 1989; Fig. 3), while on Millrock Hill the volcaniclastics directly overlie the rhyolite flow correlated with Mine rhyolite. The clear implication here is that the Flin Flon Mine 'horizon' is represented on Millrock Hill by the rhyolite flow; overlying breccias and domes must post-date mineralization.

CLASSIFICATION

Various geochemical schemes have been developed to help distinguish prospective rhyolites from those which likely do not host base metal massive sulphide mineral-ization. Lesher et al. (1986) subdivided Archean felsic

Figure 7 Facing page: chondrite-normalized rare earth element plots for rhyolites and mafic rocks in this study. Rhyolites in the Flin Flon Mine sequence have flat patterns and pronounced negative Eu anomalies, serving to distinguish then from barren arc assemblage rhyolites (top, and shaded fields). Extension-related rhyolites (top right) have patterns similar to rhyolites in the Mine sequence but tend to have higher LREE. Bottom left: South Main basalt (in the stratigraphic footwall of Flin Flon Mine) and Hidden Lake basalt (stratigraphic hanging wall) have distinct REE patterns which indicate they are not related by fractionation. Bottom right: Railway volcaniclastics and Millrock Hill mafic volcaniclastics have very similar REE patterns, consistent with their major and trace element geochemistry, suggesting they are stratigraphically correlative.

metavolcanic rocks into FI, FII and FIII types based on their trace element geochemistry (summarized in Table 3). Type FI rocks are considered to be barren of significant VMS deposits and derived from deep magma chambers where fractional crystallization has taken place. Type FII felsic rocks 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 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 (e.g., Paleoproterozoic Lynn Lake Belt: Syme 1985; Snow Lake area, Flin Flon Belt: Bailes and Galley, 1996; Ordovician Bathurst camp: Lentz, 1996), it provides a useful basis of comparison and is applied below to the Flin Flon data.

Type FI rhyolites, characterized by steep chondrite-normalized REE patterns (high $[La/Yb]_N$ ratios), are imperfectly represented in the Flin Flon data set by Solodiuk Lake rhyolite (Table 3). Although Solodiuk Lake rhyolite is HREE-depleted (Fig. 7) it differs significantly from Archean FI rhyolites in, for example, Zr and Hf contents, and Zr/Y ratio (Table 3). Flin Flon Belt calc-alkaline and tholeiitic arc rhyolites correspond in their REE systematics to type FII, but also have significantly lower Zr/Y ratios than Archean rhyolites in the Lesher et al. (1986) study (Table 3). This is due to the fact that all Flin Flon arc assemblage rhyolites are depleted in HFSE, and particularly Zr, relative to Archean felsic metavolcanic rocks. Mafic rocks (basalt, basaltic andesite) in the Flin Flon Belt are similarly strongly depleted in HFSE and are interpreted to have been derived from a highly refractory sub-arc mantle source (Stern et al., 1995). Mine rhyolite, Millrock Hill rhyolites and South Main domes correspond to type FIII (Table 3) but again differ significantly in HFSE and Th abundances. Based on Sc contents, the Mine rhyolite basal phase and Millrock Hill flow are type FIIIa, while the remainder are FIIIb. The extension-related Grassy Narrows and TPL rhyolites have no precise correspondence with any of the Archean rhyolite geochemical types. Clearly, the Flin Flon data can be accommodated only with reservations into the FI-FII-FIII classification. Note that at Snow Lake, rhyolites associated with the Chisel Lake and Photo Lake deposits correspond most closely to type FII (based on REE patterns), while rhyolites associated with the Anderson deposit do not correspond to any of the Lesher et al. (1986) types (Bailes and Galley, 1996; Bailes, 1997). Thus, generalizations regarding rhyolite classification and productivity in the Flin Flon Belt appear premature.

Barrie et al. (1993) define a specific high-silica rhyolite group (Group I) which host >50% of the VMS deposits in the Abitibi subprovince. These rhyolites have elevated, flat REE patterns with negative Eu anomalies, >73% SiO_2, Zr/Y ratios <5, and Rb/Sr ratios >1 (Barrie et al., 1993). These high-silica rhyolites are interpreted to have been derived from partial melting of hydrated basaltic rocks and were emplaced at very high temperatures (ca. 900° C; Barrie et al., 1993; Barrie, 1995). In the central Flin Flon Belt, only the rhyolites in the Flin Flon Mine package (78-86% SiO_2, Zr/Y = 2.3-4.9, Rb/Sr = 0.1-1.0) approach geochemical similarity to Abitibi Group I rhyolites.

IMPLICATIONS FOR EXPLORATION

The volcanic sequence hosting the Flin Flon and Callinan VMS deposits is clearly bimodal (basalt - rhyolite), a characteristic of extensional tectonic regimes in oceanic or continental arcs (Lentz, 1996). Minimal fractional crystallization (Lentz, 1996) in the felsic magmas which gave rise to the rhyolites in the Mine sequence is suggested by low Zr/Y, $[La/Yb]_N$ and Th/Yb ratios, relatively high Y, Yb, and Zr, and relatively flat REE profiles. The barren calc-alkaline and tholeiitic arc assemblage rhyolites in this study display lower HREE and Y, characteristic of felsic rocks generated through fractional crystallization of hornblende ± clinopyroxene (Lentz, 1996). These observations can be encapsulated in an extensional model for the setting of the Flin Flon deposit (Syme et al., in press), in which felsic magmas generated by high heat flows associated with rifting ascend, with minimal fractional crystallization, to high level magma chambers, where plagioclase fractionation results in the pronounced negative Eu anomalies characteristic of the Mine sequence rhyolites. An extensional setting also provides heat to the near-surface environment that would drive hydrothermal convection, forms faults that would promote seawater circulation, and develops basins that may accumulate exhalative mineralization (e.g., Lentz, 1996).

Extension-related rift basins or the magmatic products of intra-arc rifting have been identified throughout the Flin Flon belt (Syme et al., in press; Gilbert, in review; Bailes and Galley, in review) through a combination of stratigraphic mapping and attendant geochemistry. These sequences are highly prospective given the close association, in rocks ranging in age from Archean to Phanerozoic, of VMS deposits and extension.

CONCLUSIONS

This study has implications for both the Flin Flon Belt in general, and for the Flin Flon Mine felsic package in particular.

Rhyolites in tholeiitic arc sequences, calc-alkaline arc sequences and extension-related (rift) sequences can each be defined, in a first-order fashion, using simple geochemical characteristics. The existence of these diverse rhyolite types is consistent with the diversity of tectonostratigraphic assemblages defined from basalt geochemistry (e.g., Stern et al., 1995).

Rhyolites in the Flin Flon Mine package are geochemically distinct from non-mineralized tholeiitic arc, calc-alkaline arc and extension-related rhyolites. Rhyolites in the Mine package have high silica contents and flat chondrite-normalized REE patterns with prominent negative Eu anomalies, suggesting they correspond to Lesher et al. (1986) types FIIIa and FIIIb and Barrie et al. (1993) Group I. In Archean greenstone belts these rhyolite types are the most prolific hosts of VMS deposits. However, HFSE contents and Zr/Y ratios are distinctly lower in Flin Flon Belt rhyolites than in Archean rhyolites, probably due to derivation from a more depleted source.

Stratigraphic and geochemical evidence supports correlation of the lowermost rhyolite flow on Millrock Hill with Mine rhyolite (specifically the basal, dominantly fragmental phase of Mine rhyolite). Similarly, mafic volcaniclastic rocks overlying the Millrock Hill flow are correlated with the 'Railway volcaniclastics' (Bailes and Syme, 1989), which directly overlie Mine rhyolite northwest of the HBMS smelter. These correlations uniquely identify the Flin Flon Mine felsic sequence over a strike length of over 5 km and constitute a stratigraphic marker from which reconstruction of the footwall facies relationships can be assembled (Fig. 3).

Rhyolites in the two high level intrusive domes exposed at South Main shaft are geochemically similar to the exogenous domes, breccias and hypabyssal intrusions exposed on Millrock Hill, and are not equivalent to Mine rhyolite. They contain multiple phases, defined in the field by variation in phenocryst abundance, that are geochemically distinguishable.

Geochemical similarity between Millrock Hill/Mine rhyolites and extension-related rhyolites suggests that these felsic rocks may owe their distinct compositions to high heat flows attending rifting of the footwall basalt sequence. This interpretation is consistent with the gross stratigraphic relationships exhibited in the stratigraphic footwall of the deposit (Fig. 3).

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APPENDIX A

Appendix A
Geochemical analyses of rhyolites from the central Flin Flon Belt

SAMPLE	UNIT	DESCRIPTION	SiO_2	TiO_2	Al_2O_3
Calc-alkaline arc					
52-87-1752-C1	Paradise rhyolite	Massive rhyolite lobe	81.58	0.34	10.75
52-87-1751-C1	Paradise rhyolite	Massive rhyolite lobe	76.57	0.37	10.70
52-87-1744-C1	Paradise rhyolite	Massive rhyolite lobe	70.67	0.46	13.89
52-87-1744-C2	Paradise rhyolite	Rhyolite breccia/hyaloclastite	70.02	0.46	13.00
52-87-1751-C2	Paradise rhyolite	Rhyolite breccia/hyaloclastite	67.87	0.59	14.23
52-87-1580-C1	Islands flow	Dacite	69.52	0.41	13.66
52-87-1576-C1	Islands flow	Andesite/dacite	71.34	0.41	12.83
52-87-1653-C1	Islands flow	Rhyolite	75.47	0.25	11.96
52-87-2421-C1	Bakers Narrows block rhyolite	massive rhyolite	75.37	0.28	12.65
52-87-2448-C1	Campground rhyolite	massive rhyolite	78.69	0.25	12.09
52-87-2419-C1	Campground rhyolite	massive rhyolite	76.34	0.25	11.61
52-79-1552-C1	Bear Lake block rhyolite	aphyric rhyolite	63.94	0.63	16.31
07-79-429-C1	Solodiuk Lake rhyolite	Massive, .5% qz phens	77.00	0.26	12.07
Tholeiitic arc					
52-95-293-A	FIA, Unit C, porph. rylt	porph. rrhyolite	75.88	0.18	11.86
52-84-6108-C1	Burley Lake rhyolite	Massive, 3% pg phens	85.71	0.14	7.39
52-91-771-A	Tee Lake rhyolite	Massive rhyolite	74.01	0.35	13.63
52-83-6228-C1	Hook Lake block rhyolite	Rhyolite, Schist Lake (Hook L. block)	84.73	0.18	9.16
52-86-433-1	Schist Lake rhyolite	Rhyolite, Schist Lake (NW Arm)	69.41	0.46	12.70
52-88-3414-C1	Hook Lake block rhyolite	Rhyolite, Schist Lake	70.80	0.34	11.90
Extension-related					
07-80-3438-C1	Grassy Narrows rhyolite	Rhyolite, massive lobe	80.89	0.12	10.44
07-80-3438-C2	Grassy Narrows rhyolite	Rhyolite hyaloclastite	76.51	0.14	14.52
07-80-3438-C3	Grassy Narrows rhyolite	Rhyolite hyaloclastite	78.13	0.17	12.75
07-80-3438-C4	Grassy Narrows rhyolite	Rhyolite, massive lobe	79.74	0.15	11.28
07-80-3438-C5	Grassy Narrows rhyolite	Rhyolite, massive lobe	79.52	0.13	11.46
07-80-3441-C1	Grassy Narrows rhyolite	Rhyolite, massive	77.05	0.12	11.76
07-79-453-C2	Two Portage Lake rhyolite	rhyolite crystal tuff; near bed top	74.88	0.17	12.37
07-79-453-C1	Two Portage Lake rhyolite	rhyolite crystal tuff; bed base	73.38	0.19	12.39
Flin Flon Mine					
52-97-M8	Millrock Hill rhyolites: het bx	qz phyric clast in heterolithologic breccia	83.28	0.09	9.53
52-97-M9	Millrock Hill rhyolites: het bx	qz phyric clast in heterolithologic breccia	81.34	0.14	10.22
52-97-M10	Millrock Hill rhyolites: het bx	qz phyric clast in heterolithologic breccia	84.40	0.08	8.87
52-97-M13	Millrock Hill rhyolites: dome	qz phyric clast in autoclastic breccia	80.54	0.10	11.73
52-97-M12	Millrock Hill rhyolites: dome	qz phyric clast in autoclastic breccia	83.17	0.08	9.44
52-97-M14	Millrock Hill rhyolites: massive	massive, weakly qz phyric rhyolite	81.29	0.09	10.94
52-97-M11	Millrock Hill rhyolites: dome	qz phyric massive rhyolite	78.09	0.15	14.06
52-97-M1	Millrock hill rhyolites: dyke	aphyric rhyolite dyke	80.18	0.09	12.11
52-97-M4	Millrock hill rhyolites: dyke	spherulitic rhyolite intrusion	79.99	0.10	9.30
52-97-M5	Millrock Hill rhyolites: lower flow	massive, qz phyric	80.59	0.21	10.41
52-97-M6	Millrock Hill rhyolites: lower flow	pumice breccia, qz phyric	78.76	0.23	11.64
52-97-N2	Mine rhyolite: base	massive clast/lobe	85.64	0.15	8.26
52-84-6139-C1	Mine rhyolite: base	Mine rhyolite; 2% pg and qz phens	83.74	0.18	8.66
52-97-N1	Mine rhyolite: base	basal qz phyric breccia	75.25	0.23	12.46
52-84-6141-C1	Mine rhyolite: main	massive, 5% qz, 3% pg	79.63	0.14	12.02
52-97-N3	Mine rhyolite: main	massive qz phyric Mine rhyolite	79.86	0.14	11.57
52-97-N4	Mine rhyolite: flow top	flow-banded clast in flow-top breccia	83.17	0.14	8.70
52-97-S5	South Main domes: NW	massive,qz phyric	78.40	0.21	11.67
52-97-S3	South Main domes: NW	massive qz phyric rhyolite	77.64	0.15	10.84
52-97-S4	South Main domes: NW	massive qz phyric rhyolite	76.01	0.11	13.25
52-97-S1	South Main domes: SE	coarsely qz phyric massive rhyolite	76.69	0.14	11.51
52-97-S2	South Main domes: SE	massive qz phyric rhyolite	81.42	0.09	10.79
07-83-7127-C1	South Main domes: SE	5% qz phens	78.65	0.09	11.97

* Major element analyses have been recalculated volatile-free

Appendix A (continued)
Geochemical analyses of rhyolites from the central Flin Flon Belt

SAMPLE	FeO	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SUM*	H_2O	CO_2	LOI
Calc-alkaline arc												
52-87-1752-C1	1.79		0.04	0.76	1.03	1.09	2.51	0.11	7.33	1.42	0.26	
52-87-1751-C1	2.85		0.08	0.95	3.24	4.67	0.43	0.12	12.36	0.80	1.74	
52-87-1744-C1	5.18		0.08	1.37	1.50	6.25	0.47	0.12	14.98	1.07	0.31	
52-87-1744-C2	6.13		0.10	2.46	2.00	4.03	1.69	0.11	16.52	1.52	0.24	
52-87-1751-C2	6.06		0.11	1.97	5.05	2.78	1.19	0.14	17.31	1.80	0.96	
52-87-1580-C1	5.95		0.11	2.20	1.35	4.24	2.43	0.13	16.41	1.18	0.14	
52-87-1576-C1	6.09		0.10	3.30	0.62	2.60	2.55	0.14	15.41	2.50	0.02	
52-87-1653-C1	3.26		0.06	0.93	1.28	4.10	2.65	0.05	12.32	0.88	1.60	
52-87-2421-C1	3.04		0.03	1.57	0.81	5.35	0.83	0.07	11.70	1.06	0.82	
52-87-2448-C1	1.34		0.03	0.40	0.62	4.93	1.58	0.06	8.96	0.66	0.32	
52-87-2419-C1	3.14		0.09	0.38	2.77	4.69	0.69	0.04	11.81	0.88	1.33	
52-79-1552-C1	4.58		0.07	2.15	3.75	8.06	0.26	0.24	19.12	0.82	0.15	
07-79-429-C1	1.51		0.02	0.54	0.56	2.81	5.12	0.10	10.66	0.52	0.44	
Tholeiitic arc												
52-95-293-A		3.61	0.06	0.60	2.45	4.25	1.03	0.06	12.08			
52-84-6108-C1	2.14		0.05	0.11	0.86	2.91	0.65	0.04	6.76	0.61	0.58	
52-91-771-A	2.62		0.05	0.45	3.23	4.42	1.16	0.08	12.01	0.82	1.29	
52-83-6228-C1	0.24		0.00	0.31	0.53	3.96	0.86	0.03	5.93	0.31	0.53	
52-86-433-1	6.67		0.14	1.95	2.93	4.71	0.85	0.17	17.43	1.12	6.31	
52-88-3414-C1	5.70		0.17	1.37	5.64	1.64	2.35	0.09	16.95	2.10	3.70	
Extension-related												
07-80-3438-C1	0.18		0.00	0.12	0.32	2.40	5.50	0.03	8.55	0.22	0.37	
07-80-3438-C2	1.17		0.02	1.59	0.50	0.70	4.83	0.01	8.83	1.73	0.38	
07-80-3438-C3	2.14		0.03	1.73	0.70	0.08	4.23	0.03	8.95	1.83	0.81	
07-80-3438-C4	1.38		0.02	0.67	0.67	5.69	0.37	0.03	8.83	0.48	0.69	
07-80-3438-C5	2.18		0.03	0.56	0.30	5.60	0.18	0.03	8.88	0.67	0.34	
07-80-3441-C1	2.00		0.02	1.36	0.91	0.54	6.22	0.03	11.07	1.08	1.24	
07-79-453-C2	2.45		0.04	1.01	1.19	3.11	4.73	0.05	12.58	0.82	0.86	
07-79-453-C1	5.43		0.12	1.13	1.57	3.23	2.49	0.06	14.04	1.60	0.64	
Flin Flon Mine												
52-97-M8		0.90	0.01	0.22	0.46	4.47	1.02	0.03	100.00			0.21
52-97-M9		1.81	0.03	0.60	0.71	4.35	0.78	0.02	99.99			0.65
52-97-M10		0.77	0.01	0.16	0.63	3.86	1.23	0.01	100.01			0.29
52-97-M13		0.67	-0.01	0.28	0.68	4.92	1.03	0.03	99.98			0.83
52-97-M12		1.23	0.02	0.34	1.03	3.84	0.81	0.01	99.99			0.90
52-97-M14		0.49	-0.01	0.27	0.76	5.28	0.86	0.01	99.98			1.02
52-97-M11		0.60	-0.01	0.21	0.89	3.28	2.71	0.01	99.99			1.72
52-97-M1		0.56	-0.01	0.24	1.74	3.08	1.95	0.02	99.97			1.38
52-97-M4		2.75	0.07	0.82	4.86	0.28	1.79	0.02	99.99			3.21
52-97-M5		1.55	0.04	0.16	2.99	2.48	1.53	0.03	100.00			1.80
52-97-M6		2.80	0.05	0.40	2.08	2.21	1.76	0.06	100.00			1.24
52-97-N2		0.50	0.02	0.08	0.95	3.90	0.44	0.08	100.02			0.63
52-84-6139-C1	2.25		0.06	0.13	1.46	2.36	1.14	0.03	7.43	0.81	0.88	
52-97-N1		4.05	0.10	0.50	3.07	1.73	2.59	0.04	100.02			3.58
52-84-6141-C1	0.75		0.03	0.01	1.04	5.96	0.40	0.01	8.20	0.28	0.70	
52-97-N3		1.00	0.02	0.10	0.76	6.29	0.23	0.03	100.00			0.73
52-97-N4		2.91	0.05	0.27	0.47	3.12	1.17	0.03	100.02			0.86
52-97-S5		2.15	0.03	0.13	1.42	5.36	0.57	0.05	100.00			1.18
52-97-S3		3.80	0.03	0.36	3.77	0.91	2.49	0.02	100.01			3.64
52-97-S4		2.20	0.02	0.47	3.33	1.29	3.30	0.03	100.01			3.55
52-97-S1		2.59	0.04	0.35	5.73	0.53	2.43	0.02	100.02			5.47
52-97-S2		0.73	0.02	0.23	3.41	0.83	2.47	-0.01	99.98			3.32
07-83-7127-C1	1.80		0.02	0.18	4.25	0.90	2.13	0.02	9.29	1.08	0.51	

Total iron shown as either FeO or Fe_2O_3

Appendix A (continued)
Geochemical analyses of rhyolites from the central Flin Flon Belt

SAMPLE	Ni	Cr	Sc	Co	Zn	V	Cu	Rb	Ba	Sr	Cs	U
Calc-alkaline arc												
52-87-1752-C1	1.6	1	13.2	38.6	42.1	30.0	22.8	29.3	202.5	92.6	0.36	0.48
52-87-1751-C1	1.6	1	14.0	39.7	36.8	10.1	19.9	4.2	71.1	162.9	0.06	0.66
52-87-1744-C1	0.7	0	17.7	37.9	71.5	26.4	37.6	3.3	83.4	81.8	0.03	0.67
52-87-1744-C2	1.2	0	20.9	36.5	66.6	26.5	42.0	15.8	448.1	137.0	0.48	0.58
52-87-1751-C2	2.4	3	23.3	32.5	74.5	43.6	44.5	15.3	297.7	317.2	0.25	0.69
52-87-1580-C1	0.4	0	18.4	22.9	59.9	17.4	26.9	25.6	389.2	62.5	0.16	1.22
52-87-1576-C1	0.6	0	20.4	30.0	85.6	6.4	32.2	29.2	447.5	53.9	0.34	1.04
52-87-1653-C1	1.2	1	12.7	36.3	52.3	3.6	28.3	29.2	630.5	50.9	0.28	1.65
52-87-2421-C1	0.9	0	15.0	33.8	30.6	5.1	53.0	8.7	247.8	104.0	0.07	1.04
52-87-2448-C1	1.1	1	11.9	39.7	93.7	1.3	17.0	22.7	287.3	85.6	0.42	1.24
52-87-2419-C1	1.5	1	14.1	36.2	69.1	4.7	29.7	10.3	308.9	186.6	0.28	1.65
52-79-1552-C1	20.0	68			23.0		11.0	4.0	71.0	375.0		
07-79-429-C1					32.0		283.0	57.0	1387.0	107.0		0.90
Tholeiitic arc												
52-95-293-A	10.2	5	19.5			35.7		19.7	267.0	145.6	0.76	0.42
52-84-6108-C1	1.2	1	8.9	71.6	31.4	2.7	14.8	10.0	158.4	58.4	0.11	0.62
52-91-771-A		9	10.1		16.7	8.7	13.1	14.0	216.2	142.7		
52-83-6228-C1	1.3	1	8.6	43.1	35.3	0.9	39.8	8.4	133.3	63.1	0.31	0.68
52-86-433-1	1.3	1	21.5	51.7	124.8	14.0	18.2	8.5	143.9	59.2	0.33	0.67
52-88-3414-C1	1.7	0	23.0	22.4	80.6	16.1	21.1	47.2	311.4	95.0	0.88	0.44
Extension-related												
07-80-3438-C1	0.8	0	3.2	47.2	36.2	0.8	2.8	60.0	1139.8	71.9	0.99	2.69
07-80-3438-C2	0.4	0	4.8	17.2	45.4	1.0	9.8	137.8	365.3	26.3	3.77	3.45
07-80-3438-C3	1.9	1	3.5	22.9	45.0	2.2	15.6	139.6	366.5	10.9	3.64	2.73
07-80-3438-C4	1.3	1	2.8	56.2	50.2	2.3	7.1	3.2	46.7	132.7	0.08	2.92
07-80-3438-C5	0.6	0	3.8	41.2	51.3	2.1	2.9	1.8	37.6	121.9	0.04	2.90
07-80-3441-C1	0.7	0	3.5	23.8	45.8	1.0	11.9	96.9	588.2	24.5	2.00	2.71
07-79-453-C2					29.0		12.0	66.0	677.0	151.0		
07-79-453-C1					28.0		6.0	39.0	730.0	125.0		
Flin Flon Mine												
52-97-M8	1.6	2	3.4	1.5	10.8	11.5	3.2	16.2	723.9	70.6	0.17	2.14
52-97-M9	2.2	1	7.3	3.5	99.0	23.9	11.4	5.1	649.1	54.6	0.20	2.37
52-97-M10	1.6	2	3.9	1.1	11.6	4.6	3.3	12.8	712.0	78.0	0.30	1.85
52-97-M13	3.0	7	3.6	1.1	118.3	9.1	5.2	11.8	258.8	31.9	0.02	2.45
52-97-M12	1.5	1	3.6	1.0	19.7	7.2	4.5	12.0	357.3	54.9	0.03	1.66
52-97-M14	3.4	2	3.9	1.0	49.7	7.6	8.0	11.7	136.9	42.1	0.20	3.00
52-97-M11	1.4	1	5.6	0.8	48.8	10.8	2.7	31.6	355.2	32.9	0.26	5.68
52-97-M1	2.5	2	3.0	1.3	6.7	7.5	2.6	25.6	260.2	59.7	0.12	1.90
52-97-M4	2.8	1	4.6	3.5	57.6	5.3	12.3	24.3	826.1	53.1	0.61	1.66
52-97-M5	2.8	1	9.7	1.6	102.7	1.2	3.9	21.9	277.4	65.0	0.31	1.34
52-97-M6	1.7	1	12.0	1.0	202.0	1.7	5.8	24.1	275.3	70.4	0.46	1.62
52-97-N2	1.0	1	8.3	0.7	18.9	0.4	23.1	4.4	198.2	37.4	0.62	1.05
52-84-6139-C1	0.8	0	10.7	67.5	40.8	0.6	2.6	14.2	305.9	57.6	0.07	1.05
52-97-N1	0.2	1	13.6	2.7	86.5	0.3	1.7	28.6	805.7	53.2	0.81	0.84
52-84-6141-C1	4.0	26	10.4		54.0	0.2	21.0	4.6	68.0	33.4	0.02	1.48
52-97-N3	1.1	2	9.1	1.0	16.6	0.4	2.1	4.2	82.5	57.8	0.72	1.69
52-97-N4	0.9	1	9.5	2.6	121.5	0.5	4.2	16.8	274.4	28.6	0.69	1.09
52-97-S5	1.7	1	13.5	1.5	37.8	0.9	13.6	7.7	174.3	58.1	0.03	1.10
52-97-S3	8.2	12	8.6	8.1	15.7	17.8	185.4	34.0	338.3	55.4	0.77	1.48
52-97-S4	3.8	1	4.5	4.9	24.3	5.3	14.7	40.7	215.6	51.4	0.20	2.00
52-97-S1	3.3	1	4.8	2.8	16.6	8.3	10.9	34.5	272.9	82.4	0.75	2.43
52-97-S2	3.0	1	4.1	2.1	10.7	5.2	32.1	31.7	315.0	78.2	0.76	2.79
07-83-7127-C1	0.5	0	4.2	32.4	11.8	1.6	10.9	32.2	272.8	95.2	0.29	1.87

Appendix A (continued)
Geochemical analyses of rhyolites from the central Flin Flon Belt

SAMPLE	Pb	Th	Bi	Zr	Y	Ta**	Hf	Nb	Li	Mo	La	Ce
Calc-alkaline arc												
52-87-1752-C1	1.4	1.39	0.03	58.1	15.5		1.47	1.64	10.1	0.87	6.75	14.96
52-87-1751-C1	3.4	1.34	0.06	60.7	15.9		1.53	2.23	9.0	0.97	6.53	14.88
52-87-1744-C1	3.8	1.57	0.06	74.7	17.3		2.05	3.15	7.3	1.09	8.99	18.67
52-87-1744-C2	5.5	1.53	0.05	75.4	18.6		2.03	2.85	19.8	0.89	9.35	18.25
52-87-1751-C2	2.8	1.73	0.07	81.7	20.9		2.18	4.50	25.7	1.11	8.95	19.65
52-87-1580-C1	4.8	3.45	0.07	86.2	18.6		2.18	3.89	15.4	0.95	15.08	28.55
52-87-1576-C1	11.5	3.06	0.05	82.2	18.7		2.08	5.38	22.9	1.68	13.11	27.51
52-87-1653-C1	2.2	5.69	0.03	127.9	23.6		3.34	5.66	4.9	0.76	18.51	38.21
52-87-2421-C1	4.2	2.74	0.17	84.6	19.9		2.15	5.02	15.8	1.47	8.46	19.31
52-87-2448-C1	2.0	3.26	0.06	95.9	20.8		2.35	2.23	1.2	0.88	11.35	25.91
52-87-2419-C1	6.2	5.32	0.11	120.4	24.8		3.13	6.51	6.5	0.88	20.40	40.36
52-79-1552-C1		3.07		143.6	26.9		4.02	7.19			11.93	29.57
07-79-429-C1		1.03		30.3	7.9		0.87	1.33			9.40	21.37
Tholeiitic arc												
52-95-293-A	3.1	0.84	0.12	45.7	16.4		1.26	2.15		1.56	6.18	14.25
52-84-6108-C1	3.3	1.18	0.60	47.9	16.8		1.11	1.11	0.0	186.15	7.09	15.60
52-91-771-A		1.59		98.8	18.1		3.03	5.21			8.17	18.95
52-83-6228-C1	1.9	1.28	0.04	84.4	20.8		2.22	3.84	6.5	1.33	8.21	18.62
52-86-433-1	3.3	1.17	0.05	66.6	21.4		1.80	2.78	18.2	1.24	7.79	17.32
52-88-3414-C1	1.4	0.72	0.05	74.0	29.0		2.17	2.71	17.1	1.24	7.12	16.25
Extension-related												
07-80-3438-C1	13.4	7.78	0.15	114.5	26.5		3.24	1.76	2.3	1.33	25.63	52.75
07-80-3438-C2	3.4	10.74	0.31	186.1	45.1		5.78	11.01	30.2	0.86	34.76	72.66
07-80-3438-C3	1.9	9.82	0.15	237.6	47.9		6.64	16.69	17.6	0.76	30.11	68.59
07-80-3438-C4	3.8	9.08	0.19	219.5	52.9		5.94	13.00	3.8	2.72	35.82	78.02
07-80-3438-C5	3.0	9.83	0.18	240.0	57.3		6.54	8.61	15.1	1.76	43.54	91.90
07-80-3441-C1	7.0	11.20	0.19	219.6	59.1		6.79	10.81	15.0	1.00	43.82	91.51
07-79-453-C2		7.02		243.6	66.9		3.61	18.60			24.43	56.12
07-79-453-C1				263.0	82.0							
Flin Flon Mine												
52-97-M8	3.1	2.74	0.07	128.2	26.3	0.22	3.47	4.01	1.8	0.40	8.98	22.41
52-97-M9	4.3	2.91	0.14	152.8	33.9	0.32	4.05	4.69	5.1	0.79	12.59	27.83
52-97-M10	4.8	2.66	2.79	107.5	42.3	0.21	3.58	3.41	0.4	2.33	12.06	27.15
52-97-M13	3.7	3.26	0.03	152.4	37.9	0.27	4.56	4.83	2.2	0.22	16.27	38.38
52-97-M12	2.0	2.87	0.09	122.8	44.7	0.22	3.81	3.89	1.6	0.26	11.85	30.13
52-97-M14	8.3	3.14	0.17	133.7	52.3	0.33	4.19	4.72	3.9	0.45	14.27	29.41
52-97-M11	4.7	3.52	0.03	187.3	55.9	0.33	5.15	5.89	5.0	0.31	17.04	36.55
52-97-M1	2.2	3.72	0.09	175.0	36.5	0.35	5.13	5.54	4.2	0.47	17.08	37.28
52-97-M4	3.6	3.31	0.11	134.7	48.5	0.20	3.76	3.88	9.4	0.31	14.21	31.38
52-97-M5	3.2	1.57	0.11	77.9	33.0	0.14	2.30	2.68	5.2	0.30	9.63	21.89
52-97-M6	4.7	1.84	0.02	94.2	41.3	0.16	2.62	3.21	8.0	0.88	11.06	25.16
52-97-N2	3.6	1.17	0.11	61.3	23.4	0.11	1.88	2.22	1.4	0.34	6.62	14.40
52-84-6139-C1	2.9	1.29	0.02	60.9	24.8		1.54	1.29	9.0	1.68	6.72	15.42
52-97-N1	3.0	1.67	0.09	90.9	35.5	0.15	2.60	3.21	9.7	0.52	11.80	26.73
52-84-6141-C1	2.1	1.80	0.05	109.4	26.6		3.56	3.93	1.4	0.89	9.65	22.25
52-97-N3	1.7	1.86	0.02	118.4	32.9	0.20	3.65	3.47	1.7	0.27	14.74	33.52
52-97-N4	3.2	1.75	0.08	115.1	31.9	0.17	3.22	3.67	6.1	0.19	2.53	5.73
52-97-S5	2.6	1.52	0.05	87.8	27.5	0.15	2.53	2.73	1.8	0.68	10.89	23.89
52-97-S3	2.6	2.79	0.32	135.2	33.6	0.24	3.93	3.86	2.1	0.33	11.63	23.60
52-97-S4	3.4	3.59	0.19	160.7	53.4	0.30	4.84	5.09	2.7	0.59	16.40	36.54
52-97-S1	3.1	2.61	0.05	136.7	36.9	0.22	4.00	3.94	6.4	0.33	14.88	31.26
52-97-S2	6.2	3.22	0.12	128.1	38.2	0.26	4.26	4.68	2.2	0.34	14.51	34.71
07-83-7127-C1	5.9	3.40	0.07	137.7	61.2		4.00	5.50	9.2	1.97	16.99	37.27

** Ta reported only for samples pulverized in an agate mill

Appendix A (continued)
Geochemical analyses of rhyolites from the central Flin Flon Belt

SAMPLE	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Calc-alkaline arc												
52-87-1752-C1	1.90	8.15	2.10	0.51	2.38	0.41	2.55	0.54	1.63	0.25	1.61	0.24
52-87-1751-C1	1.94	8.13	2.11	0.53	2.34	0.40	2.64	0.57	1.64	0.26	1.69	0.25
52-87-1744-C1	2.43	10.71	2.66	0.69	3.00	0.49	3.31	0.69	2.00	0.30	1.92	0.28
52-87-1744-C2	2.30	9.82	2.48	0.77	2.93	0.48	3.16	0.70	2.06	0.31	2.15	0.33
52-87-1751-C2	2.56	11.24	2.97	0.87	3.29	0.55	3.61	0.77	2.24	0.34	2.14	0.34
52-87-1580-C1	3.43	14.07	3.01	0.85	3.10	0.49	3.14	0.70	2.13	0.32	1.99	0.31
52-87-1576-C1	3.33	13.33	2.99	0.74	3.23	0.51	3.27	0.67	1.97	0.30	1.95	0.29
52-87-1653-C1	4.57	17.98	3.84	0.81	3.89	0.65	4.22	0.92	2.71	0.42	2.86	0.43
52-87-2421-C1	2.48	10.68	2.67	0.74	3.04	0.52	3.51	0.76	2.21	0.33	2.18	0.34
52-87-2448-C1	3.35	14.14	3.51	0.94	3.57	0.59	3.87	0.80	2.28	0.34	2.20	0.33
52-87-2419-C1	4.90	19.06	4.24	0.95	4.20	0.70	4.54	0.98	2.84	0.45	2.98	0.45
52-79-1552-C1		18.21	4.71	0.89	4.72		5.07		3.16		2.91	0.48
07-79-429-C1		12.28	2.60	0.51	2.27		1.96		0.90		0.76	0.11
Tholeiitic arc												
52-95-293-A	1.92	9.10	2.29	0.65	2.37	0.40	2.64	0.61	1.86	0.32	1.98	0.29
52-84-6108-C1	2.05	8.82	2.15	0.47	2.32	0.42	2.83	0.64	1.94	0.30	2.06	0.30
52-91-771-A		10.77	2.73	0.80	2.81	0.44	2.90	0.62	1.90	0.30	1.92	0.32
52-83-6228-C1	2.52	11.28	2.88	0.74	3.27	0.56	3.81	0.83	2.39	0.37	2.30	0.34
52-86-433-1	2.32	10.61	2.89	0.76	3.09	0.52	3.68	0.83	2.44	0.38	2.50	0.39
52-88-3414-C1	2.31	10.85	3.28	0.99	4.05	0.72	5.07	1.13	3.31	0.53	3.49	0.52
Extension-related												
07-80-3438-C1	6.35	24.24	5.49	0.75	5.21	0.88	5.25	1.02	2.92	0.42	2.43	0.35
07-80-3438-C2	9.02	34.49	7.96	0.99	7.95	1.31	8.52	1.74	5.13	0.79	4.94	0.71
07-80-3438-C3	8.67	34.33	8.03	1.24	7.76	1.39	9.22	1.95	5.77	0.91	5.76	0.86
07-80-3438-C4	9.83	39.48	8.60	1.30	8.56	1.42	9.31	2.02	5.96	0.92	6.03	0.86
07-80-3438-C5	11.57	45.53	9.63	1.54	9.25	1.51	9.97	2.12	6.39	1.00	6.52	0.93
07-80-3441-C1	11.41	45.46	10.21	1.75	10.10	1.73	11.04	2.34	6.77	1.05	6.88	0.95
07-79-453-C2		34.50	8.26	1.18	9.70		12.34		7.99		8.32	1.28
07-79-453-C1												
Flin Flon Mine												
52-97-M8	3.01	12.38	3.04	0.32	3.48	0.63	4.51	1.05	3.48	0.59	4.14	0.63
52-97-M9	3.55	15.35	3.86	0.42	4.58	0.81	5.98	1.39	4.62	0.76	5.44	0.85
52-97-M10	3.45	14.86	3.70	0.36	4.67	0.87	6.45	1.54	5.08	0.84	5.91	0.92
52-97-M13	5.03	20.57	4.92	0.42	5.59	0.96	6.97	1.58	5.02	0.84	5.87	0.92
52-97-M12	3.94	15.93	4.10	0.39	4.85	0.90	6.67	1.58	5.25	0.86	6.11	0.96
52-97-M14	3.71	15.37	3.90	0.42	5.09	0.99	7.45	1.82	6.15	1.01	7.22	1.13
52-97-M11	4.79	20.87	5.48	0.56	7.09	1.28	9.40	2.12	6.80	1.10	7.51	1.12
52-97-M1	4.69	19.13	4.94	0.39	5.37	0.94	6.54	1.44	4.61	0.76	5.49	0.82
52-97-M4	4.03	17.18	4.54	0.78	5.68	1.00	7.31	1.66	5.41	0.83	5.79	0.90
52-97-M5	3.03	13.84	3.75	0.98	4.41	0.78	5.51	1.23	3.68	0.55	3.60	0.52
52-97-M6	3.49	15.85	4.35	1.14	5.40	0.90	6.72	1.54	4.94	0.77	5.40	0.83
52-97-N2	1.95	8.78	2.47	0.42	3.10	0.54	3.88	0.89	2.76	0.43	2.89	0.45
52-84-6139-C1	2.12	9.23	2.62	0.56	3.19	0.60	4.39	1.00	3.11	0.51	3.44	0.51
52-97-N1	3.69	16.60	4.57	1.07	5.39	0.92	6.62	1.49	4.73	0.77	5.47	0.86
52-84-6141-C1		13.35	3.76	0.93	4.36		5.23	1.13	3.56		4.15	0.69
52-97-N3	4.67	21.01	5.50	1.23	6.08	1.01	6.69	1.46	4.33	0.69	4.72	0.72
52-97-N4	0.82	3.86	1.59	0.41	2.96	0.63	5.23	1.30	4.34	0.73	5.26	0.88
52-97-S5	3.24	14.72	3.90	1.28	4.53	0.76	5.21	1.15	3.36	0.53	3.49	0.52
52-97-S3	2.93	12.02	2.96	0.45	3.68	0.65	4.99	1.19	4.00	0.67	4.69	0.75
52-97-S4	4.66	19.30	4.88	0.46	5.88	1.09	8.20	1.95	6.48	1.11	7.80	1.23
52-97-S1	4.01	16.87	4.16	0.72	4.86	0.85	6.47	1.48	4.80	0.77	5.42	0.84
52-97-S2	4.52	18.12	4.39	0.45	5.14	0.90	6.43	1.48	4.86	0.81	5.67	0.89
07-83-7127-C1	4.77	19.45	5.09	0.46	6.33	1.30	9.38	2.27	7.23	1.23	8.37	1.26

Appendix A (continued)
Geochemical analyses of rhyolites from the central Flin Flon Belt

SAMPLE	P	Ti	Sn	Sb	Tl	ZONE	EASTING	NORTHING
Calc-alkaline arc								
52-87-1752-C1	0.22	357	1741	0.6	240.7	14	331065	6057569
52-87-1751-C1	0.35	489	2026	0.6	186.5	14	331024	6057486
52-87-1744-C1	0.38	439	2705	2.3	184.0	14	330722	6057718
52-87-1744-C2	0.37	455	2604	2.7	193.2	14	330722	6057718
52-87-1751-C2	0.33	525	3124	0.9	116.6	14	331024	6057486
52-87-1580-C1	0.41	277	1538	0.9	170.4	14	330171	6060883
52-87-1576-C1	0.35	514	2376	1.0	172.9	14	330355	6061168
52-87-1653-C1	0.58	205	1375	1.7	184.7	14	329373	6059618
52-87-2421-C1	0.37	201	1207	0.8	163.7	14	330370	6063086
52-87-2448-C1	0.41	238	1533	0.9	305.3	14	327983	6061051
52-87-2419-C1	0.60	122	1446	1.6	239.1	14	328139	6060737
52-79-1552-C1						14	327048	6068354
07-79-429-C1						14	326403	6070267
Tholeiitic arc								
52-95-293-A								
52-84-6108-C1		140	875	0.7	532.0	14	316735	6067126
52-91-771-A						14	379443	6085268
52-83-6228-C1		153	1134	1.1	354.9	14	320025	6059800
52-86-433-1		631	2432	1.0	283.8	14	318969	6062805
52-88-3414-C1	0.56	346	1846	0.8	94.5	14	320016	6060025
Extension-related								
07-80-3438-C1		12	542	3.6	304.6	14	323238	6075193
07-80-3438-C2		0	543	5.1	91.8	14	323235	6075190
07-80-3438-C3		19	817	5.1	111.5	14	323233	6075194
07-80-3438-C4		34	862	4.2	312.1	14	323238	6075199
07-80-3438-C5		0	713	2.8	233.0	14	323239	6075193
07-80-3441-C1		4	708	6.2	112.9	14	323187	6075478
07-79-453-C2						14	326890	6071074
07-79-453-C1						14	326888	6071072
Flin Flon Mine								
52-97-M8		23	523	0.7	0.1			
52-97-M9		54	911	1.8	0.2			
52-97-M10		25	473	1.7	0.1			
52-97-M13		23	627	1.5	0.3			
52-97-M12		24	495	1.2	0.2			
52-97-M14		40	540	1.3	34.7			
52-97-M11		25	869	1.9	0.6			
52-97-M1		43	561	1.0	0.8			
52-97-M4		21	582	1.3	0.2			
52-97-M5		1228	1	0.2	0.1			
52-97-M6		126	1358	0.9	0.3			
52-97-N2		78	929	0.7	0.3			
52-84-6139-C1		90	1069	0.7	482.8	14	314217	6073309
52-97-N1		109	1259	1.1	0.5			
52-84-6141-C1						14	314245	6073357
52-97-N3		46	845	1.2	0.1			
52-97-N4		36	875	1.2	0.2			
52-97-S5		22	1315	1.1	0.8			
52-97-S3		104	908	1.0	0.9			
52-97-S4		21	666	1.6	2.8			
52-97-S1		83	762	1.7	2.5			
52-97-S2		42	597	1.3	1.1			
07-83-7127-C1		0	478	1.5	228.7	14	314784	6071500