PRELIMINARY LITHOGEOCHEMISTRY AND POLYMETALLIC VHMS MINERALIZATION IN EARLY DEVONIAN AND(?) EARLY CARBONIFEROUS VOLCANIC ROCKS, FOREMORE PROPERTY

By James Logan

KEYWORDS: gold-enriched, polymetallic VHMS, Devono-Mississippian, Kuroko, Stikine assemblage, U-Pb dates, NWBC

INTRODUCTION

The recent discovery on the Foremore property of new VHMS mineralization that contains significant precious metal values has caused resurgence in the exploration interests of Paleozoic volcanic rocks in northern British Columbia. VHMS deposits are well documented in Devonian and Early Carboniferous volcanic sequences at the Kudz Ze Kayah and Wolverine deposits in the southern Yukon (Yukon-Tanana terrane) and at the Tulsequah Chief deposit in northern British Columbia (Stikine terrane). Devono-Mississippian rocks of the Stikine terrane also host polymetallic mineralization at the Foremore property (Fig. 1).

The Foremore project is a private-public partnership developed between the Ministry of Energy and Mines and Roca Mines Inc. The main objectives of the project are: to isolate the felsic magmatic and carbonaceous sedimentary interval(s) that are associated with the massive sulphide mineralization and identify their ages and positions within the volcanic stratigraphic on the property, establish the chemical affinity of the felsic units (extrusive and/or subvolcanic) to evaluate their prospectivity, and test the hypothesis that the different styles of mineralization (syngenetic, massive/laminated and epigenetic, carbonate replacement) represented by float boulders in the north, south and eastern parts of the property are genetically linked through a single mineralizing event or represent multiple events and finally to establish a tectonic and metallogenic model that can direct VHMS exploration to prospective strata within the remnant Paleozoic volcano-plutonic belt of rocks.

REGIONAL GEOLOGICAL SETTING

The study area straddles the boundary between the Intermontane Belt and the Coast Belt and is underlain mainly by rocks of the Stikine Terrane (Stikinia), the westernmost terrane of the Intermontane Superterrane (Fig. 1). Like other terranes of the North American Cordillera, its pre-Jurassic geological history, paleontological and paleomagnetic signatures are unique. They have been interpreted to indicate that the Stikine Terrane originated far removed from the margin of ancestral North America (Gabrielse and Yorath, 1991) and was amalgamated with the Cache Creek, Quesnel and Slide Mountain terranes prior to accretion to the North American craton (Fig. 1).

Recent studies suggest that the Stikine terrane developed adjacent to the ancestral margin of North America (McClelland, 1992; Mihalynuk et al., 1994; Gunning 1996) and that parts of the Paleozoic Stikine assemblage are correlative with and depositionally tied to Paleozoic rocks of the Yukon-Tanana Terrane. Depositional ties between the Quesnel and Yukon-Tanana terranes are also known and this together with the hook-like geometry of the 0.706 initial 87Sr/86Sr line around the northern end of Stikinia (Fig. 1) led Nelson and Mihalynuk (1993) and Mihalynuk et al. (1994) to propose a single arc model consisting of the Quesnel, Yukon Tanana, Nisling and Stikine terranes.

The distribution of Devono-Mississippian VHMS camps for British Columbia, Yukon and parts of Alaska (Fig. 1) define a similar hook-like geometry that closely follows the contact between the ancient Pacific margin terranes (Kootenay-Yukon-Tanana-Nisling) or their displaced equivalents, and the allochthonous (?) island-arc terranes (Quesnellia-Stikinia). Deposits and occurrences include Homestake, Samatosum (Eagle Bay), Kudz Ze Kayah and Wolverine (Finlayson Lake district), Bonnington and Delta districts (Alaska), Tulsequah Chief and Big Bull, Foremore and Ecstall. Deposits of Wrangellia-Alexander terranes (*i.e.* Myra Falls) are not shown. The Devono-Mississippian deposits have characteristics of the Kuroko/Noranda subclass of volcanic-hosted massive sulphide deposits (VHMS) that typically form within, or behind oceanic- or continental margin-arc settings undergoing rifting or local extension (Sawkins, 1990; Hoy, 1991; Lentz, 1998). The Kuroko/Noranda or polymetallic VHMS subclass are major producers of Cu, Zn, Ag, Au and Pb in Canada and worldwide and constitute important exploration targets in Devono-Mississippian volcanic rocks of northern British Columbia.

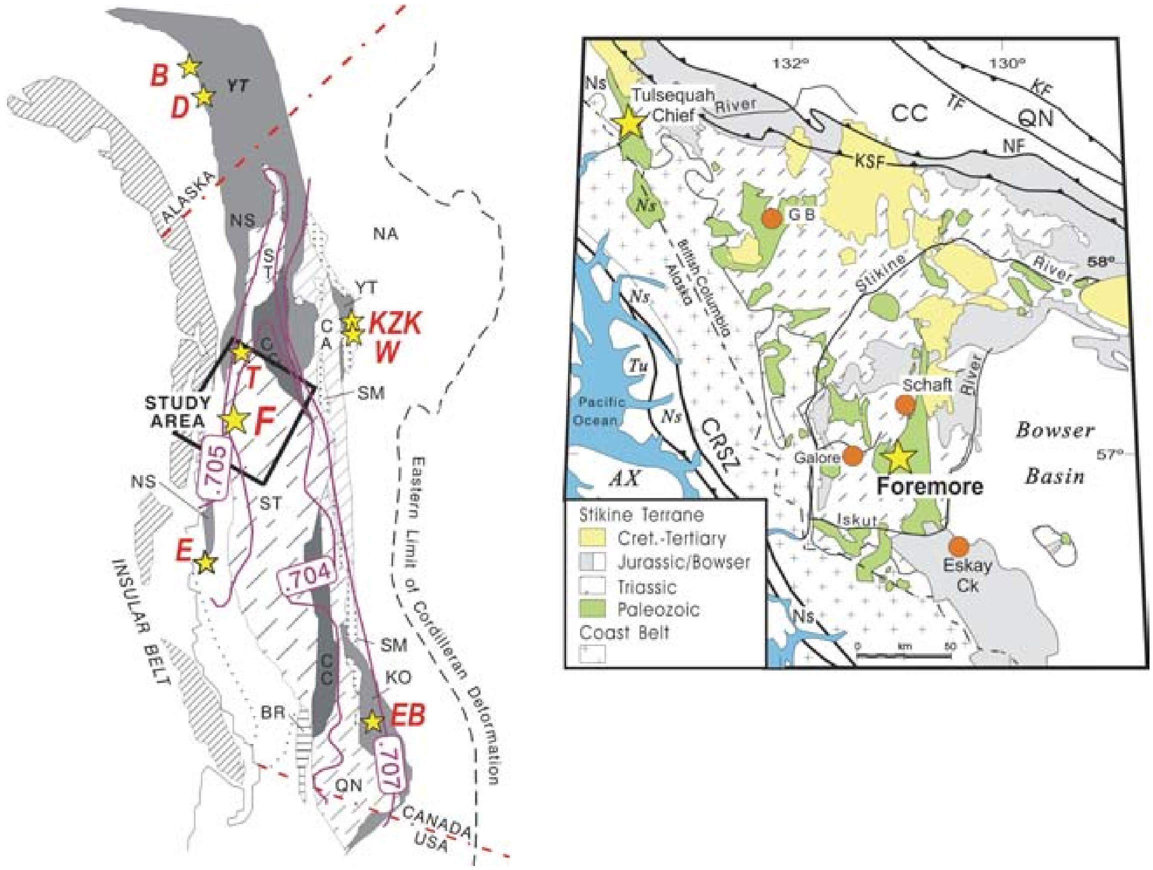


Figure 1. (a) Terrane map showing tectonostratigraphic setting of the study area and the location of Devono-Mississippian VHMS deposits. EB=Eagle Bay deposits, W=Wolverine, KZK=Kudz Ze Kayah, B=Bonnington district, D=Delta district, T=Tulsequah, F=Foremore, E=Ecstall. Mesozoic initial strontium isopleths from Armstrong (1988). NA=Ancestral North America, CA=Cassiar, NS=Nisling, KO=Kootenay, SM=Slide Mountain, QN=Quesnellia, CC=Cache Creek, ST=Stikinia, BR=Bridge River, YT=Yukon Tanana (modified from Wheeler and McFeely, 1991). (b) Inset shows location of study area relative to the major tectonostratigraphic features of the northwestern Cordillera, regional distribution of Paleozoic, Triassic, Jurassic and Cretaceous-Tertiary rocks of Stikinia and regionally significant mineral occurrences. AX=Alexander Terrane, TU=Taku Terrane, Ns=Nisling Terrane, CRSZ=Coast Range Shear Zone, KSF=King Salmon Fault, NF=Nahlin Fault, TF=Thibert Fault, KF=Klinkit Fault.

The stratigraphic and plutonic framework of northwestern Stikinia is summarized by Anderson (1993), Gunning (1996) and Logan (2000). It consists of a Paleozoic to Mesozoic sedimentary and volcano-plutonic arc assemblage that includes: the Devonian to Permian Stikine assemblage, the Late Triassic Stuhini Group and the Early Jurassic Hazelton Group. These are overlain by Middle Jurassic to early Tertiary successor-basin sediments of the Bowser Lake and Sustut Groups, Late Cretaceous to Tertiary continental volcanic rocks of the Sloko Group, and Late Tertiary to Recent bimodal shield volcanism of the Edziza and Spectrum ranges.

PALEOZOIC STIKINE ASSEMBLAGE

Rocks of the Stikine assemblage are the structurally and stratigraphically lowest supracrustal rocks observed in the study area. Stikine assemblage rocks were informally named by Monger (1977) to include all upper Paleozoic rocks (within Stikinia) that cropped out around the periphery of the Bowser Basin. The assemblage consists of Permian, Upper Carboniferous, Lower Carboniferous and Devonian age strata and plutons. The dominant lithologies are calcalkaline, mafic and bimodal flows and volcaniclastics, interbedded carbonate, minor shale and chert. The Permian carbonates and volcanics are a distinctive part of the Stikine assemblage, traceable for over 500 kilometres from the Taku River to south of Terrace, but the Devonian and Carboniferous volcanic rocks have the highest potential to host polymetallic VHMS deposits (Fig. 1).

The Late Paleozoic history of Stikinia comprises three volcanic cycles: Early Devonian, Early Carboniferous and Late Carboniferous separated by three intervening sedimentary cycles (Logan and Koyanagi, 1994; Gunning, 1996). A composite stratigraphic section of the Stikine assemblage is presented which includes five main subdivisions (Fig. 2). From the oldest to the youngest, they are: (I) an Early to Middle Devonian

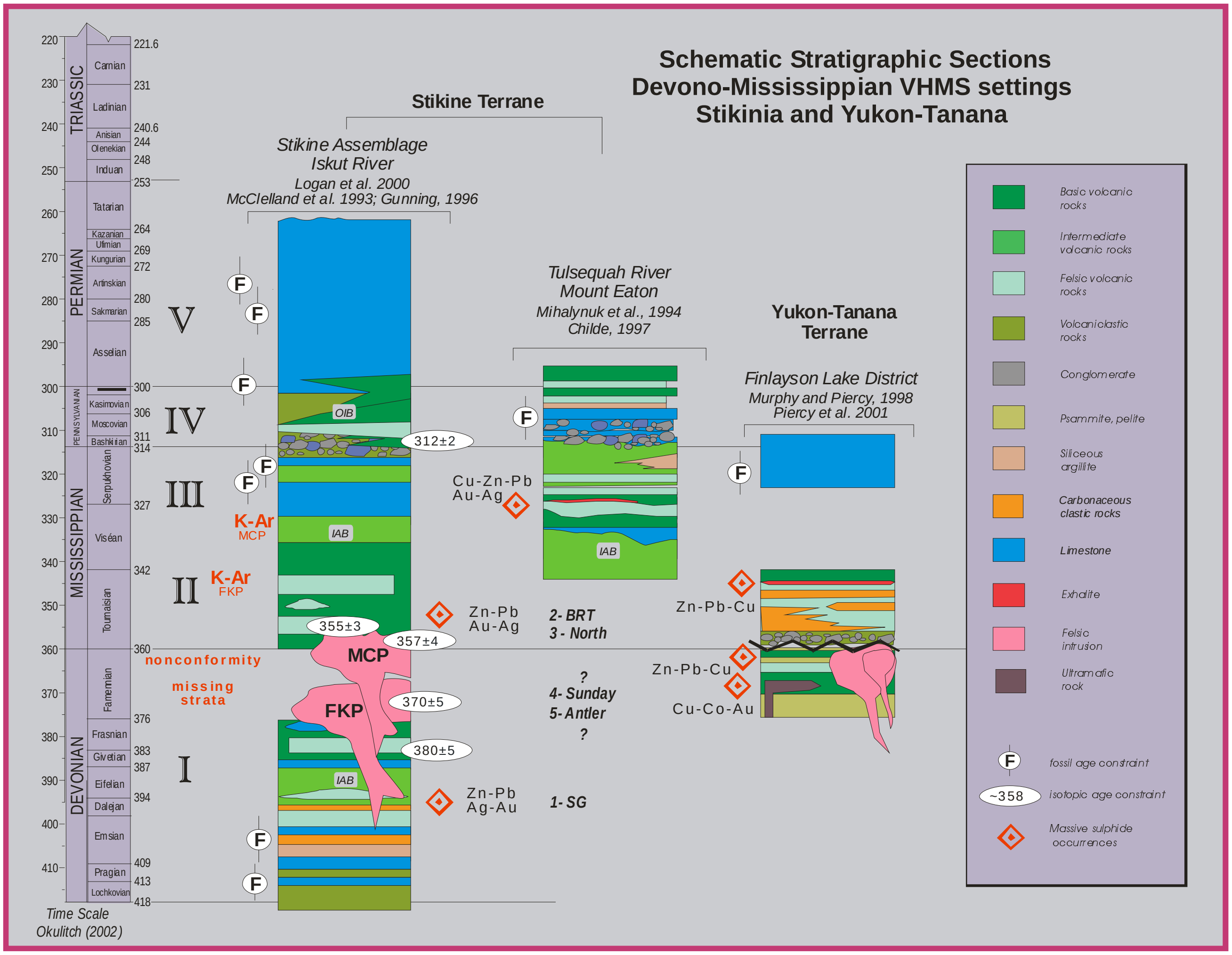


Figure 2. Schematic Late Paleozoic Stratigraphic columns for northwest Stikine terrane; Forrest Kerr-Mess Lake and Tulsequah River areas, British Columbia and one for the Yukon-Tanana terrane; Finlayson Lake district, Yukon. Sources referenced on Figure.

package of penetratively deformed, intermediate to mafic metavolcanic tuff, flows, diorite and gabbro, recrystallized limestone, graphitic schist, rhyolite and quartz sericite schist; (II) an Early Carboniferous package of bimodal mafic and felsic volcanic flows and tuffs; (III) a mid Carboniferous echinoderm-rich limestone and cherty tuff unit, which overlies the Early Mississippian volcanic flows and clastic rocks along the northern edge of the Andrei Glacier; (IV) Late Carboniferous to Early Permian aphyric basalt, limestone and intermediate to felsic tuffs and flows and (V) thick Early Permian carbonate that forms the top of the Paleozoic section north of the study area. Early and middle Devonian macro- and microfossils from the carbonates interlayered with the sedimentary and volcanic rocks constrain ages for Division I. Missing or unrecognized from the section are Late Devonian stratified rocks, although magmatism during this period is evident from Late Devonian composite diorite-tonalite plutons. Intrusion of an Early Carboniferous (Tournaisian) 355±3Ma U/Pb zircon age from waterlain felsic tuff located above Devonian limestone (Logan *et al.*, 2000) and Early and mid Carboniferous U/Pb zircon ages (345±5 Ma and 319±3Ma, Friedman, in Gunning, 1996) from intermediate to felsic crystal tuffs sampled below and above mid-Carboniferous fossil-rich limestone (Division III) constrain the age of the second volcanic cycle (Fig. 2). Coeval, in part comagmatic intrusive episodes include the Early Mississippian More Creek plutons. The Late Carboniferous volcanic cycle is constrained by an early Late Carboniferous (Bashkirian) 312±2Ma U/Pb zircon age and Mid-Carboniferous microfossils from stratigraphically lower carbonate units and Early Permian microfossils from carbonate units which depositionally overlie the volcanic rocks (Fig. 2).

In general, the Foremore property is underlain by a primitive calcalkaline suite of volcanic rocks, and fine-grained sedimentary and carbonate rocks that range in age from Early Devonian to mid Carboniferous. It is flanked on the east and south by two synvolcanic and comagmatic plutons, the Late Devonian Forrest Kerr and Early Mississippian More Creek bodies. These composite plutons (each ~250 km^2) comprise a peraluminous felsic phase, which ranges from biotite granodiorite to biotite tonalite and trondhjemite, and an older metaluminous mafic phase of mainly hornblende monzodiorite and gabbro composition. Initial $^{87}Sr/^{86}Sr$ values from the diorite and tonalite phases range between 0.7039 to 0.7043 and suggest a relatively primitive magma source region; consistent with the juvenile Nd-isotopic signatures from the felsic phases (unpublished data) and lack of inheritance patterns in zircon. Proterozoic inheritance in zircons at Tulsequah indicate a north and westward transition from an intraoceanic-setting to one either underlain by pericratonic crust or continent-derived sediments, similar to the modern Aleutian Arc.

STRATIGRAPHY AND LITHOGEOCHEMISTRY

Three distinct episodes of mafic volcanism are recognized within the Stikine assemblage: Early Devonian, Early Carboniferous and Late Carboniferous. Representative samples of these volcanic cycles were collected during the current study. Fifteen samples collected during regional mapping in 1990-1992 (Logan et al., 2000) were re-analyzed with the current samples to augment the current database and characterize the regional volcanic stratigraphy and discriminate the tectonic setting in which they formed.

Samples were steel milled at the British Columbia Geological Survey Branch Laboratory in Victoria. Splits were shipped for analyses to: Cominco-Teck Laboratories, Vancouver for major element and trace element abundances (Ba, Rb, Sr, Nb, Zr and Y) by X-ray fluorescence (XRF); to ACME analytical Labs, Vancouver for trace element analyses using inductively coupled plasma emission spectrometry (ICP-ES); and to Memorial University, Newfoundland for trace element analyses using inductively coupled plasma mass spectrometry (ICP-MS).

Due to the highly mobile nature of the alkalis (Na, Ca and K), SiO_2 and Mg particularly during hydrothermal alteration and metamorphism much of the preliminary data set was culled and the following characterization of geochemical data relies primarily on alteration-insensitive immobile element ratios (with the exception of TiO_2 and Al_2O_3. Only select elements and ratios are presented in this paper (Tables 1, 2 and 3).

In the region around the Foremore property, lithogeochemistry indicates a mainly calcalkaline assemblage of submarine autoclastic basalt, pillowed basalt, tuff and cherty argillite (Unit 1 and 2), that is overlain disconformably by an alkaline assemblage of autoclastic basalt and pillowed basalt (Unit 3). The lithogeochemical and stratigraphic relationships between Unit 1 and 2 are equivocal and may also be separated by nonconformable relationships.

UNIT 1

Early Devonian (Lochkovian and Emsian) cherty carbonaceous argillite, fossiliferous limestone and chert pebble conglomerate are the oldest known rocks in Stikinia. This predominantly fine grained sedimentary package is characterized by dark black, green and white, well-bedded siltstone, sandstone, tuffaceous siltstone and ash tuff that form the basement to an unknown thickness of Early to middle Devonian volcanic rocks in the More Creek area. A single U/Pb zircon age of 380±5 Ma from felsic tuffs in the Forrest Kerr area indicates local volcanism. Maroon feldspar phyric volcaniclastic and epiclastic units underlie the fossiliferous Devonian limestone and much of lower portions of the Hanging valley on the Foremore property. This intermediate volcanic package is composed of a sequence of coarse-grained heterolithic volcaniclastic rocks, that vary from coarse cobble sized angular to sub-rounded, poorly sorted debris flows to fine-grained graded sandstones. Interlayered are well-bedded and commonly normal graded crystal tuffs.

In the vicinity of the SG mineralized zone the volcaniclastic rocks form the base of an upward fining and upright interpreted sequence defined by Oliver (2003) as follows: the base of the section is a thick, poorly-bedded heterolithic maroon volcaniclastic conglomerate with lesser fine-grained epiclastic units that are overlain by approximately 100m of basic flows and volcaniclastic rocks. Above the mafic volcanic rocks are approximately 100m of fine-grained phyllite, tuffite and limestone that have been intruded and inflated by basic sills and dikes. Overlying the sedimentary rocks are felsic tuffs (which host the Au-Ag-Pb-Zn±Cu mineralization) and massive felsic flows that together comprise less than 100m. A heterolithic (pyrite clast bearing) breccia unit, recognized only in float is postulated to overlie the felsic flows. The uppermost package consists of well-bedded volcanic siltite and sandstone, volcaniclastic rocks and sills that lie unconformably above the felsic volcanic rocks and are interpreted to be Triassic age (Barnes, 1989; Oliver, 2003).

Fewer lithogeochemical samples from this unit were collected due to its generally higher degree of alteration and deformation and because it is comprised primarily of heterolithic volcaniclastic units that are less desirable samples to use when characterizing rock chemistry. Rhyolite at the SG zone was sampled and is described below with Unit 2 felsic rocks

UNIT 2

Early Carboniferous volcanic rocks are well described for the More Creek area (Logan et al., 1992; Gunning, 1996; Logan et al., 2000). The base of the section (355±3 Ma waterlain felsic tuff) is located on a

Subgroup	Basalt Unit 2	Average	Basalt Unit 3	Average
Mg#	35.8-67.6	(45.9)	43.8-56.8	(51.53)
SiO2	46.98-57.54	(54.16)	43.3-57.68	(50.89)
TiO2	0.96-1.39	(1.16)	0.84-3.41	(2.4)
Na2O	2.87-6.23	(5.12)	4.12-6.11	(4.56)
K2O	0.52-1.65	(1.0)	0.55-2.51	(1.47)
La/Yb_{CN}	1.70-3.15	(2.2)	10.40-14.25	(12.5)
Zr/Y	1.82-3.83	(2.53)	7.83-11.71	(10.4)
Th/Yb	0.37-0.82	(0.58)	1.1-1.73	(1.36)
Zr	39.0-75.9	(56.6)	232-329	(269)
Nb	<3-5	(3.25)	24-75	(49.8)

CN = normalized to Chondrite values.

Table 1. Selected element concentrations and ratios for Early Carboniferous basalt and basaltic andesites (Unit 2) and Late Carboniferous basalts and trachyandesites (Unit 3). Values in brackets are average values.

Subgroup	Rhyodacite(2)	Average	Rhyolite A (1)	Average	Rhyolite B (2)	Average
SiO2	65.3-67.5	(65.5)	73.62-80.19	(76.25)	72.27-78.88	(74.05)
Na2O	4.05-8.0	(6.03)	2.25-2.64	(2.48)	2.80-6.94	(4.56)
K2O	1.51-1.96	(1.7)	1.45-3.23	(2.23)	1.26-1.64	(1.51)
La/Yb_{CN}	6.60-8.54	(7.57)	4.12-5.22	(4.69)	1.36-2.96	(2.37)
Zr/Y	2.49-3.19	(2.84)	3.07-6.58	(4.58)	2.62-3.82	(3.26)
Th/Yb	1.56-3.15	(2.36)	0.83-1.92	(1.64)	0.61-0.93	(0.76)
Zr	86-117	(102)	92-230	(145)	84-160	(121)
Eu/Eu*[1]	0.89-0.99	(0.93)	0.37-0.75	(0.57)	0.61-0.78	(0.72)

[1] $Eu/Eu^* = Eu_N/(Sm_N{*}Gd_N)^{1/2}$; N = normalized to primitive mantle values;

CN = normalized to Chondrite values.

Table 2. Selected element concentrations and ratios for Early Devonian rhyolite (Unit1) and Early Carboniferous rhyodacite and rhyolite-b (Unit 2). Values in brackets are average values.

Subgroup	FKPS felsic	Average	FKPS mafic	Average
SiO2	72.19-75.44	(74.16)	48.71-64.96	(54.39)
Na2O	3.92-4.97	(4.22)	1.30-3.12	(2.33)
K2O	0.85-1.43	(1.11)	0.15-1.18	(0.69)
La/Yb_{CN}	4.56-9.0	(6.78)	1.51-2.13	(1.87)
Zr/Y	4.79-14.4	(7.78)	1.57-5.61	(3.45)
Th/Yb	2.22-2.88	(2.55)	0.31-2.49	(1.23)
Zr	89-173	(114)	31-112	(67)
Eu/Eu*[1]	0.79-1.24	(1.02)	0.94-1.38	(1.10)

[1] $Eu/Eu^* = Eu_N/(Sm_N{*}Gd_N)^{1/2}$; N = normalized to primitive mantle values;

CN = normalized to Chondrite values.

Table 3. Selected element concentrations and ratios for Late Devonian to Early Carboniferous Forrest Kerr Plutonic Suite felsic rocks (tonalite and trondhjemite) and Forrest Kerr Plutonic Suite mafic rocks (hornblende diorite). Values in brackets are average values.

nunatak in More Glacier (Logan et al., 2000) and the top of the section (319±3 Ma, intermediate to felsic crystal tuffs; Friedman, in Gunning, 1996) is exposed north of Andrei Glacier where volcanics are overlain depositionally by mid-Carboniferous fossil-rich limestone. On the Foremore property the basal unit comprises a well-bedded section of pale green intermediate volcanic sandstone and siltstone, felsic lapilli tuff and black mafic ash tuff which overlie Devonian limestone on both north and south sides of Hanging Valley. Barnes (1989) and Oliver (2003) mapped these as Late Triassic Stuhinni Group rocks in part due to their unconformable relationship to the Early Devonian rocks.

Elsewhere, Unit 2 volcanic rocks are mainly basalt, dolerite, lesser intermediate andesite, dacite and rhyolite. The mafic and felsic rocks are intercalated, although Gunning (1996) recognized multiple individual small felsic eruptive centers associated with the Early to mid Carboniferous volcanic cycle. The mafic rocks comprise dark green massive to amygdaloidal flows, pillowed flows and pillow breccias, but the most common are green and purple autoclastic breccias, reworked volcaniclastic or epiclastic rocks are rare. The monolithic, scoriaceous tephra contain variably sized, non-sorted fragments of plagioclase microphenocrystic basalt in a finer matrix of similar composition. Fragments are often globular shaped, showing plastic deformation or chilled and altered margins. Hyaloclastite breccias with characteristic curvilinear fracture surfaces, quench-texture brecciation and clusters of sigmoidal to equant devitrified quenched basalt occur west and south of the Hanging valley in thick sections of autoclastic breccias. Further west (on nunataks in More Glacier) the proportions of fine-grained, planar-bedded volcanic sandstones and siltstones exceed the proportions of coarse basalt breccias and flows.

Intermediate rocks appear to be subordinate to the mafic rocks and felsic rocks based on the analyses, but again this might be an artifact of sampling. The intermediate rocks comprise andesite flows and small intrusive sills. The rocks are grey to green in colour, feldspar-rich and typically porphyritic. Light green, grey and white intermediate composition centimeter-thick, sharp-based beds with planar laminations are indicative of distal water lain tuff or resedimented tuffite.

Felsic rocks are mainly fragmentals and are localized around eruptive centres, cryptodomes. Proximal deposits include flows, breccias, agglomerates and coarse tuffs. Distal felsic deposits include well-bedded often-graded tuffs, tuffaceous siltstone and cherty tuff. Compositions range from dacite to rhyolite. Textures include complex flow banded, to massive felsite and a variety of fragmental and autobrecciated forms. Devonian rhyolite flows and proximal deposits of felsic breccias are known to occur (i.e. SG rhyolite).

The North and BRT mineralized zones are hosted in rocks with no definitive age constraints. Limestone is missing from the section and deformation has transposed the stratigraphy. The sequence is interpreted to be Early Mississippian based on lithologic characteristics and the more radiogenic Pb-isotope character of the mineralization (see section on isotopes). At the BRT-North zones Oliver (2003) divided the stratigraphy into three packages; an upper mafic volcanic flow and breccia unit (correlated with Unit 3 on the basis of lithogeochemistry), a medial package of well-bedded cherty tuffs and fine-grained siliceous sediment and a lower package of mixed volcaniclastics, mafic flows, felsic tuffs and light and dark siliciclastic rocks (correlated with Unit 2). In addition, the upper and medial units occupy the hanging wall of the North Zone Thrust fault, separating them from the structurally lower bimodal volcaniclastic and sedimentary rock package which hosts the BRT and North mineralized zones.

Major and trace element contents of rhyolites (type a) from the lower volcanic package (Unit 1) and from a wide variety of mafic to felsic volcanic rocks from the medial volcanic package (Unit 2) permit the data to be subdivided into four geochemical suites (Table 1, Fig. 3a and b).

Using the Zr/Ti - Nb/Y and SiO2 - Zr/Ti projections of Winchester and Floyd (1977) it is possible to discriminate a mafic, an intermediate and two felsic suites having basaltic to basaltic-andesite, andesitic to rhyodacite and rhyolite affinities, respectively. They have low Zr/TiO2 and Nb/Y values that suggest a subalkaline affinity (Fig. 3a). In contrast, Unit 3 alkalic basalts have moderate Nb/Y values (Table 1) that suggest alkalic affinities (see description for Unit 3).

Zr/Y, La/Yb and Th/Yb ratios have been shown to be useful in discriminating between felsic volcanic rocks associated with calc-alkaline versus tholeiitic sequences (Pearce and Norry, 1979; Lesher et al., 1986; Barrett and MacLean, 1999). Using Zr/Y ratios and the divisions suggested by Barrett and MacLean (1994), that tholeiitic sequences have lower Zr/Y (2-4.5) and calcalkaline rocks Zr/Y (>7), with a transitional group having Zr/Y (4.5 to 7); the majority of felsic volcanic rocks in the Foremore area have Zr/Y ratios between 2 and 4.5, which are compatible with the association of tholeiitic volcanic rocks (Fig. 3c). Two rhyodacites from rhyolite B have higher Zr/Y ratios (4.5 to 7) indicative of transitional affinity, while the alkaline basalts and one trachy-andesite have higher Zr/Y ratios (7-15) consistent with a calcalkaline to alkaline affinity. The felsic to intermediate Foremore lavas contain only 90-170 ppm Zr and 25-47 ppm Y, which are abundances more characteristic of calcalkaline than tholeiitic lavas (Lentz, 1998; Barrett and MacLean, 1999). La/Yb and Th/Yb ratios are more effective to determine magmatic affinity for calcalkaline lavas because La and Th typically remain incompatible with fractionation, whereas Zr and Y commonly become compatible to varying degrees (Barrett and MacLean, 1999). On the Th/Yb plot the majority of mafic volcanic

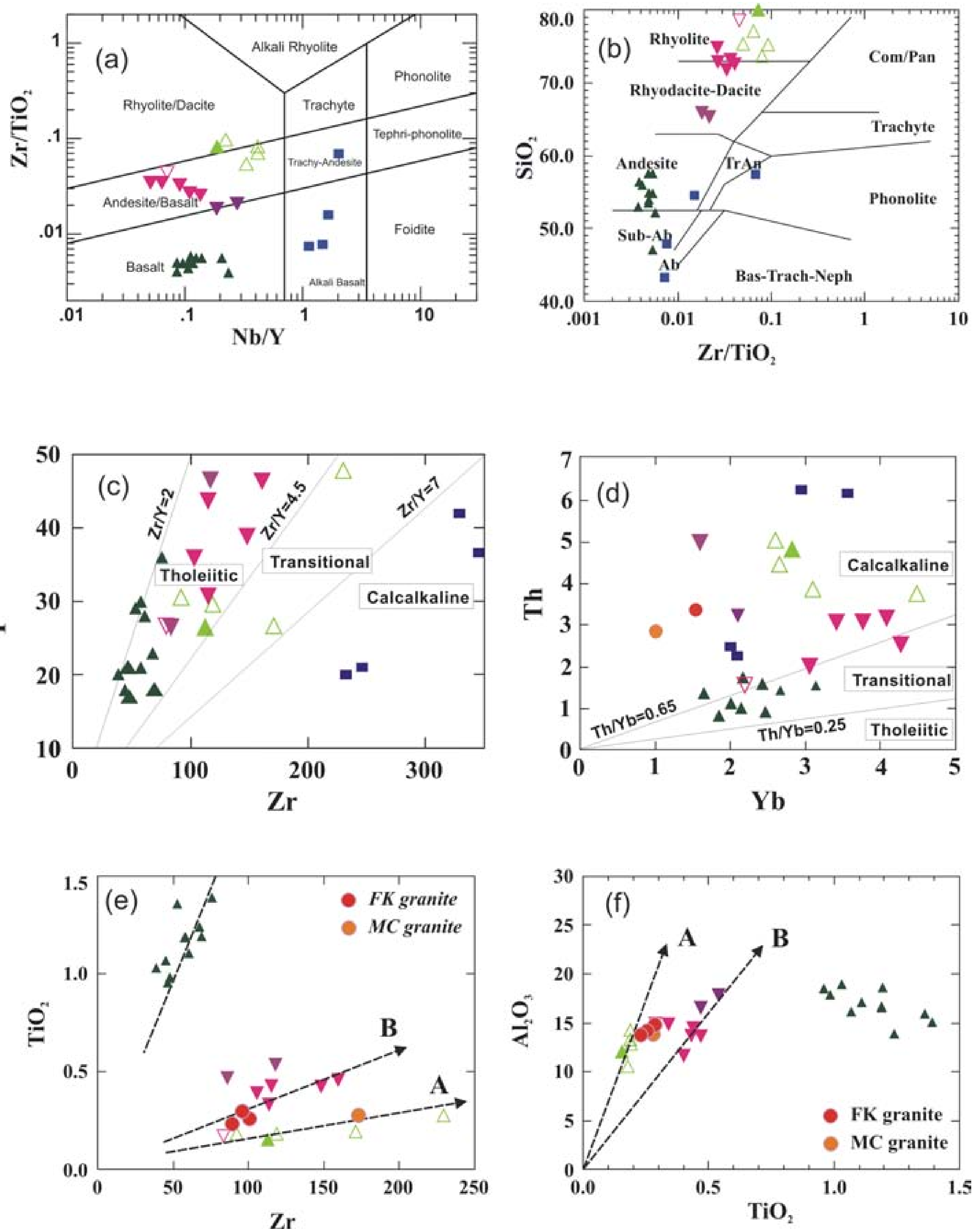
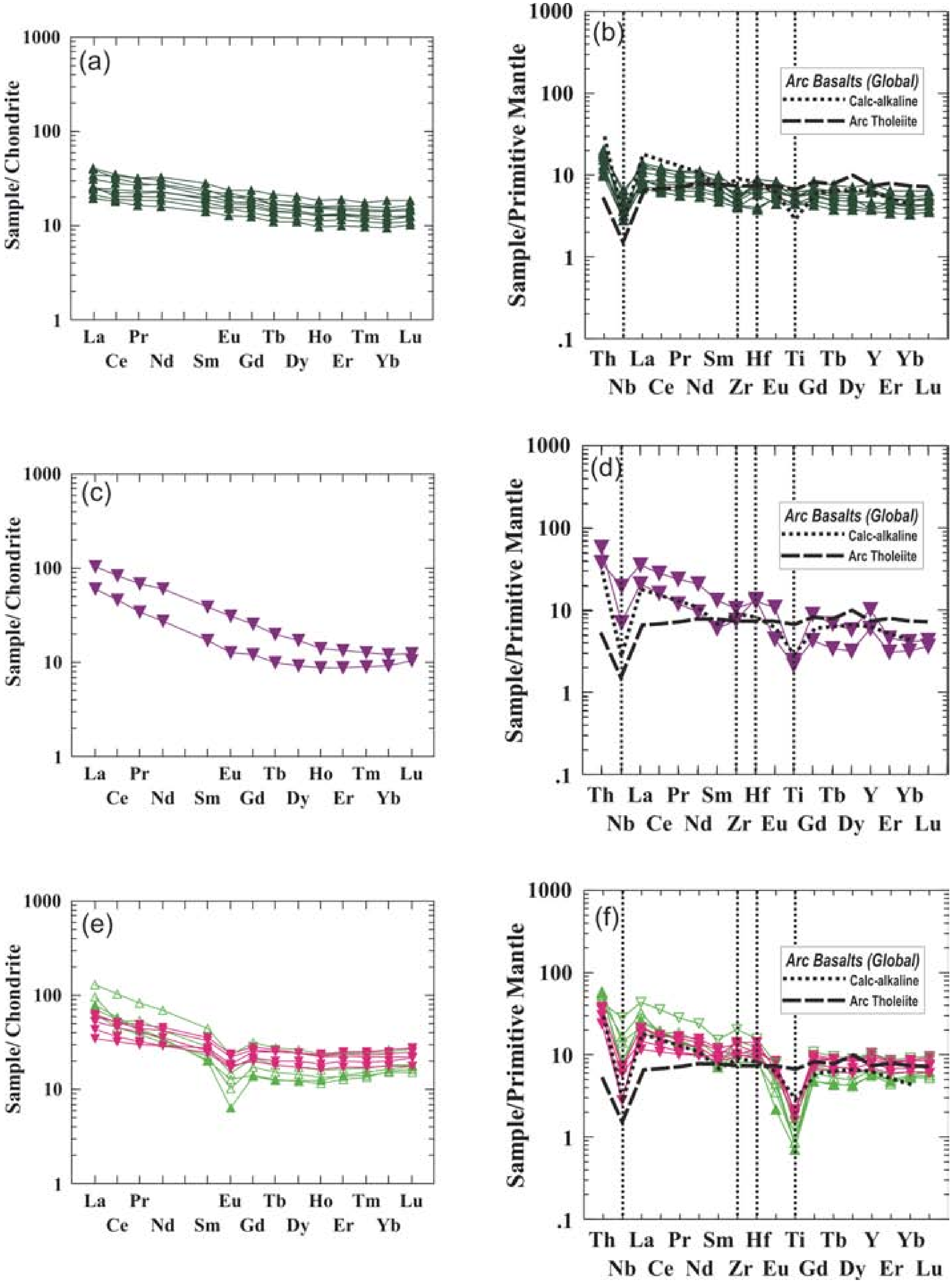


Figure 3. (a) Zr/TiO2 vs. Nb/Y diagram of Winchester and Floyd (1977), revised after Pearce (1996). (b) SiO2 vs. Zr/TiO2 diagram of Winchester and Floyd (1977). (c) Y vs. Zr plot (after Barrett and MacLean, 1984) showing Zr/Y ranges for the various magmatic affinities. (d) Th vs. Yb plot (after Barrett and MacLean, 1999) showing Th/Yb ranges for the various magmatic affinities. (e) TiO2 vs. Zr. (f) Al2O3 vs. TiO2. Symbols for Figure 3 and subsequent plots as follows: Unit 1, rhyolite A (green triangle); Unit 2, basalt (dark green-filled triangle), rhyodacite-dacite (inverted purple-filled triangle), rhyolite B (inverted pink-filled triangle), Unit 3, alkalic basalt (filled square).

FIGURE 4


(a)
Sample/ Chondrite
1000
100
10
1
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
(b)
Sample/Primitive Mantle
1000
100
10
1
.1
Arc Basalts (Global)
Calc-alkaline
Arc Tholeiite
Th Nb La Ce Pr Nd Sm Zr Hf Eu Ti Gd Tb Dy Y Er Yb Lu
(c)
(d)
(e)
(f)

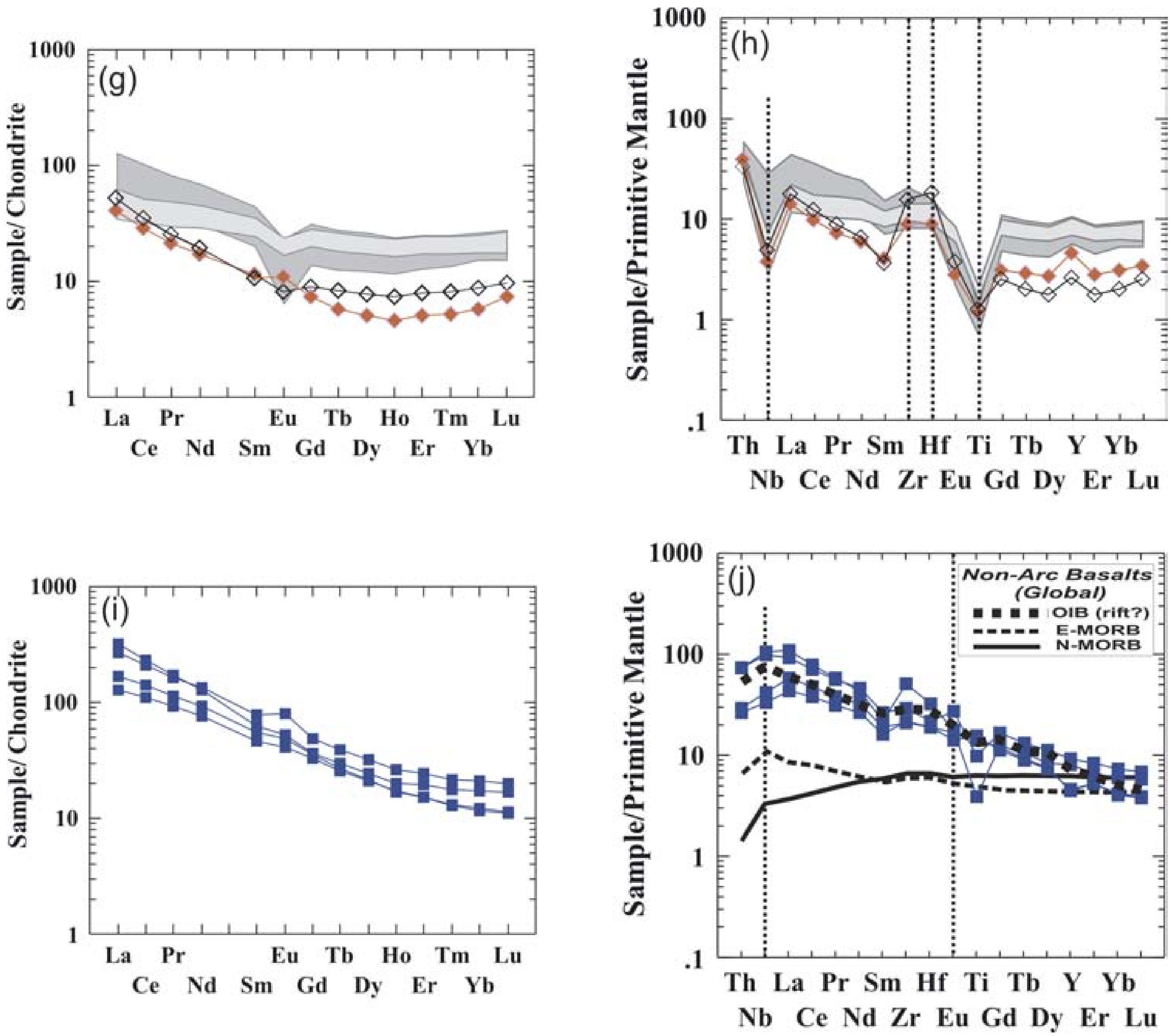


Fig. 4. Chondrite-normalized REE and primitive mantle-normalized multi-element plots for: (a and b) basalt and basaltic andesite from Early Mississippian Unit 1; (c and d) intermediate rhyodacite of Unit 1; (e and f) Rhyolite A and Rhyolite B from Unit 1; (g and h) tonalite and trondhjemite of the FKPS, shaded areas corresponds to the range of values for Rhyolite A (dark) and B (light); (i and j) alkaline basalt and trachy-andesite of Unit2. Chondrite and primitive mantle normalization values are from Sun and McDonough (1989). Primitive mantle normalized patterns for Arc basalts (global) include: a calcalkaline profile from the Sunda arc (Jenner, in Piercey, 1999) and an arc tholeiite from Valu Fa ridge in the Lau Basin (Rautenschlein et al., 1985). Primitive mantle normalized profiles for Non-Arc basalts (global) include: compilations of ocean island basalts (OIB), mid-ocean ridge basalts (MORB) of both the normal type (N-MORB) and enriched type (E-MORB) from Sun and McDonough (1989).

rocks have transitional affinities with Th/Yb ratios between 0.37 and 0.82. The intermediate and felsic suites have Th/Yb ratios >0.65 and strong calcalkaline affinities. Rhyolite B has Th/Yb ratios between 0.61 and 0.93 and averages 0.76 (Table 1). The Th/Yb ratios for rhyolite A and the alkaline suite samples average 1.64 and 1.56 respectively. There are no lavas with tholeiitic Th/Yb ratios of 0.25 to 0.1.

TiO_2 -Zr and Al_2O_3-TiO_2 relationships for the basaltic andesite, rhyodacite and rhyolite suites (from Fig 3a) are shown in Figure 3e and f, respectively. The alkaline lavas have elevated Zr and TiO_2 values which lie outside the plot. Although limited by the number of samples, a two-fold subdivision of the rhyolites (A and B) as well as basaltic andesite is apparent from their Al-Ti-Zr relationships. The covariation between TiO_2 and Zr reflects compatible behaviour of Zr at higher silica compositions (rhyolite vs. rhyodacite) and indicates both low Zr and high Zr subgroups for both. Two rhyodacite samples show affinities with rhyolite B. Also shown is data for granites of the Forrest Kerr Plutonic Suite as they may be coeval with one or the other felsic unit. It is generally possible to identify primary fractionation trends on these plots (Barrett and Maclean, 1999), however the variable ages and differing Zr/Y ratios imply that the felsic units are not related to the mafic unit(s) by fractionation.

Mafic rocks are mainly basalt and basaltic andesites. The basalts have TiO_2 contents of 1.0 to -1.4 percent and low Nb contents of <3 to 4 ppm (Table 1). The chondrite-normalized REE patterns for the Foremore basalts are characterized by LREE enrichment (La/Yb_{CN} = 1.7-3.1) and a downward sloping pattern towards the HREE elements (Fig. 4a). The HREE are essentially flat, (10-20 x's chondrite). The primitive mantle-normalized patterns of the subalkaline basalt suite is similar to the REE plot, with the exception of the negative Nb anomaly with respect to Th and La, and the negative Zr anomaly relative to Sm and Hf. Unit 2 has primitive mantle-normalized patterns (Fig.4b) that are variably depleted, but closely parallel the pattern for calcalkaline arc basalts from the Sunda arc (Jenner, in Piercey, 1999), which supports the field relationships (i.e. interlayered pillowed flows, hyaloclastite breccias and coarse to fine tuffs).

The lithogeochemical data for the intermediate to felsic volcanic rocks are presented in Table 2. Three subdivisions: an intermediate rhyodacite suite and two rhyolite suites are based on the major and trace element chemistry. The geochemical signatures for all are broadly similar and suggest affinities to a calcalkalic continental arc. Rhyolite A is associated with intermediate volcaniclastic rocks and limestone of Unit 1. The intermediate rhyodacite suite and rhyolite B are intimately interlayered with mafic volcanic rocks of unit 2 and show chemical affinities for the FKPS rocks.

Rhyolite A is characterized by higher Ti, Fe, P, and Zr than rhyolite B and a Na:K ratio of approximately 1. In contrast, the intermediate rhyodacite and rhyolite B have Na:K ratios of approximately 3:1 which are more like the Na:K ratios for the tonalites of the FKPS (Table 2 and 3).

The chondrite-normalized REE patterns for rhyolite A are characterized by relatively flat HREE patterns, moderate LREE enrichment (La/Yb_{CN} = 4.12-5.22) sloping downward towards the HREE elements and a moderate negative Eu anomaly (Eu/Eu* = 0.37-0.75), Zr/Y (3.07-6.58) and moderate Th/Yb (1.25-1.92; Table 2; Fig. 4e and f).

The rhyodacite subunit is characterized by steep chondrite-normalized REE patterns (La/Yb_{CN} = 6.60-8.54), a slight to non-negative Eu anomaly (Eu/Eu* = 0.89-0.99), low Zr/Y (2.49-3.19) and high Th/Yb (1.56-3.15; Table 2; Fig. 4c and d). The chondrite-normalized REE patterns for Rhyolite B show a slight LREE enrichment (La/Yb_{CN} = 1.36-2.96), a slight negative Eu anomaly (Eu/Eu* = 0.61-0.78), low Zr/Y (2.62-3.82) and low Th/Yb (0.61-0.93; Table 2; Fig. 4e and f). The primitive mantle-normalized values for all three felsic suites have broadly similar patterns (Fig. 4d and f). All are characterized by either moderate or strong negative Nb anomalies relative to Th and La, all possess variable negative Ti anomalies and a generally downward sloping profile from LREE to HREE. Rare-earth element patterns of the rhyolites show distinct enrichment in the light REE, with relatively flat heavy REE patterns implying derivation from an undepleted mantle source (Fig. 4e and f).

Unit 2 subalkaline basalt and basaltic andesites have HFSE abundances (specifically Nb depletion) that are characteristic of volcanic arc basalts, and plot in the calcalkaline (Hf/Th ratios of less than 3) portion of the arc basalt field on Figure 5 (after Wood, 1980). On the Zr, Y, Nb tectonic discrimination diagram (after Meschende, 1986) the basalt and basaltic andesites from Unit 2 fall predominantly in the VAB field (D).

Unit 3

An extensive package of primarily mafic volcanic flows and breccias, and lesser trachyte and rhyolite occupy the structural and topographic highest positions in the northern part of the study area. This package is not constrained by isotopic dates or fossil ages in the immediate area, but to the north correlative, massive alkalic basalt and fragmental rocks are depositionally overlain by latest Late Carboniferous limestone (Logan et al., 2000).

The volcanic rocks comprise dark green and grey mafic basalt flows, flow breccias and pillowed flows, lesser purple and green lapilli tuffs and coarse volcanic conglomerate to well-bedded, fine-grained epiclastic

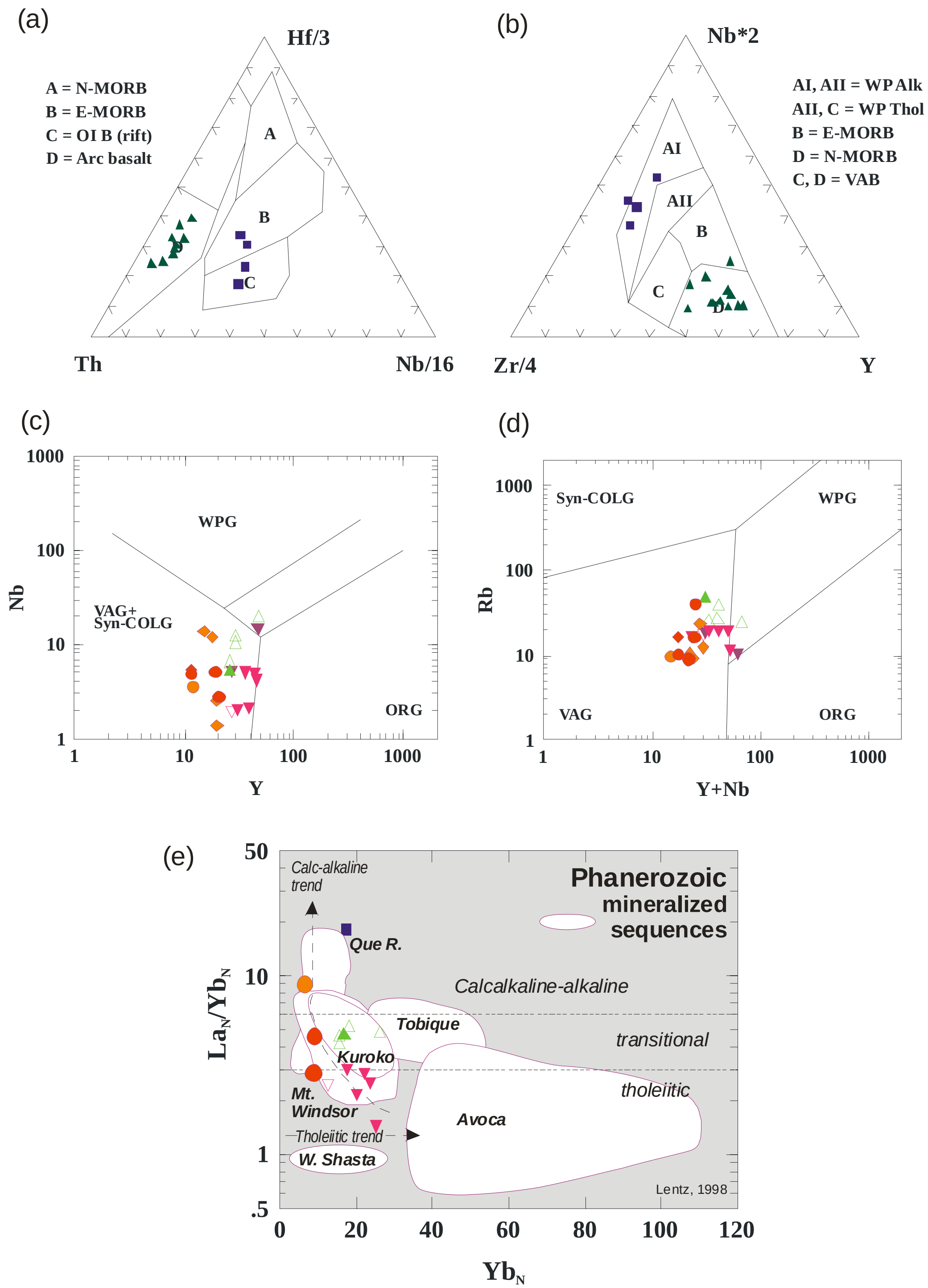


Fig. 5. (a) Tectonic discrimination diagram based on Th, Hf, Nb (after Wood, 1980) used to distinguish arc basalts (and theoretically between calcalkaline and tholeiitic arc basalts) from non-arc basalts (Nb depletion in the former). Basalt and basaltic andesite from Unit 1 fall within the calcalkaline arc basalt field (D). Unit 2 alkaline basalts and trachy-andesite plot within the OIB (rift) and E-MORB fields. (b) Tectonic discrimination diagram based on Zr, Y, Nb (after Meschende, 1986) used to distinguish non-arc basalts (Nb depletion) The diagram is also useful in deciphering within plate alkalic (AI) versus within plate tholeiitic (AII) rocks. Basalt and basaltic andesite from Unit 1 fall predominantly in the VAB field (D). Unit 2 alkaline basalts and trachy-andesite plot in the within plate alkaline basalt field (A1). (c and d) Nb *vs.* Y and Rb *vs.* Y+Nb plots (after Pearce et al., 1984) showing the majority of the intrusion and rhyolite samples lying within the I-type volcanic arc granite (VAG) field. The extension of several samples into the within-plate granite (WPG) probably reflects their high degree of fractionation. (e) La_{CN}/Yb_{CN} *vs.* Yb_{CN} plot (after Lentz, 1998) showing the fields for selected Phanerozoic felsic volcanic rocks associated with VHMS deposits and estimated tholeiitic and calcalkaline fractionation trends.

units. The pillows are well preserved, <1m oblate and pillow bud forms interlayered with amoeboid-shaped autoclasts and breccia fragments. Massive to amygdaloidal (chlorite and/or calcite) basalt flows are present throughout and comprise approximately one third of the section. The flows are characterized by fine white microphenocrysts of plagioclase and commonly <1cm long elliptical amygdules. Above the BRT/North zone (Fig 3), a distinctive monolithic purple vesicular basalt breccia with green matrix forms the lowermost unit (Oliver, 2003). Prismatic primary igneous amphibole crystals occur within some basalt flows and is a distinctive feature in some of the interflow lapilli and crystal tuffs of Unit 3. Block and lapilli-sized coarse-grained amphibolite fragments (Photo 1) are also common in Unit 3 tuffs located north and south of More Creek. These are thought to represent zenoliths of mafic cumulates incorporated and extruded during subsequent eruptions.

Photo 1. Coarse-grained amphibolite lapilli fragment in amphibole crystal-rich alkaline tuffs of Unit 3.

Correlative strata occupy the area immediately east of the headwaters of Mess Creek and north of More Creek. Gunning (1996) divided this area into a western succession of coherent and autobrecciated basalt, pillowed and pillow breccia basalt and an eastern dacite-rhyolite flow complex and speculated that the morphology and composition represented a steep-sided volcanologic dome cored by the eastern felsic complex. The author mapped and sampled a single traverse down through the western assemblage of mafic basalt breccias and flows. Close to the bottom of the valley, at the contact between volcanic rocks of Unit 3 and lapilli and cherty felsic tuff, sericite-chlorite schist and siliceous graphitic phyllite of Unit 1, the structure style changes abruptly from brittle, non-penetrative fabrics in the overlying rocks to recumbently folded and penetratively foliated fabrics within the lower finer-grained section. A similar structural discordance is evident at the lower contact of Unit 3 above the BRT zone. At this location an angular unconformity has been suggested to explain the discordant relationship between the gently dipping, 025^{o} trending lower contact of Unit 3 basalts and the steeply-dipping, 150^{o} to 170^{o} striking fine-grained, well-bedded tuffaceous and siliciclastic rocks of Unit 2.

Above the BRT the estimated thickness of unit 3 is 50 to 100 m (Oliver, 2003), whereas north of More Creek, Gunning (1996) shows a combined thickness of close to 5,000 m. The composite thickness is complicated by normal faulting and includes an eastern section, which incorporates calcalkaline basalts that underlie the dacite-rhyolite complex. These might be more appropriately assigned to Unit 1 or 2 on the basis of their igneous affinity. Regardless, thickness estimates for the alkaline volcanic section located north of More Creek are impossible to estimate due to the network of normal faults (Gunning, 1996).

Chemical analyses of pillowed and flow breccia basalts are basaltic and trachy-andesite in composition (Fig. 3a and b), Gunning (1996) also reports trachyte compositions and alkaline igneous affinity (Fig. 3a). The chondrite-normalized REE patterns for the alkaline rocks of Unit 3 are characterized by a LREE enrichment (La/Yb_{CN} = 10.40-14.25) and a steep downward sloping pattern towards the HREE elements, Zr/Y (7.83-11.71) and moderate Th/Yb (1.1-1.73); Table 2; Fig. 4i). All possess slightly positive Eu anomalies. The primitive mantle-normalized patterns for Unit 3 (Fig. 4j) are similar to the REE patterns, with steep negative slopes that closely overlap the global compilation patterns for OIB (Sun and McDonough, 1989). All are characterized by either moderate or strong positive Nb anomalies relative to Th and La, a variable positive Zr and positive Ti anomalies (with the exception of the more fractionated trachy-andesite). Unit 3 rocks have higher HFSE contents typical of non-arc basalts and Nb values (24-75, Table 1) that reflect a relatively large degree of within plate enrichment.

Unit 3 basalt and trachy-andesite samples have non-arc basalt abundances of Th, Hf and Nb and show characteristics of within plate ocean island basalt (rift-related) and enriched mid ocean ridge basalt affinities (Fig. 5a) on the arc *vs*. non-arc tectonic discrimination diagram of Wood (1980). Figure 5b (after Meschende, 1986) uses Nb /Y ratios to separate the within plate basalts into alkalic and tholeiite subgroups and clearly indicates within plate alkalic affinities of Unit 3 rocks.

Paleozoic Intrusions

FKPS

The Late Devonian to Early Mississippian Forrest Kerr Plutonic Suite comprises two individual plutons in the More Creek area, the Forrest Kerr Pluton and More Creek Pluton. Textural, mineralogical, and chemical characteristics of each are surprise ngly similar (Logan et al., 2000), and have been interpreted to represent the roots of a Devono-Mississippian volcano-plutonic arc (Logan et al., 1993). Each comprises a peraluminous felsic phase, which ranges from biotite granodiorite to biotite tonalite and trondhjemite, and an older metaluminous mafic phase of mainly hornblende monzodiorite and gabbro composition. They are synvolcanic and probably comagmatic to the Late Devonian and Early Mississippian extrusive rocks recognized regionally in this part of northern Stikinia (McClelland, et al., 1993; Mortensen in Sherlock et al., 1994; Grieg and Gehrels, 1995; Friedman in Gunning, 1996; Childe, 1997).

The major trace element abundances of the FKP suite show a strong Na_2O enrichment and K_2O depletion from mafic (~50 wt% SiO_2) to felsic (>70 wt% SiO_2) compositions and follow the differentiation trend of gabbro-trondhjemite series rocks located in southwest Finland (Arth et al., 1978). The plutons show a wide spectrum of compositions on normative Qz-Pl-Or plots, with most samples lying in the tonalite-trondhjemite field and the diorite and quartz diorite fields (Gunning, 1996; Logan et al., 2000). The FKP suite belong to the low-Al (< 15 wt % Al_2O_3), calcalkaline trondhjemite-tonalite types which are characteristic of subvolcanic arc environments and usually have low abundances of Rb, Sr, slight enrichments in LREE, negative Eu anomalies and flat HREE patterns (Barker and Arth, 1976).

Chondrite normalized REE patterns for trondhjemites from oceanic settings typically have flat or light REE depleted patterns showing whole-rock heavy REE values greater than 10 and negative Eu anomalies (Arth, 1979). Continental rocks (continental-margin and -interior examples) on the other hand have highly fractionated patterns showing HREE values less than 5 and small positive Eu anomalies (Arth, 1979). Trondhjemite (FKP) and tonalite (MKP) have steep chondrite normalized REE patterns (La/Yb_{CN} = 4.56-9.0), with a small negative or positive Eu anomaly and essentially flat or dish-shaped HREE profile (Fig. 4g), with HREE values between 5 and 10 times chondrite (Sun and McDonough, 1989). Early Mississippian diorite (MCP) has flat (La/Yb_{CN} = 1.51-2.13), chondrite normalized REE values 10 to 20 times chondrite. The chondrite normalized REE patterns for the FKPS show a steep highly fractionated LREE profile which corresponds to 'continental' trondhjemites and a flat, slightly depleted HREE profile similar to oceanic arc trondhjemites (Arth, 1979). Primitive mantle-normalized plots for the FKPS are characterized by weak to strong negative Nb anomalies relative to Th and La, a moderate sloping profile from LREE to the HREE, and a negative Ti relative to Eu and Gd (Fig. 4h). On Yb-Al_2O_3 tectonic discrimination diagram, the FKP suite extends from the oceanic (low Yb/Al_2O_3 ratios) into the continental arc (lower Yb and higher Al_2O_3) fields (Arth, 1979).

Tonalite and diorite of the More Creek and Forrest Kerr plutons have Nb-Y compositions (Fig. 5c) that plot within the volcanic arc-field, typical of I- and S-type igneous rocks (VAG; Pearce et al., 1984). The felsic volcanic units (rhyolite A and rhyolite B) have compositions that straddle the boundaries between volcanic-arc (I-type) and within-plate (A-type/OR-type) igneous rocks. The low Rb contents of both intrusive and extrusive rocks (<100 ppm) indicate that they do not have a syn-collisional affinity (Fig. 5d).

Small, <0.5 km^2 equant plugs, dikes and sills of tonalite intrude the metavolcanic rocks in the vicinity of the North zone, above the BRT zone and along the north-facing cliffs of More Creek. The intrusions show pervasive alteration and penetrative deformation that is related to the dominant phase of regional deformation. These are interpreted to be subvolcanic Devono-Mississippian intrusions that are related to the FKPS. Although undated, these intrusions have age and mineralizing implications for the host rocks. Subvolcanic intrusions have been linked to the majority of Archean VHMS deposits (Galley, 1995, 2003), so the spatial association of these intrusions in metavolcanic and siliciclastic rocks that host the North and BRT VHMS mineralized zones may not be fortuitous and should be tested further as a potential exploration vector.

An undated equigranular, medium grained hornblende-biotite to tonalite sill complex intrudes the well-bedded volcanic siltstones, tuffs and flows which overlie the Early to middle Devonian rocks of Unit 1 at the SG zone. Pervasive propylitic alteration has replaced feldspars and mafic minerals in the intrusion with epidote-quartz-pyrite assemblages. The alteration is focused and limited primarily to the intrusion and probably represents magmatic-hydrothermal alteration associated with late stage fluids.

Mesozoic Intrusions

A 1km^2 leucocratic granodiorite plug intrudes and metamorphoses mafic metavolcaniclastic breccias, maroon phyllite, felsic tuff and argillaceous phyllite west of the terminus of More Glacier. The intrusion is well jointed but not foliated and consists of biotite-hornblende-plagioclase-potassium feldspar and quartz. Metavolcanic rocks adjacent to the contact are converted to amphibolites and contact-metamorphic minerals overprint the dominant foliation in argillaceous phyllite. The intrusion is cut by a series of east-trending auriferous quartz veins (Harris, 2002) that, have Jurassic galena lead model ages (Logan et al., 2000), suggesting that the plug is related to the regionally extensive Early Jurassic intrusive event.

DISSCUSSION

Primitive mantle normalized trace element profiles of the lower (Early to Middle Devonian) and medial (Early to Late Carboniferous) subalkaline volcanic sequences in the Foremore area have trace element patterns that are similar to calcalkaline volcanic arc basalts. They compare well with calc-alkalic rocks from the Sunda arc (Jenner in, Piercey, 1999), which have trace element patterns characterized by a very strongly pronounced negative Nb anomaly, a slight negative Ti anomaly, LREE enrichment and steeply downward trending profiles. Calc-alkaline basalts reflect more mature arc evolution and/or the influence of continental crust on arc-basalt petrogenesis (Pearce and Peate, 1995). Primitive mantle normalized trace element profiles of the upper (Late Carboniferous) alkaline volcanic sequence have trace element patterns that are similar to non-arc ocean island basalts (OIB) of rift affinities. The calcalkaline and alkaline magmatic events in the Foremore area are two distinct magmatic events of different ages and stratigraphic position. The switch from subduction arc magmatism to within-plate rifting has regional tectonic implications with respect to arc configuration and polarity, but because rifting is characterized by high heat flow, rapid and shallow emplacement of intrusions and development of second or third order basins it can be an important period of VHMS generation.

The variable Th/Yb ratio of rhyolite A (1.2-1.9), and rhyolite B (0.6-0.9) is good evidence that the two are the result of different magma sources and/or volcanic centre. The two rhyolites type A and B also display subtle variations in their chondrite normalized REE patterns and primitive mantle normalized trace element plots. Felsic suites have variably negative Nb, Eu and Ti anomalies (Fig. 4f). The negative Eu and Ti anomalies are consistent with fractional crystallization of feldspar and oxides, respectively, or retention of such phases as a restite in the source region. The overall REE patterns of rhyolite A and B fall within the range of rifted mature arcs and continental back arc rift settings that compare with calcalkaline arc basalt profile from the Sunda arc.

Felsic phases of the FK and MK plutons are coeval with extrusive felsic tuff and flow units (Logan et al., 2000). The limited trace element and REE data available shows abundances for hornblende diorites from the Early Mississippian More Creek pluton that are identical to Early Carboniferous Unit 2 basalt samples (Table 3). Primitive mantle normalized trace element patterns of tonalite and trondhjemite of the FKPS are characterized by elevated LREE and with the exception of a positive Y anomaly relative to Dy and Er; flat HREE profile that are depleted relative to patterns for Unit 1 (rhyolite A) and Unit 2 (dacite and rhyolite B). The characteristic pattern of depleted HREE is related to the partition coefficient for hornblende. The FKPS also show a decoupling between niobium and zirconium typical of relatively reduced melts (Galley, 2003). Large synvolcanic intrusions of quartz diorite-tonalite-trondhjemite composition are spatially associated with many of the Precambrian VMS camps (Noranda, Sturgeon Lake and Snow Lake VMS camps, Galley, 2003). Limited geochemistry (Logan et al., 2000; and unpublished data) indicates that the tonalite-trondhjemite phases of the FK and MC plutons have low Al_2O_3 (<14.7 wt. %), high SiO_2 (>70 wt. %) and low-K_2O (<1.5 wt. %) which are characteristic of the synvolcanic trondhjemite-tonalite intrusive complexes that are known to be associated with Archean VHMS mineralization (Noranda, Manitouwadge and Snow Lake VMS districts; see Galley, 1995; Galley, 2003).

Drobe and Logan (1992) and Logan et al., (1993) proposed that this part of northern Stikinia evolved in a mainly intraoceanic setting. This conclusion is based on: low initial Sr-ratios, + ϵ_{Nd} values and lack of inheritance patterns in zircons from the FKPS intrusions. The Proterozoic inheritance in zircons at Tulsequah (Childe, 1997) indicate a north and westward transition from an intraoceanic-setting to one either underlain by transitional or pericratonic crust or continent-derived sediments, similar to the modern Aleutian Arc. Gunning (1996) on the other hand postulated a long-lived (~150 Ma) continental margin arc setting for the Paleozoic Stikine assemblage rocks based on: the predominantly differentiated calcalkaline character of the volcanic rocks, the presence of a large, I-type polyphase pluton (FKPS) and trace element abundances of volcanic domains in the Iskut River area, and made analogy with the Java portion of the Sunda arc. The Sunda arc is characterized by calcalkaline basalt, dacite and rhyolite volcanic succession developed on 25-30 km of continental crust (Nicholls and Whitford, 1976; and Gill, 1981). The volcanics of Unit 2 have low Zr/Y ratios (Table 1 and 2) corresponding to oceanic arc and high Ta/Yb ratios of calcalkaline oceanic arc fields (Pearce, 1983; Pearce et al., 1981).

VHMS deposits form in a number of different geotectonic environments and most are associated with felsic volcanic-bearing sequences. Major- and trace element geochemical abundances of mafic (Pearce and Cann, 1973; Pearce et al., 1977; Wood, 1980; Shervais, 1982; Meschede, 1986) and felsic (Pearce et al., 1984; Whalen et al., 1987; Christiansen and Keith, 1996) volcanic rocks have been shown to reflect their source and geotectonic environments of formation. Various workers have used felsic volcanic geochemistry to define prospective versus nonprospective volcanic environments for VHMS deposits (Lesher et al., 1986; Lentz, 1998). These studies are based on HFSE-REE systematics of the felsic rocks (see Piercey et al., 2001). Preliminary geochemistry from the felsic volcanic rocks in the More Creek area (Logan et al., 2000; unpublished data and this study) have low Zr/Y ratios and Low La_{CN}/Yb_{CN} that are also similar to Archean and Phanerozoic VHMS associated felsic rocks (Barrie et al., 1993; Lentz, 1998), but rather than tholeiitic have calcalkaline affinities that have more analogies with Phanerozoic VHMS associated felsic rocks (Lentz, 1998; Piercey, et al., 2001). Calcalkaline fractionated sequences, which probably formed in arc-building (neutral to compressional) environments, are not as favorable as extensional tectonic settings (Fig. 10 in, Lentz, 1998) to host VHMS deposits.

The $(La/Yb)_{CN}$ ratios reflect the slope of the chondrite-normalized REE patterns (Fig. 4e, Table 1) and when plotted against Yb_{CN} can be used to evaluate the relative degree of compatibility between LREE versus HREE. In addition, they have been used to distinguish VHMS favorability (Lesher et al., 1986; Barrie et al., 1993; Lentz, 1998). Low $(La/Yb)_{CN}$ ratios are characteristic of tholeiitic or alkaline affinity and high ratios reflect calcalkaline affinity (Cullers and Graf, 1984, in Lentz, 1998). Figure 5e compares the Foremore/More Creek samples to the fields of Phanerozoic felsic-VHMS deposits (Lentz, 1998) formed in four different geotectonic settings. Rhyolite B and the FKPS granites have variable LREE/HREE ratios (1.5-9.5), which are dispersed along the estimated calcalkaline fractionation trend and plot in the Mt. Windsor (intra-continental back-arc) field of Lentz (1998). Rhyolite A samples, cluster together in the field for Kuroko (rifted mature intra-oceanic island-arc) rocks, which overlap with the data from the Mt. Windsor district. Both rhyolites overlap productive fields for Phanerozoic VHMS deposits. The commonality between these settings is that they are underlain by evolved continental crust (Ohmoto and Skinner, 1983; Stoltz, 1995; Lentz, 1999). Gunning (1996) suggests development of the Late Devonian Stikine arc on transitional continental crust, and old (up to 2040 Ma) ages from zircons at Tulsequah indicate inheritance of older Proterozoic zircons. Initial $^{87}Sr/^{86}Sr$ values from the diorite and tonalite phases of FKPS range between 0.7039 to 0.7043 and suggest a relatively primitive magma source region; consistent with the juvenile Nd-isotopic signatures from the felsic phases (unpublished data). The source for the enriched, calcalkaline rhyolites (A and B) is not compatible by simple fractionation but rather requires crustal contamination or addition.

STRUCTURE

The structural characteristics in the More Creek and Mess Creek areas are summarized by Holbek (1988), Gunning (1996) and Logan et al. (2000) and for the Foremore property in particular by Oliver (2003). Planar fabrics preserved in rocks of the area clearly indicate three and probably four phases of deformation.

Briefly, the earliest phase (D1) is characterized by large scale(?) recumbent to tight isoclinal folds and thrust faults. The flat-lying dominant foliation (Sn) is interpreted to be axial planar to these early structures. Bedding-cleavage intersections and minor folds suggest the earliest structures trended north and verged west-southwesterly(?). Younger, second generation folds deform bedding and the dominant foliation (Sn) about open, generally northwest-trending, southeast plunging D2 folds. The second phase cleavage (S_{n+1}) is not always well developed and is often represented by a spaced fracture cleavage rather than a good penetrative cleavage. Third phase (D3) structures are characterized by millimeter up to several meter amplitude east-trending folds, that crenulate earlier foliations (Sn and S_{n+1}) and produced an east-trending steep crenulation cleavage indicative of a north-south compressional event. A younger phase of regional folding, characterized by north-trending, upright, broadly open folds with wavelengths in the order of 1 to 2 kilometers may be the youngest phase of deformation in this part of Stikinia. It has been correlated with Cretaceous deformation that produced the Skeena fold and thrust belt located east of the Foremore property (Evenchick, 2001).

Faults

The North Zone Fault (NZF) is a north-northwest verging reverse fault that has localized quartz-pyrite-base metal ± precious metal mineralization, alteration and ductile deformation (Oliver, 2003). It does not appear to be folded by D1 or D2 and is interpreted to have evolved relatively late in the tectonic history of the area (Oliver, 2003). Kinematic data support north-northwest verging, reverse motion as the youngest movement on the NZF, but its overall parallelism with the dominant early foliation (Sn) suggest it may be an older structure related to inter-limb thrust failure during D1 deformation, that has since been reactivated.

MINERALIZATION

Cominco staked and began exploration on the Foremore property following the discovery of auriferous quartz vein float and several hundred mineralized boulders containing very fine-grained pyrite, barite, sphalerite, with minor galena and tetrahedrite (Mawer, 1988). The auriferous quartz vein material was traced to outcrop mineralization (Westmore gold zone), but the distribution of the massive sulphide boulders, located in outwash plains at the north and eastern lobes of the More glacier (i.e. north boulder field (NBF) and south boulder field (SBF) respectively) was interpreted to suggest the source lay to the west and beneath the main ice sheet of More glacier. Cominco drilled several holes through the glacier without success.

Current work by Roca Mines Inc. has resulted in the discovery of new mineralization located proximal to but, topographic above the mineralized boulder fields. The North and newly discovered BRT zones are situated above and northeast of the NBF; and the SG zone, located in the Hanging valley occurs above and up ice-flow direction of the SBF. These exploration successes permit reinterpretation of the probable source and the prospectivity of the intervening areas located above the two main boulder fields.

Felsic volcanic and sediment-hosted zinc-lead-copper±gold mineralization at the North/BRT and SG zones on the Foremore property share many of the characteristics of the Kuroko/Noranda VHMS deposits and this subclass of VHMS deposits is a prime exploration target in Paleozoic volcanic rocks of northern British Columbia. The polymetallic massive sulphide deposits, or Kuroko/Noranda subclass typically form within calcalkaline, bimodal, arc volcanic sequences characterized by basalt, andesite, dacite and rhyolite. The polymetallic massive sulphide lenses are general hosted within or adjacent to fragmental dacite or rhyolite rocks but which almost always comprise a subordinate component of the bimodal volcanic pile. The evolved tenor of the Foremore VMS mineralization (Zn-Pb-Cu-Ag-rich) is typical of evolved arc and back-arc felsic, volcaniclastic rock dominated successions.

Felsic Volcanic-Hosted Sulphide Mineralization

SG

SG mineralization consists of a 5-8 m thick stratabound zone comprised of 2-3 cm wide foliation parallel and discordant, quartz-carbonate veins mineralized with sphalerite-galena. The mineralization occupies the lower contact of a felsic dome complex and limestone-sedimentary package that projects northeastward beneath ice and snow cover. Trenching and sampling can follow the horizon for approximately 200 m southwest. A number of large boulders of heterolithic carbonate-rich debris flow containing felsic fragments and oxidized sulphide fragments occur immediately down ice (SW) from the SG zone. This unit has been interpreted by Oliver (2003) to stratigraphically overlie the felsic complex in a position upslope and covered beneath glacial ice. Sulphide clast-bearing breccias located at the top or flanks of the felsic complex are additional VMS exploration targets, which because of ice cover and the potential unconformable contact with the younger volcaniclastic units are difficult to assess.

Mapping has traced the footwall stratigraphy northeastward 1000 m at which point the felsic tuff /limestone-sill contact (mineralized horizon) re-emerges from the ice field, trending southeastward. Cominco defined a northwest trending 4-line, UTEM conductor (conductor "B") with coincident anomalous HLEM response in this area and based on the presence of SG-style float boulders recommended the conductor for drill testing (Holroyd, 1989). At the southeast end of the conductor, the felsic units are mineralized primarily with pyrite and overprinted with low temperature iron-carbonate alteration (although only limited geochemical sampling has been completed). The low conductance-conductor is interpreted to deepen westward under thickening ice (Holroyd, 1989). The area has not been drilled but the results of a Max-Min electromagnetic survey over the prospective area have delineated a 200m long anomaly, coincident with both the HLEM and UTEM anomalies obtained by Cominco (Roca Mines News release, Oct 10, 2003).

At the SG, a 4-hole, 225m diamond drill program tested base metal mineralization exposed in trenches at the base of the glacier. The holes were shallow (3 < 50 m) and encountered narrow widths of galena and sphalerite mineralization concentrated near the base of the felsic complex, before entering the non-mineralized-footwall limestone-sill sequence. The lower part of the felsic complex is a sericite-altered intermediate to felsic tuff/tuff breccia variably replaced by calcite and quartz veinlets and stockwork stringers which carry mineralization. Vein mineralogy includes sphalerite, galena, pyrite, tetrahedrite, and arsenopyrite, locally with gold values. The stratabound Pb-Zn-Ag mineralization at the SG was focused by permeability along stratigraphic contacts near the base of the felsic dome complex. The alteration and sulphide mineralogy suggests low temperature fluids, possibly derived from leakage and/or lateral flow away from a higher temperature (>300^{o}C) Cu-Zn rich system associated with the felsic dome complex.

North Zone

Mineralization at the North zone consists of thin foliation parallel disseminations and lenses of pyrite, sphalerite and galena.

BRT Zone

Mineralization at the BRT zone consists of layered semi-massive to massive sphalerite, galena, pyrite and trace chalcopyrite. At the discovery outcrop the BRT sulphide horizon is 0.4 to 0.5 m thick (Photo 2). Deformation has significantly thickened the sulphide layer (1.78 m in hinge zones) and folded it into a shallow, southeast-plunging anticline. Assay results from 6 chip samples across 2.95 m at the BRT discovery zone returned a weighted average of 10.24% Zn, 8.58% Pb, 0.27% Cu, 186.6 g/t Ag and 2.04 g/t Au (Roca Mines News release, July 18, 2003). Trenching to the southwest has extended the strike length of the horizon 30 m before the 0.8 m wide zone plunges into the hillside. A chip sample across the zone at this location returned 7.5% Zn, 13.9% Pb, 444.8 g/t Ag and 1.4 g/t Au over 0.8 m.

Detailed mapping (Oliver, 2003) and regional mapping (this study), recognize a structurally complex

Photo 2. Discovery outcrop, BRT zone. Massive and semi-massive galena, sphalerite, pyrite and trace chalcopyrite layers.

package of interleaved mafic breccias and tuffs, felsic tuffs and epiclastic and sedimentary rocks which in drill core comprise three main lithologies; a structural upper, maroon and green mafic volcaniclastic unit, a medial intermediate to felsic chlorite-sericite+/-pyrite altered volcaniclastic and epiclastic unit (host to the gold-enriched base metal sulphide horizon at BRT zone), and a lower black graphitic and siliclastic sedimentary unit.

The drilling on the BRT zone totaled 896m in 7 holes, from three drill sites. The three drill setups tested the sulphide-bearing horizon along 100 m of strike length, southwest from the discovery outcrop. Results from this first phase drill program at the BRT zone intersected a thick section of variably altered and tectonized intermediate to felsic volcaniclastic rock package that is mineralized by semi-massive cm-thick layers of foliation parallel pyrite and wide m-thick intervals of disseminated blebs and streaks of pyrite. Deformation has transposed the primary features of the host lithology and recrystallized and remobilized the sulphides into interstial-matrix positions and foliation parallel concentrations. Pyrite comprises the majority of the sulphides. Preliminary gold assays from drill core have recognized a 2.3 m interval within Drill hole FM03-11 that contains 7.92 g/t Au. This zone is contained within a thicker 15.9 m sulphide-enriched interval from 85.1 m to 101.0 m. Analyses from the drilling returned low base metal values.

Broken Antler

The Broken Antler consists of a gossanous outcrop (110 x 70 m) of brecciated felsite, located one kilometer northeast of the terminus of Alexander Glacier. The mineralization was first described by Gunning (1994) and attributed to a rhyolite dome complex (~2km in diameter). Subsequent work (Harris, 2002; this study) concluded that the felsite was probably a high level differentiated phase related to the More Creek Pluton that outcrops one kilometer to the east. The felsite is a fine-grained, grey to pale pink-weathering siliceous, brittle rock commonly veined by white quartz stockwork veinlets. Microgranitic-textured tonalite or granite occupies the core of the complex. Locally, a well-developed magmatic/tectonic(?) foliation is defined by segregations of chloritized biotite, plagioclase and quartz ± potassium feldspar in the coarser-grained interior phases of the intrusive complex. At the showing (1 km north), the felsite clearly intrudes and incorporates foliated metavolcanic rocks along its margins. Mineralization is focused along the structural footwall of the felsite and comprises coarse seams, fracture-fillings and disseminated pyrite that is deeply oxidized and leached. Analyses of seven samples (Gunning, 1994) returned a maximum of 200 ppb gold and low base metal values. Additional felsite bodies, numerous 1-2 meter thick feldspar-phyric and rare quartz-phyric rhyolite dikes intrude the metavolcanic rocks north and south of Alexander Glacier. Some are gossanous and many remain virtually untested.

ISOTOPES

Galena Pb-isotopes from the newly discovered SG zone mineralization overlap with feldspar Pb-isotope values calculated from feldspar separates of the Late Devonian (369±5 Ma) Forrest Kerr Pluton (Westcott, 1991; Godwin, 1993; Childe, 1997; Logan, 2000). They lie midway between values from epigenetic Zn-Pb-Ag (Type C boulders) samples and the more radiogenic conformable VHMS Zn-Pb-Cu±Au (Type D boulders) mineralized samples on conventional Pb evolution curves. Mineralization at the SG is hosted in rhyolite interpreted to be Devonian age, while the mineralization at the BRT and north zones is thought to be younger, possibly hosted in the Early Carboniferous volcanic cycle. In addition, the Foremore data cluster together with galena Pb-isotope values from the Late Devonian (377 +9/-7 Ma) Ecstall VMHS prospect located 380 km south in the Coast belt. However, comparison with the Early Mississippian (327±1 Ma), polymetallic (Pb-Zn-Cu-Au-Ag) Tulsequah Chief deposit located 350 km northwest shows that the Pb-isotopic signatures from the Foremore, Ecstall and FKP are significantly less radiogenic. The anomalous highly radiogenic Pb-isotopes and Proterozoic inheritance in zircons at Tulsequah indicate the area is underlain by evolved pericratonic crust or continental-derived sediments which interacted with and modified the Early Mississippian magmas and by inference suggest that the Devonian and Mississippian mineralization at Foremore formed in a more primitive, mainly intraoceanic setting (low initial Sr-ratios, + ЄNd values and lack of inheritance patterns in zircons). Neodymium and strontium isotope studies of volcaniclastic rocks (Samson et al., 1989) and the Forrest Kerr Pluton (Logan et al., 1993) indicate that in the Iskut River, Stikine assemblage strata are indicative of a juvenile, mantle-derived magma source compatible with an orogenic volcano-plutonic complex that evolved in an intra-oceanic environment with no continental detrital influences.

CONCLUSIONS

Mapping and preliminary lithogeochemistry has identified three distinct and regionally extensive submarine volcanic cycles of Late Paleozoic age in Stikine assemblage rocks of the More Creek area. These include: Early to middle Devonian, Early Carboniferous and Late Carboniferous intervals. Polymetallic (gold-enriched) volcanic hosted massive sulphide mineralization is associated with felsic intervals in the Early to middle Devonian and Early Carboniferous cycles. These magmatic cycles have calcalkaline affinities. The FKPS show LREE profiles, which correspond to 'continental' trondhjemites, and a flat, slightly depleted HREE profile similar to oceanic arc trondhjemites. Small tonalite sills present near the North and BRT zones may represent the well-described association of tonalite-trondhjemite subvolcanic sills and Archean VHMS deposits (Galley, 2003).

The stratigraphy at the North and BRT zones and conformable mineralization are thought to be Early Mississippian in age, based in part on the Pb-isotope analyses of the mineralization. There is no clear age constraint and it is possible these rocks and mineralization are also Devonian. The major and trace element abundances define a Devonian group of rhyolites (A) and an Early Carboniferous group of rhyolites (B).

The Late Carboniferous volcanic cycle is characterized by non-arc basalt volcanism with alkalic affinities. Age constraints on this volcanic cycle are not tightly constrained in the study area, but correlated regionally. Rifting associated with this event may have potential to deliver heat, magma and fluids to upper levels of the crust quickly and drive hydrothermal circulation cells that could deposit massive sulphide mineralization.

Further lithogeochemical work is necessary to establish the felsic volcanic and sedimentary facies that are most prospective. Additional age dating could focus exploration onto the more prospective volcanic cycles in the Foremore area.

REFERENCES

Armstrong, R.L. (1988): Mesozoic and Early Cenozoic magmatic evolution of the Canadian Cordillera; in Rodgers symposium volume, *Geological Society of America*, Special Paper 218, pages 55-91.

Arth, J.G., Barker, F., Peterman, Z.E. and Friedman, I. (1978): Geochemistry of the gabbro-diorite-tonalite-trondhjemite suite of southwest Finland and its implications for the origin of tonalitic and trondhjemitic magmas; *Journal of Petrology*, Volume 19, Part 2, pages 289-316.

Barker, F. and Arth, J.G. (1976): Generation of trondhjemitic-tonalitic liquids and Archean bimodal trondhjemite-basalt suites; *Geology*, Volume 4, pages 596-600.

Barnes, D.R. (1989): Geological-Geochemical Report, Foremore Group, Liard Mining District; B.C. Ministry of Energy, Mines and Petroleum Resources, Assessment Report 19,379.

Barrett, T.J., and MacLean, W.H. (1994): Chemostratigraphy and hydrothermal alteration in exploration for VHMS deposits in greenstones and younger volcanic rocks, in Alteration and Alteration Processes, Lentz, D.R. ed.; *Geological Association of Canada*, Short Course Notes, Volume 11, pages 433-467.

Barrett, T.J., and MacLean, W.H. (1999): Volcanic sequences, Lithogeochemistry, and hydrothermal alteration in some bimodal volcanic-associated massive sulfide systems, in Volcanic-associated massive sulfide deposits: processes and examples in modern and ancient settings, C.T. Barrie and M.D. Hannington eds; *Society of Economic Geologists*, Reviews in Economic Geology, Volume 8, pages 101-131.

Barrie, C.T., Ludden, J.N., and Green, T.H. (1993): Geochemistry of volcanic rocks associated with Cu-Zn and Ni-Cu deposits in the Abitibi subprovince; Economic Geology, Volume 88, pages 1341-1358.

Childe, F. (1997): Chronology and radiogenic isotopic studies of the Kutcho, Granduc, Anyox and Tulsequah Chief volcanogenic massive sulphide deposits; in Volcanogenic massive sulphide deposits of the Cordillera project, Unpublished M.Sc. thesis, *The University of British Columbia*, 298 pages.

Christiansen E.H., and Keith J.D. (1996): Trace element systematics in felsic magmas: a metallogenic perspective, *in* Trace element geochemistry of volcanic rocks: applications for massive sulfide exploration, D.A.

Wyman ed.; *Geological Association of Canada*, Short Course Notes, Volume 12, pages 115-154.

Evenchick, C.A. (2001): Northeast-trending folds in the western Skeena Fold Belt, northern Canadian Cordillera: a record of Early Cretaceous sinistral plate convergence; Journal of Structural Geology, Volume 23, pages 1123-1140.

Gabrielse, H. and Yorath, C.J. (1991): Tectonic Synthesis, Chapter 18; in Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., eds, *Geological Survey of Canada*, Geology of Canada, no 4, pages 677-705.

Galley, A.G. (1996): Geochemical characteristics of subvolcanic intrusions associated with Precambrian massive sulfide districts, *in* Trace element geochemistry of volcanic rocks: applications for massive sulfide exploration, D.A. Wyman ed.; *Geological Association of Canada*, Short Course Notes, Volume 12, pages 239-278.

Galley, A.G. (2003): Composite synvolcanic intrusions associated with Precambrian VMS-related hydrothermal systems; *Mineralium Deposita*, Volume 38, number 4, pages 443-473.

Gill, J.B. (1981): Orogenic andesites and plate tectonics; Springer-Verlag, 390 pages.

Godwin, C.I. (1993): Arc and back-arc related galena lead: Stikine terrane; in Metallogenesis of the Iskut River area, northwestern B.C., second annual report, Mineral Deposit Research Unit, The University of British Columbia.

Gunning, D. R. (1995): Report on the Antler Property; B.C. Ministry of Energy, Mines and Petroleum Resources, Assessment Report 24076.

Gunning, M.H. (1996): Definition and interpretation of Paleozoic volcanic domains, northwestern Stikinia, Iskut River area, British Columbia; Unpublished Ph.D. thesis, *University of Western Ontario*, 389 pages.

Gunning, M.H., Patterson, K. and Green D. (1994): New Sulphide occurrences in the Northeastern part of Iskut River map area and southeastern part of Telegraph Creek map area, Northwestern British Columbia; in Current Research 1994 Part A, *Geological Survey of Canada*, Paper 94-1, pages 25-36.

Harris, A.S. (2002): Summary report on the Foremore project; unpublished company report, Equity Engineering Ltd., 34 pages.

Höy, T. (1991): Volcanogenic massive sulphide deposits in British Columbia; in Ore deposits, tectonics and metallogeny in the Canadian Cordillera, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 89-123.

Holroyd, R.W. (1989): Foremore property assessment report on geophysical surveys 1989; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 19380.

Lentz, D.R. (1996): Trace element systematics of felsic volcanic rocks associated with massive-sulfide deposits in the Bathurst Mining Camp: Petrogenetic, tectonic and chemostratigraphic implications for VMS exploration, *in* Trace element geochemistry of volcanic rocks: applications for massive sulfide exploration, D.A. Wyman ed.; *Geological Association of Canada*, Short Course Notes, Volume 12, pages 359-402.

Lentz, D.R. (1998): Petrogenetic evolution of felsic volcanic sequence associated with Phanerozoic volcanic-hosted massive sulphide systems: the role of extensional geodynamics, in Ore Geology Reviews 12, Elsevier, New York, pages 289-327.

Lesher, C.M, Goodwin, A.M., Campbell, I.H., and Gorton, M.P. (1986): Trace element geochemistry of ore-associated and barren felsic metavolcanic rocks in the Superior Province, Canada; Canadian Journal of Earth Sciences, Volume 23, pages 222-237.

Logan, J.M., and Koyanagi, V.M. (1994): Geology and mineral deposits of Galore Creek area (NTS 104G/3 & 4); *B.C. Ministry of Energy and Mines*, Bulletin 92, 96 pages.

Logan, J.M., Drobe, J.R., McClelland W.C., and Anderson, R.G. (1993): Devonian intraoceanic arc magmatism in northwestern Stikinia; *Geological Association of Canada/Mineralogical Association of Canada*, Edmonton ’93, Program with Abstracts, page A60.

Logan, J.M., Drobe, J.R, and McClelland, W.C. (2000): Geology of the Forrest Kerr - Mess Creek area, northwestern British Columbia (NTS 104B/10, 15 & 104G/2 &7W); *B.C. Ministry of Energy and Mines*, Bulletin 104, 164 pages.

McClelland, W.C. (1992): Permian and older rocks of the southwest Iskut River map area, northwestern British Columbia; *in* Current Research, Part A, *Geological Survey of Canada*, Paper 92-1A, pages 303-307.

McClelland, W. C., Mattinson, J.M., Anderson, R. G., Logan, J.M. and Drobe, J.R. (1993): Late Devonian plutonism in the Stikine terrane, British Columbia (abstract); *Geological Society of America*, Abstracts with Programs, Volume 25, page 117.

Mawer, A.B. (1988): Geological-Geochemical Report, Foremore Group; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 18105.

Meschede, M. (1986): A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram; *Chemical Geology*, Volume 56, pages 207-218.

Mihalynuk, M.G. Smith, M.T., Hancock, K.D. and Dudka, S. (1994): Regional and economic geology of the Tulsequah River and Glacier Areas (104K/12 & 13); in Geological Fieldwork 1993, B. Grant and J.M. Newell, eds; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 171-197.

Monger, J.W.H. (1977): Upper Paleozoic rocks of the western Cordillera and their bearing on Cordilleran evolution; *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

Murphy D.C., and Piercey, S.J. (1999): Finlayson project: geological evolution of Yukon-Tanana terrane and its relationship to Campbell Range belt, northern Wolverine Lake map area, southeast Yukon; *in* Yukon Exploration and Geology 1998, Exploration and Geological Services Division, Yukon, *Indian and Northern Affairs Canada*, pages 47-62.

Murphy, D.C., van der Heyden, P., Parrish, R.R., Klepacki, D.W., McMillan, W., Struik, L.C. and Gabites, J. (1995): New Geochronological Constraints on Jurassic deformation of the western edge of North America, southeastern Canadian Cordillera; in Miller, D.M., and Busy, C., Jurassic Magmatism and Tectonics of the North

American Cordillera: Boulder Colorado, *Geological Society of America*, Special Paper 299, pages 159-171.

Nelson, J. and Payne J.G. (1984): Paleozoic volcanic assemblages and volcanogenic massive sulphide deposits near Tulsequah, British Columbia*; Canadian Journal of Earth Sciences*, Volume 21, pages 379-381.

Nelson, J. and Mihalynuk, M.G. (1993): Cache Creek Ocean: Closure or Enclosure?; *Geology*, Volume 21, pages 173-176.

Nicholls, I.A., and Whitford, D.J. (1976): Primary magmas associated with Quaternary volcanism in the western Sunda Arc, Indonesia; in Volcanism in Australasia, R.W. Johnson ed., Elsevier, pages 77-90.

Ohmoto, H. and Skinner, B.J. (1983): The Kuroko and related volcanogenic massive sulfide deposits: introduction and summary of new findings; in The Kuroko and related volcanogenic massive sulfide deposits, H. Ohmoto and B.J. Skinner eds., *Economic Geology*, Monograph 5, pages 1-8.

Oliver, J.L. (2003): Summary of geological observations: Roca Mines's Foremore property, northwestern B.C.; unpublished report for Roca Mines Inc., 30 pages.

Okulitch, (2002): Time scale, Geological Survey of Canada.

Pearce, J.A. (1996): A user's guide to basalt discrimination diagrams, *in* Trace element geochemistry of volcanic rocks: applications for massive sulfide exploration, D.A. Wyman ed.; *Geological Association of Canada*, Short Course Notes, Volume 12, pages 79-113.

Pearce, J.A., and Cann, J.R. (1973): Tectonic setting of basic volcanic rocks determined using trace element analyses; *Earth and Planetary Science Letters*, 19, pages 290-300.

Pearce, J.A. and Norry, M.J. (1979): Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks; *Contributions to Mineralogy and Petrology*, Volume 69, pages 33-47.

Pearce, J.A., Harris, N.B.W., and Tindle, A.G. (1984): Trace element discrimination diagrams for the tectonic interpretation of granitic rocks; *Journal of Petrology*, 25, pages 956-983.

Piercey, S.J., Paradis, S., Murphy, D.C., and Mortensen, J.K. (2001): Geochemistry and paleotectonic setting of felsic volcanic rocks in the Finlayson Lake volcanic-hosted massive sulphide district, Yukon, Canada; Economic Geology, Volume 96, pages1877-1905.

Rautenschlein, M., Jenner, G.A., Hertogen, J., Hofmann, A.Q.W., Kerrich, R., Schminke, H.U., and White, W.M. (1985): Isotopic and trace element composition of volcanic glasses from the Akaki Canyon, Cyprus: implications for the origin of the Troodos ophiolite; *Earth and Planetary Science Letters*, 75, pages 369-383.

Samson, S.D., McClelland, W.C., Patchett, P.J., Gehrels, G.E. and Anderson, R.G. (1989): Nd isotopes and Phanerozoic crustal genesis in the Canadian Cordillera; *Nature*, Volume 337, pages 705-709.

Sawkins, F.J. (1990): Metal deposits in relation to plate tectonics; Second Edition, *Springer-Verlag*, 461 pages.

Sebert, C. (1998): Stratigraphy, lithogeochemistry, alteration and mineralization at the Tulsequah Chief massive sulphide deposit, northwestern British Columbia; Unpublished M.Sc. thesis, *The University of British Columbia*, 331 pages.

Sherlock R.L., Childe, F., Barrett, T.J., Mortensen, J.K. Lewis, P.D., Chandler, T., McGuigan, P., Dawson, G.L. and Allen, R. (1994): Geological investigations of the Tulsequah Chief massive sulphide deposit, northwestern British Columbia; *in* Geological Fieldwork 1993, B. Grant and J.M. Newell, eds; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 279-285.

Shervais, J.W. (1982): Ti-V plots and the petrogenesis of modern and ophiolitic lavas; *Earth and Planetary Science Letters*, 59, pages 101-118.

Stolz, A.J. (1995): Geochemistry of the Mount Windsor volcanics: implications for the tectonic setting of Cambro-Ordovician volcanic-hosted massive sulphide mineralization in northeastern Australia; *Economic Geology*, Volume 90, 1080-1097.

Sun, S.S., and McDonough, W.F. (1989): Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes, in Saunders, A.D., and Norry, M.J., eds., Magmatism in the Ocean Basins; *Geological Society of London,* Special Publication 42; pages 313-345.

Webster, I.C.L. and Ray, G.E. (1991): Skarns in the Iskut River-Scud River region, Northwest British Columbia; *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-1, pages 245-253.

Westcott, M.G. (1991): An investigation of possible genetic and/or spatial links between four distinct mineralized boulder populations located on the Foremore claim group, northwest British Columbia, Unpublished M.Sc. Thesis, *Queen's University*, 45 pages.

Westcott, M.G. (1991): Geological work on Fore 29 and Fore 30 mineral claims, Liard Mining Division; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 21936.

Whalen, J.B., Currie, K.L., and Chappell, B.W. (1987): A-type granites: geochemical characteristics, discrimination and petrogenesis; Contributions to Mineralogy and Petrology, Volume 95, pages 420-436.

Wheeler, J.O. and McFeely P. (1991): Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; *Geological Survey of Canada*, map 1721A.

Winchester, J. A., and Floyd, P. A. (1977): Geochemical discrimination of different magma series and their differentiation products using immobile elements; *Chemical Geology* (Isotope Geoscience Section), Volume 20, pages 325-343.

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

Zartman, R.E. and Doe, B.R. (1981): Plumbotectonics - The model, in Evolution of the Upper Mantle, Zartman, R.E. and Taylor, S.R., eds; Tectonophysics, Volume 75, pages 135-162.