Lithogeochemistry of meta-volcanic rocks from Yukon-Tanana Terrane, Finlayson Lake region, Yukon: Preliminary results

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Abstract

In this paper, we present a preliminary assessment of the lithogeochemical characteristics of meta-volcanic rocks in the Finlayson Lake region. Unit 2 mafic meta-volcanic rocks are subdivided into three suites: 1) low Ti tholeiites and boninites (suite 2a); 2) transitional (oceanic island basalt, OIB?), Light Rare Earth Element (LREE) -enriched tholeiites (suite 2b); and 3) normal mid-ocean ridge basalts (suite 2c; N-MORB). Suite 2a has similarities to rocks formed in ancient suprasubduction zone ophiolites and in forearcs in modern intraoceanic arcs. Unit 3 felsic meta-volcanic rocks comprise two subdivisions: 1) a low Eu/Eu*, Zr/Y, and Ce/Yb_N suite (3a); and 2) a higher Eu/Eu*, Zr/Y and Ce/Yb_N suite (3b). All unit 3 felsic meta-volcanic rocks have calc-alkalic continental arc signatures. Meta-basaltic rocks of the Campbell Range belt (CRB) fall into three suites: 1) moderately LREE enriched E-MORB type rocks (CRB_1); 2) LREE depleted N-MORB type rocks (CRB_2); and 3) a high Mg#, High Field Strength Elements (HFSE) and LREE-enriched tholeiitic suite (CRB_3). All CRB meta-basaltic rocks have features consistent with generation in an ocean basin and/or back-arc/marginal basin setting. The most prospective suites for volcanogenic massive sulphide mineralization in the Finlayson Lake region are 2a, 3a, and CRB_1 and CRB_2.

Résumé

Dans cette étude, on présente une évaluation préliminaire des caractéristiques lithogéochimiques des roches métavolcaniques de la région du lac Finlayson. Les roches métavolcaniques mafiques de l'unité 2 sont subdivisées en trois ensembles : 1) tholéiites et boninites à faible teneur en Ti (2a); 2) roches de transition (basalte d'île océanique, OIB?), tholéiites enrichies en éléments de terres rares légers (LREE; 2b); et 3) basaltes normaux de dorsale médio-océanique (2c; N-MORB). L'ensemble 2a présente des similitudes avec les roches formées dans les anciennes ophiolites de zone de suprasubduction et dans les avant-arcs d'arcs intraocéaniques modernes. Les roches métavolcaniques de l'unité 3 sont subdivisées en deux : 1) un ensemble à faibles rapports Eu/Eu*, Zr/Y, et Ce/Yb_N (3a); et 2) un ensemble à rapports Eu/Eu*, Zr/Y et Ce/Yb_N plus élevés (3b). Toutes les roches métavolcaniques felsiques de l'unité 3 présentent des signatures calco-alcalines d'arc continental. Les roches métabasaltiques de la zone de la chaîne Campbell (CRB) se répartissent en trois ensembles : 1) roches de type E-MORB modérément enrichies en LREE (CRB_1); 2) roches de type N-MORB appauvries en LREE (CRB_2); et 3) un ensemble tholéiitique à forte teneur en Mg#, dont les roches sont enrichies en HFSE et en LREE (CRB_3). Toutes les roches métabasaltiques CRB présentent des caractéristiques conformes à celles des roches formées dans un cadre de bassin océanique et/ou de bassin arrière-arc/marginal. Dans la région du lac Finlayson, les ensembles les plus prometteurs quant à la minéralisation en sulfures massifs d'origine volcanique sont les 2a, 3a, et CRB_1 et CRB_2.

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INTRODUCTION

Any appreciation of the geological controls on mineral deposits relies heavily on an acute knowledge of the stratigraphic and geodynamic setting in which mineral deposits occur. It has been shown from numerous examples that the tectonic setting of a mineral deposit often plays a strong control on the nature, style, and distribution of that mineral deposit type, both in space and time (e.g., Barley and Groves, 1992; Kerrich and Wyman, 1996,1997). In particular, various studies have illustrated that many volcanogenic massive sulphide (VMS) occurrences have specific tectonic settings (and subsets of these settings), and their genesis is related to the petrotectonic processes related to these settings (e.g., Franklin et al., 1981; Lesher et al., 1986; Swinden, 1991; Barrie et al., 1993; Kerrich and Wyman, 1996, 1997; Lentz, 1998). The recent discoveries of VMS deposits and occurrences (e.g., Kudz Ze Kayah, Wolverine Lake, Fyre Lake, Ice, Money; Fig. 1) has prompted the Yukon Geology Program (and collaborators) to seek a better understanding of the geological and geodynamic controls on this mineralization in the Finlayson Lake area, including: 1:50 000-scale regional mapping (Murphy and Timmerman, 1997; Murphy, 1997, 1998; Hunt and Murphy, 1998; Murphy and Piercey, this volume), mineral deposit studies (Hunt, 1997, 1998a,b), and lithogeochemical studies (Sebert and Hunt, this volume; this study).

In this paper we present preliminary chemostratigraphic information on meta-volcanic rocks in the Finlayson Lake area to provide a preliminary overview and interpretation of the petrotectonic affinity and evolution of the Yukon-Tanana Terrane and contained VMS mineralization. The specific signatures of given deposits or occurrences are not given but the implications of these preliminary results to VMS exploration in this region are discussed.

STRATIGRAPHIC SETTING OF SAMPLES

Yukon-Tanana Terrane in the Finlayson Lake massive sulphide belt comprises complexly deformed and metamorphosed sedimentary, volcanic and plutonic rocks (Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Mortensen, 1992; Murphy,

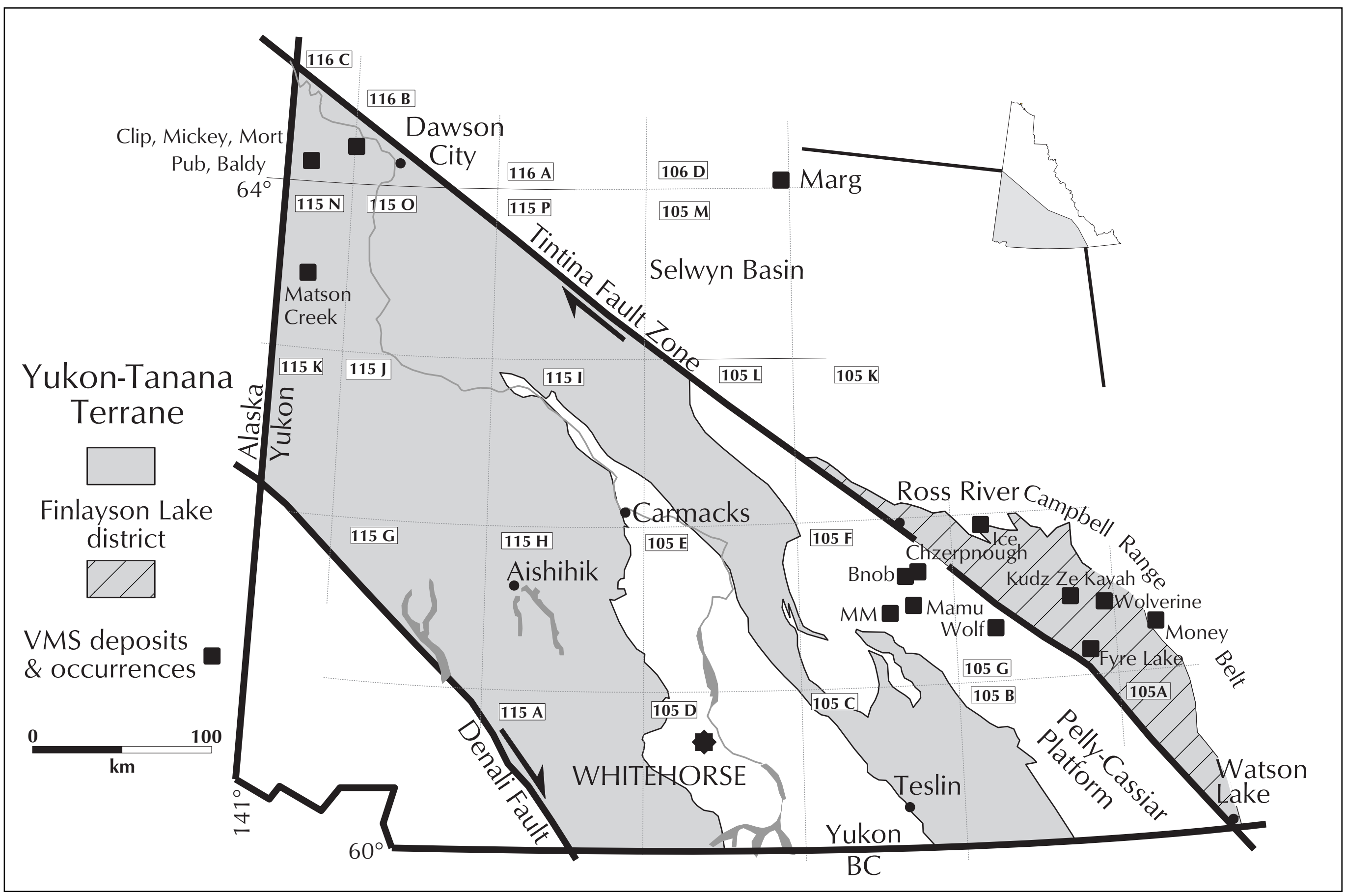


Figure 1. *Location of the Finlayson Lake district and related volcanogenic massive sulphide deposits/occurrences in relation to the distribution of Yukon-Tanana Terrane in the Yukon (Modified from Wheeler and McFeely, 1991).*

1998). Based on 1:50 000-scale geological mapping, Murphy (1998) and Murphy and Piercey (this volume) outlined a stratigraphic framework for this part of Yukon-Tanana Terrane and placed the syngenetic mineral occurrences within this framework. Figure 2 schematically shows the stratigraphy for this area (units 1-7 and Campbell Range belt).

Meaningful conclusions from geochemical data on complexly deformed and metamorphosed rocks requires a knowledge of the stratigraphic position and protoliths of the rocks. We selected 41 samples that were either of clearly igneous origin, or that are reasonably well constrained as to have an igneous protolith. These data presented here include chloritic schist and metabasitic rocks of unit 2 from the Grass Lakes map area (Murphy, 1998) and the Fire Lake area (Hunt and Murphy, 1998), felsic meta-volcanic rocks from unit 3 (host of the Kudz Ze Kayah deposit), Simpson Range plutonic suite (SRPS), and mafic meta-volcanic rocks from the Campbell Range belt (those that host the Ice deposit and Money occurrence). This preliminary dataset does not contain unit 2 rocks from the area adjacent to the Fyre Lake deposit; those rocks are discussed in Sebert and Hunt (this volume), and lithogeochemical samples from units 4-7 that were collected during 1998 and remain to be investigated.

GEOCHEMISTRY OF META-VOLCANIC ROCKS

Samples were analyzed for major, trace, and rare-earth elements (REE) at Activation Laboratories in Ancaster, Ontario. Major elements were analyzed on fused discs by X-ray fluorescence, while trace elements and REE were analyzed by research-grade inductively coupled plasma mass spectrometry (ICP-MS). Figures 3-8 summarize the analytical data, plotted on both discrimination diagrams and primitive-mantle/chondrite-normalized plots. Complete data are not presented in this paper (Tables 1-3) but will be published in forthcoming papers; representative data for each suite can be obtained from the authors upon request.

It should be noted that most of the rocks from the Finlayson Lake region have been affected by greenschist to amphibolite facies metamorphism, and some have also experienced hydrothermal alteration. This restricts which elements can be used for conventional rock and tectonic classifications (e.g., total alkalis versus silica plots). Most major elements, with the exceptions of Al_2O_3 and TiO_2, are considered partly mobile during alteration and metamorphism (Rollinson, 1993). Major

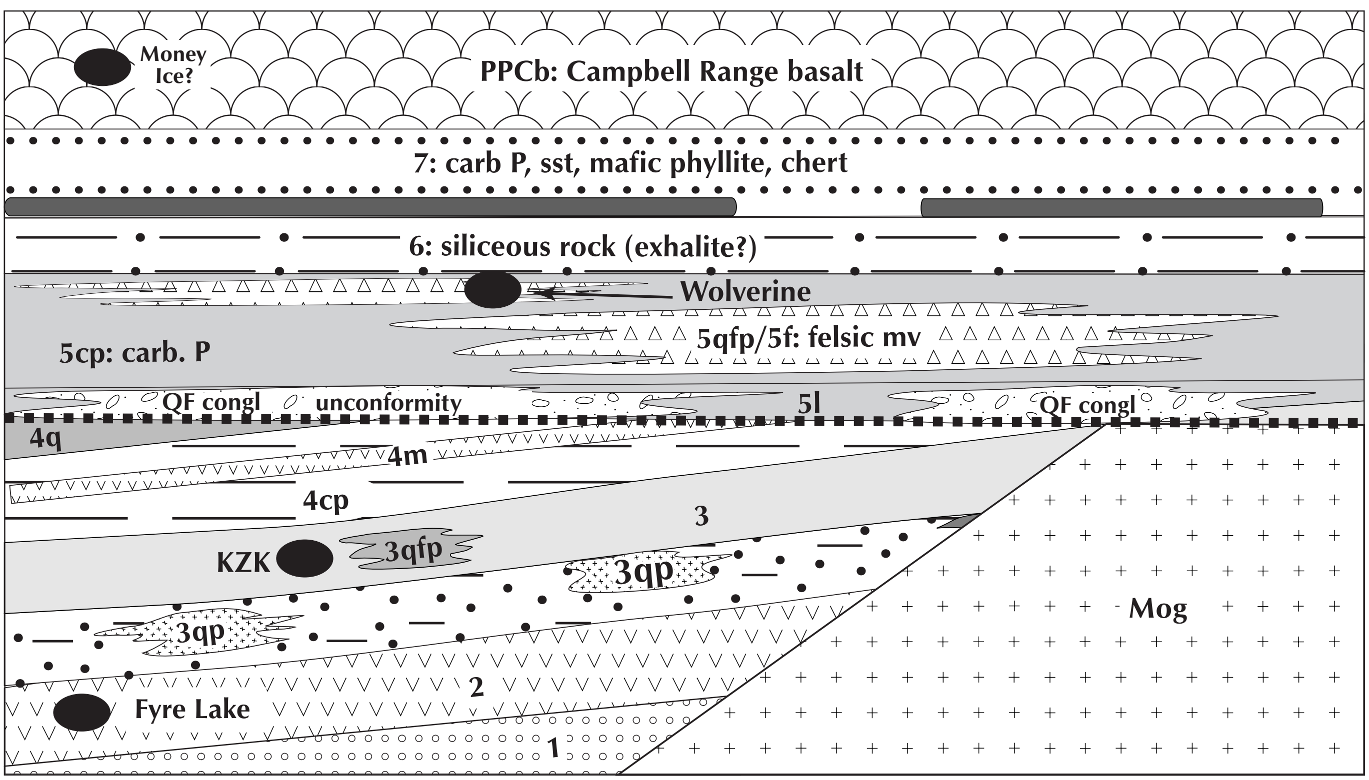
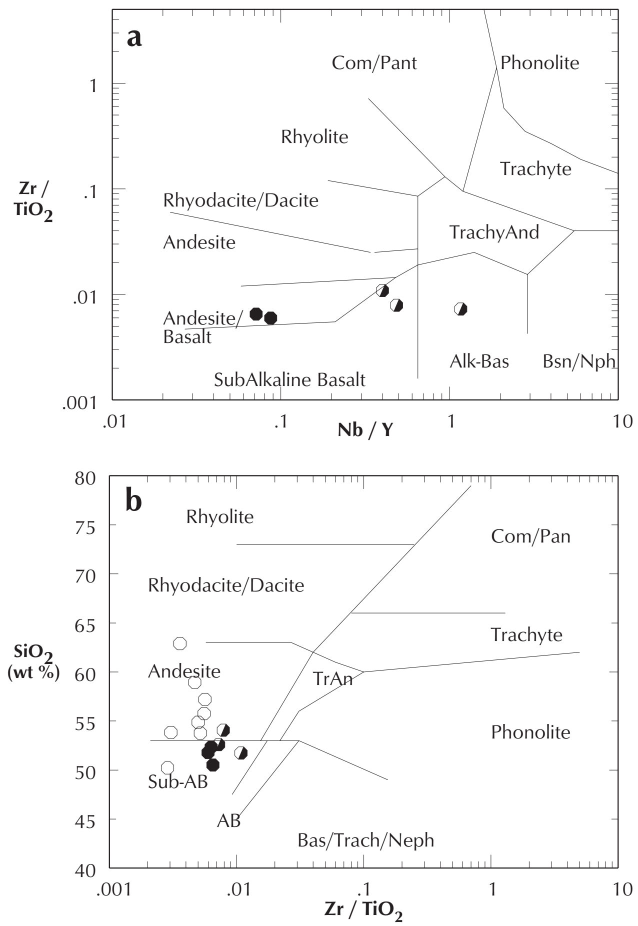


Figure 2. *The stratigraphy and distribution of volcanogenic massive sulphide mineralization in the Finlayson Lake district. Units are defined in Murphy and Piercey (this volume).*



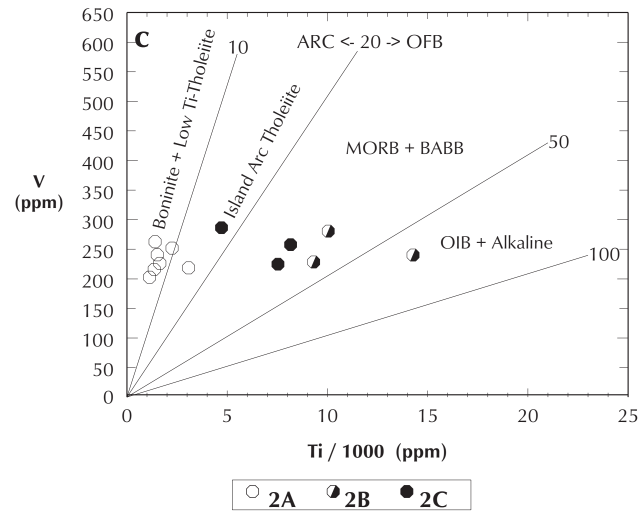


Figure 3. *Discrimination diagrams of unit 2 mafic meta-volcanic rock. Fields in **a)** and **b)** from Winchester and Floyd (1977) and **c)** modified from Shervais (1982).*

Table 1. *Selected elemental concentrations and ratio ranges for unit 2 mafic meta-volcanic rocks. Values in brackets are the average values. SiO_2 and TiO_2 are given as weight percent oxides (wt%); Zr, Nb, Ni and Cr are in parts per million (ppm).*

Subgroup	2A	Average	2B	Average	2C	Average
Mg#	48.37-73.69	(65.41)	52.73-69.32	(55.88)	52.82-59.17	(55.93)
SiO_2	47.17-61.25	(53.78)	47.98-50.16	(49.23)	46.09-50.47	(48.51)
TiO_2	0.17-0.89	(0.36)	1.49-2.21	(1.74)	0.76-1.32	(1.07)
Ce/Yb_N	0.66-1.60	(1.08)	7.39-11.86	(10.10)	1.64-2.15	(1.96)
Zr/Y	1.13-2.08	(1.57)	4.63-6.48	(5.36)	2.09-3.07	(2.67)
Zr	8-25	(14)	111-274	(149)	48-86	(67)
Nb	< LD		(10-28)	(18)	(0-2.0)	(1)
Ni	30-259	(133)	0-89	(47)	32-85	(45)
Cr	12-855	(324)	0-211	(185)	61-238	(133)

element plots are nevertheless shown for descriptive purposes because in many cases the data for each suite cluster together (e.g., Zr/TiO_2 –SiO_2 Figs. 3, 5, 7) and are considered to be close to original compositions. Furthermore, Mg#'s [(Mg/Mg+Fe)*100] appear to be relatively undisturbed except where rocks have been affected by alteration at high water-rock ratios (Dunning et al., 1991). In terms of trace elements, most of the low field strength elements (LFSE=Cs, Rb, Ba, Sr, U), with the exception of Th, can be considered mobile during alteration and metamorphism; whereas the high field strength elements (HFSE=Zr, Hf, Nb, Ta, Y), transition elements (V, Cr, Ni, Sc), and REE (La-Lu) can be considered immobile under most circumstances (Rollinson, 1993; Kerrich and Wyman, 1996, 1997). The diagrams and normalized plots used in this report use immobile elements in most cases.

UNIT 2

Unit 2 of Murphy (1998) and Murphy and Piercey (this volume) can be subdivided into three geochemical suites based on their trace and major element contents (Figs. 3a and b). Figure 3a shows that the 2b and 2c suites have basaltic-andesite and transitional subalkalic basalt/alkaline basalt affinities, respectively. Owing to the low Nb content of suite 2a, it doesn't plot on Figure 3a (see Table 1); however, it ranges from subalkalic basalt to andesite on Figure 3b.

The 2a suite is characterized by low Ti/V ratios, TiO_2 (0.17-0.87%) and HFSE contents (Zr=8-25 ppm, Nb < detection) and Zr/Y ratios (1.12-2.08), yet has elevated SiO_2 (47.17-61.25%), Mg#'s (48.37-73.69), and compatible element contents (Ni=30-259 ppm; Cr=12-855 ppm; Fig. 3c, Table 1). Suite 2a is strongly depleted in total REE (1-10x chondrite), with relative LREE depletions (Ce/Yb_N=0.66-1.60; N-normalized to primitive mantle values), but some samples have slightly elevated La, leading to dish-shaped profiles (Fig. 4a). When compared to the primitive mantle, suite 2a has very low HFSE contents, (Zr, Nb, Y), and a crudely dish-shaped profile of all elements (Fig. 4b). The dish-shaped profile, low TiO_2, HFSE, and total REE contents, irregularly high transition metal contents (Ni, Cr), Mg#'s, and andesitic levels of SiO_2 are consistent with the 2a suite having a boninite to low-Ti tholeiite affinity, common to many rocks found in modern day forearcs and suprasubduction zone ophiolites (Jenner, 1981; Hickey and Frey, 1982; Crawford et al., 1989; Pearce et al., 1992; Piercey et al., 1997; Bédard et al., 1998).

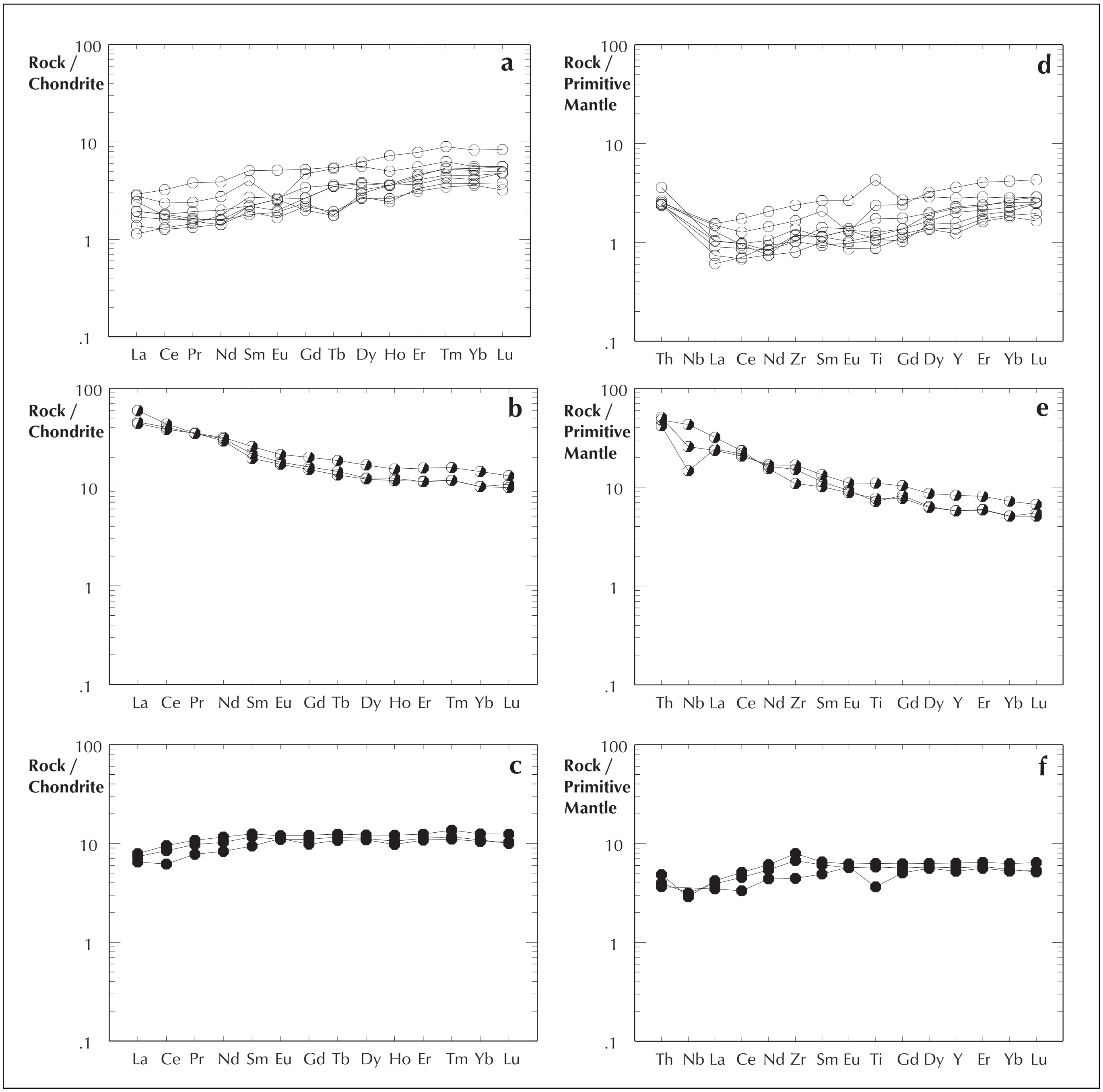
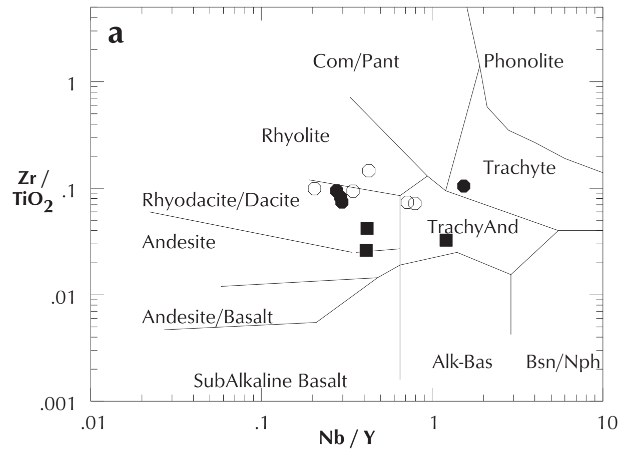
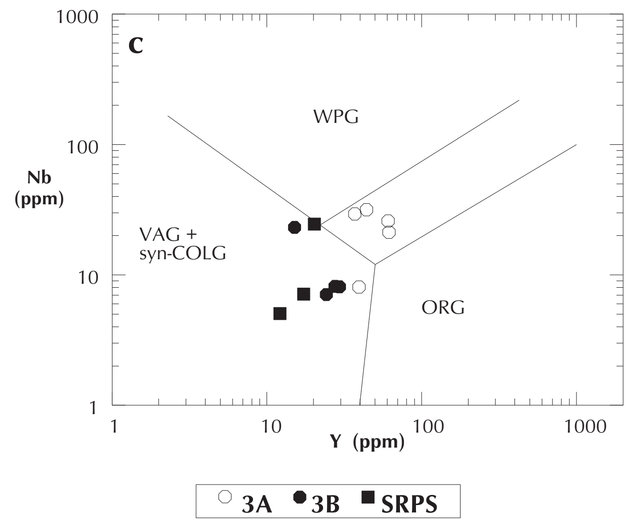


Figure 4. *Chondrite-normalized REE and primitive mantle-normalized multi-element plots for unit 2 mafic meta-volcanic rocks: **a)** and **d)** – 2a suite; **b)** and **e)** – 2b suite; and **c)** and **f)** – 2c suite. Chondrite normalization values from Taylor and McLennan (1985), and primitive mantle values from Sun and McDonough (1989).*





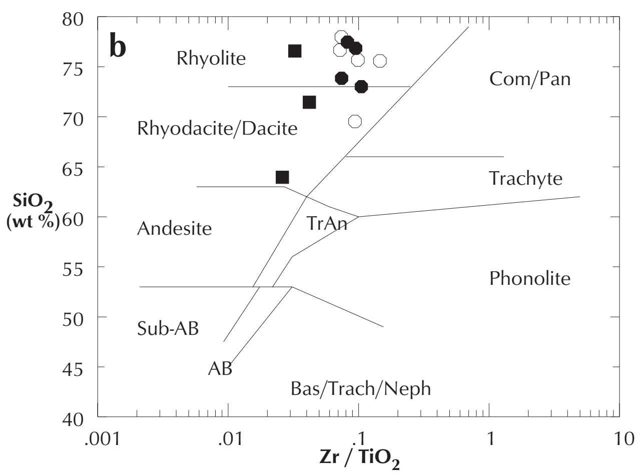


Figure 5. *Discrimination diagrams of unit 3 felsic meta-volcanic rocks. Fields in **a)** and **b)** from Winchester and Floyd (1977), and in **c)** from Pearce et al. (1984).*

Table 2. *Selected elemental concentrations and ratio ranges for unit 3 felsic meta-volcanic rocks and the Simpson Range Plutonic Suite. Values in brackets are the average values. SiO_2, Na_2O and K_2O are given as weight percent oxides (wt%); Zr is given in parts per million (ppm).*

Subgroup	3A	Average	3B	Average	SRPS	Average
SiO_2	68.84-75.85	(72.68)	72.42-74.66	(74.97)	62.87-71.86	(68.45)
Na_2O	0.94-3.26	(1.60)	0.25-6.39	(2.87)	1.64-2.67	(2.19)
K_2O	2.96-9.65	(6.45)	0.63-7.74	(3.94)	0.94-2.44	(2.36)
Ce/Yb_N	4.45-7.46	(6.15)	5.54-20.00	(10.76)	6.92-8.51	(7.59)
Zr/Y	4.16-7.18	(5.86)	2.54-12.60	(6.47)	8.75-12/16	(9.32)
Zr	163-438	(261)	99-189	(142)	105-231	(152)
Eu/Eu*[1]	0.16-0.62	(0.34)	0.35-0.72	(0.56)	0.69-0.92	(0.80)
Ti*[2]	4.50-12.63	(8.65)	14.32-25.88	(17.22)	2.34-4.40	(3.29)

[1]$Eu/Eu^* = Eu_N / (Sm_N{}^*Gd_N)^{1/2}$; [2]$Ti^* = 0.5^* (Sm_N+Eu_N)/ Ti_N$; N = normalized to primitive mantle values.

In contrast to suite 2a, suite 2b has elevated Ti/V ratios, TiO_2 (1.49-2.21%), HFSE (Zr=111-174 ppm; Nb=10-28 ppm) and Zr/Y ratios (4.63-6.48), while having lower SiO_2 (47.98-50.16%), Mg#'s (52.73-69.32), and transition metal contents (Ni=0-89 ppm; Cr=12-855 ppm; Fig. 3c, Table 1). The chondrite-normalized REE plot for suite 2b is characterized by a distinctive LREE (light rare earth element) enrichment (Ce/Yb_N=7.39-11.86) and has a downward sloping profile towards the heavy rare earth elements (Fig. 4c). The primitive-mantle normalized plot of suite 2b is similar to the REE plot with the exception of one sample that has a slight negative Nb anomaly relative to Th and La (Fig. 4d). This suite with the steep LREE-enriched patterns (Fig. 4c), high Ti contents and HFSE contents (Fig. 4d; Table 1) is consistent with rocks from enriched source regions transitional between tholeiitic and alkaline oceanic island basalts (OIB); however, the sample with low Nb relative to La and Th (Fig. 4d) suggests a possible relationship to arc magmatism (e.g., Kostopoulos and Murton, 1992).

Suite 2c has chemical affinities that are intermediate between suites 2a and 2b. Suite 2c has moderate Ti/V ratios, moderate TiO_2 (0.76-1.32%), HFSE (Zr=48-86ppm; Nb=0-2.0 ppm; Zr/Y=2.09-3.07), and Mg#'s (52.82-59.17; Fig. 3c, Table 1). Silica contents are consistent with basaltic parentage (SiO_2=46.09-50.47), and transition metal contents overlap with those of the 2b suite (Ni=32-85 ppm; Cr= 61-238 ppm). The REE character of suite 2c is presented in Fig. 4c and these rocks have relatively flat MREE (middle rare earth elements) to HREE (Sm-Lu), yet have a slight depletion of the LREE (Ce/Yb_N=1.64-2.15). The primitive-mantle normalized plot of suite 2c is similar to the REE plot; however, there is a slight negative Nb anomaly relative to Th and La, and a slight positive anomaly of Zr relative to Nd and Sm (Fig. 4c). Both of these features may reflect arc-related magmatism (slab-fluid metasomatism?), although there is some concern that the negative Nb anomaly relative to Th is an analytical artifact. The moderate Ti content, LREE-depleted nature, and moderate HFSE and transitional element contents of suite 2c are consistent with normal mid-ocean ridge basalt magmatism (N-MORB).

UNIT 3

Lithogeochemical data for unit 3 are presented in Table 2 and Figures 5 and 6. Unit 3 meta-volcanic rocks have been subdivided into two suites based on their geochemical affinities; data for the Simpson Range Plutonic Suite (SRPS) are also presented as they may be coeval with unit 3 meta-volcanic rocks (Mortensen, 1992; Grant, 1997). All of the unit 3 meta-

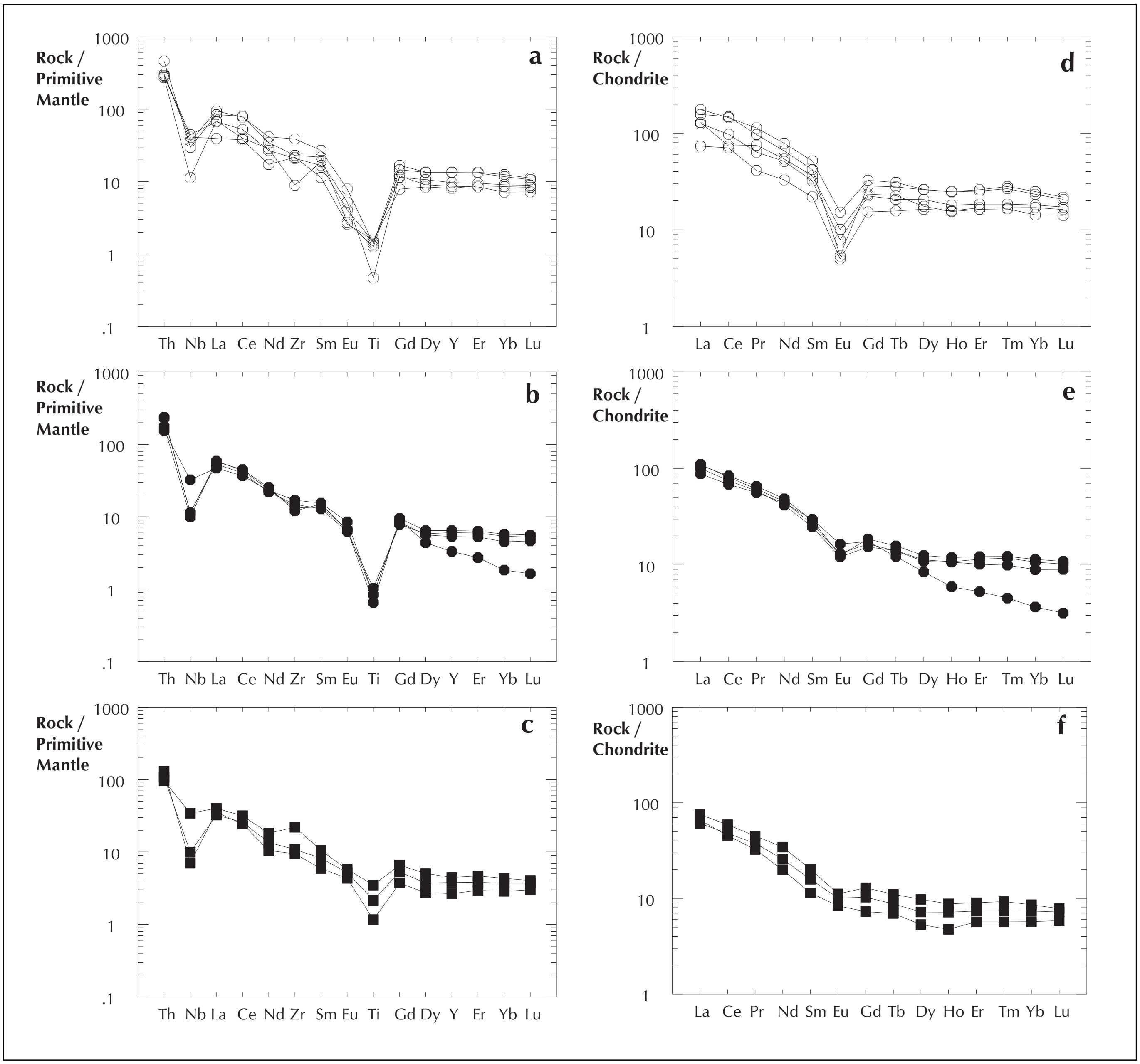


Figure 6. *Primitive mantle-normalized multi-element and chondrite-normalized REE plots for unit 3 felsic meta-volcanic rocks, including:* ***a)*** *and* ***d)*** *– 3a suite;* ***b)*** *and* ***e)*** *– 3b suite; and* ***c)*** *and* ***f)*** *– Simpson Range Plutonic Suite. Chondrite normalization values from Taylor and McLennan (1985), and primitive mantle values from Sun and McDonough (1989).*

volcanic rocks and the SRPS have broadly dacitic to rhyolitic composition with some samples exhibiting more alkaline trachyandesite to trachyte compositions (Fig. 5a-b). Felsic meta-volcanic rocks of suite 3a have broadly rhyodacitic-rhyolite to trachyandesite affinities and have characteristics akin to within-plate (rift-related) granitoids and volcanic arc granitoids (Figs. 5a-c). In contrast, the SRPS and suite 3b felsic meta-volcanic rocks have predominantly volcanic arc granitoid affinities (Fig. 5c).

Primitive-mantle normalized plots for unit 3 felsic meta-volcanic rocks and the SRPS are given in Figures 6a to 6c. On these plots there is little difference between the three groupings. All are characterized by weak to very strong negative Nb anomalies relative to Th and La (arc signature), have gently downward trending profiles from the LREE/LFSE to the HREE/HFSE, and all exhibit variably negative Ti relative to meta-volcanic and metaplutonic rocks with calc-alkalic continental arc affinities.

Although there is a cursory similarity between the three groupings, there are differences. For instance, the chondrite-normalized REE patterns for suite 3a are characterized by relatively flat HREE profiles, slight LREE enrichments (Ce/Yb_N=4.54-7.46), a very strong negative Eu anomaly (Eu/Eu*=0.16-0.62), moderately high Ti* (4.50-12.63) and Zr values (163-438 ppm), yet they exhibit the lowest Zr/Y values (4.16-7.18; Figs. 6a and 6d; Table 2). In contrast, suite 3b is characterized by steep chondrite-normalized REE patterns (Ce/Yb_N=5.54-20.00), moderately negative Eu anomalies (0.35-0.75), moderate Zr contents (99-189 ppm), relatively low Zr/Y ratios (2.54-12.60), and very high Ti* values (14.32-25.88; Figs. 6b and 6e; Table 2). The SRPS is somewhat different than unit 3 meta-volcanic rocks in having the highest TiO_2 content (Ti*=2.34-4.40), having moderate LREE enrichment (Ce/Yb_N=6.92-8.51), a slight negative Eu anomaly (Eu/Eu*=0.69-0.92), while having moderate Zr (195-231 ppm) and high Zr/Y (8.75-12.16; Figs. 6c and 6f, Table 2).

All three felsic groupings are characterized by high to very high silica (62.87-75.85%; Table 2), with the SRPS having the lowest SiO_2 contents (62.87-71.86%) and moderate Na_2O (1.64-2.67) and K_2O (0.94-2.44). Suite 3a is characterized by high SiO_2 (68.84-75.85%) and low Na_2O (0.94-3.26%) and high K_2O (2.96-9.65%), while suite 3b has higher Na_2O (0.25-3.69%) and lower K_2O (0.63-7.74%) than suite 3a (Table 2). The highly variable Na_2O and K_2O in the aforementioned suites may be a function of variable alteration and mobility of elements during hydrothermal alteration.

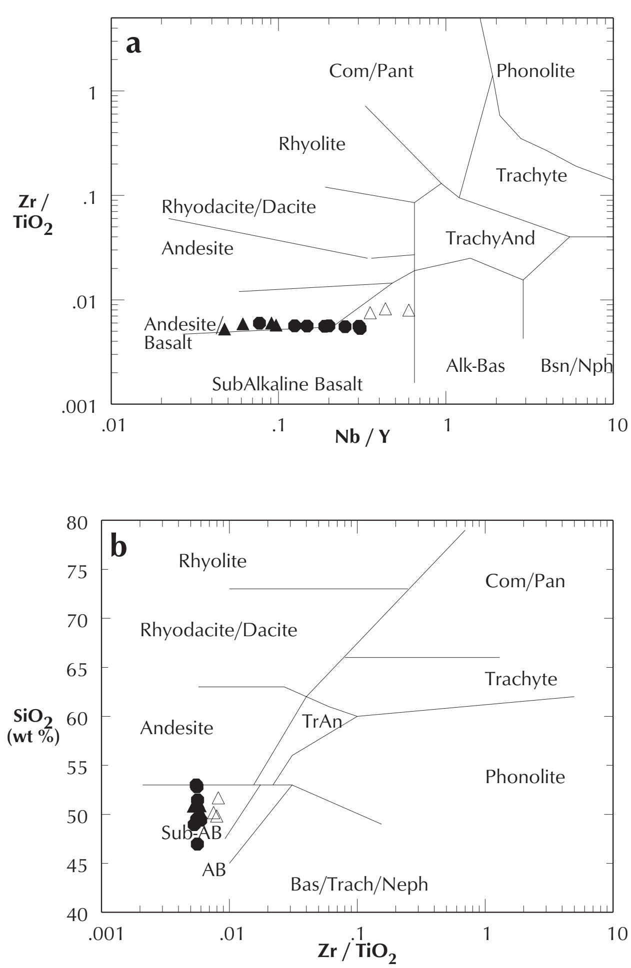
CAMPBELL RANGE BELT

Mafic meta-volcanic rocks from the Campbell Range belt (CRB) are much less ambiguous with respect to their origin when compared to the chloritic schists of unit 2. Most of these rocks are pillowed and massive lavas, interbedded with lesser volcaniclastic and epiclastic rocks, and locally chert and marble (e.g., Murphy and Piercey, this volume; Plint and Gordon, 1997). Our preliminary data show that the CRB meta-volcanic rocks are basaltic-andesite to subalkaline basalt (Fig. 7a-b) and have moderate Ti/V ratios consistent with eruption in an ocean floor or marginal basin setting (Fig. 7c; cf. Nelson, 1993; Plint and Gordon, 1997).

Three subdivisions of the CRB meta-basalt are proposed based on their trace element chemistry. The first subdivision, CRB_1, is characterized by moderate Ti/V ratios, TiO_2 (1.08-1.86%), HFSE contents (Zr=61-104 ppm; Nb=2-10 ppm), Zr/Y ratios (2.51-3.15), moderate transition metal contents (Ni=0-118 ppm; Cr= 36-402 ppm) with slightly to well fractionated Mg#'s (51.37-65.84; Fig. 7, Table 3). The REE profiles for the CRB_1 suite are relatively flat with flat to slightly enriched LREE abundances (Ce/Yb_N=0.98-1.77; Fig. 8a). The primitive mantle-normalized multi-element plot for the CRB_1 suite has a relatively flat to slightly enriched character, with one sample having very low Nb contents (Fig. 8d).

The CRB_2 suite is chemically similar to the CRB_1 suite: SiO_2 (47.72-49.41%), TiO_2 (0.84-2.17%), Ti/V ratios, Zr (44-130 ppm), Nb (1-4 ppm), transitional metal contents (Ni=0-105 ppm; Cr= 60-282 ppm), and Zr/Y ratios (2.10-2.95; Fig. 7c, Table 3). Magnesium numbers for suite CRB_2 are lower and more fractionated than suite CRB_1 (45.81-59.30), and the major difference between CRB_1 and CRB_2 lies in their REE chemistry, as suite CRB_2 has quite a strong LREE depletion (Ce/Yb_N=0.84-2.17; Fig. 8b). The primitive-mantle-normalized plot for suite CRB_2 is also somewhat different, with two samples having low Nb relative to Th and La, consistent with arc-like rocks (Fig. 8e). However, the relative imprecision of the Th analyses makes any interpretation of arc influence somewhat tentative. Based on the aforementioned characteristics, suite CRB_1 has geochemical characteristics consistent with enriched mid-ocean ridge basalts (E-MORB); while the LREE depleted nature of suite CRB_2 is consistent with N-MORB parentage.

The CRB_3 suite has a different signature relative to the CRB_1 and CRB_2 suites. Although having similar SiO_2 and Zr contents (49.84-51.68% and 65-89 ppm, respectively), suite CRB_3 is characterized by lower TiO_2 (0.86-1.12) and Ti/V ratios, high and only slightly fractionated Mg#'s (61.07-71.11). It also has higher Nb (5.8-11.2 ppm), Ni (65-170 ppm), Cr contents (224-586 ppm), and Zr/Y ratios (3.95-4.77; Fig. 7c, Table 3). The REE pattern for suite CRB_3 is also different, characterized by a very steep, LREE enriched pattern (Ce/Yb_N=2.83-3.56), which decreases downward toward the HREE end (Fig. 8c). The primitive-mantle-normalized plot is similar with steep downward trends towards the HREE/HFSE end of the diagrams (Fig. 8d). Suite CRB_3 has some characteristics, at least in terms of their REE, to suite 2b; however, there are some major differences. Suite CRB_3 has lower average TiO_2, higher Mg#'s, lower total REE and



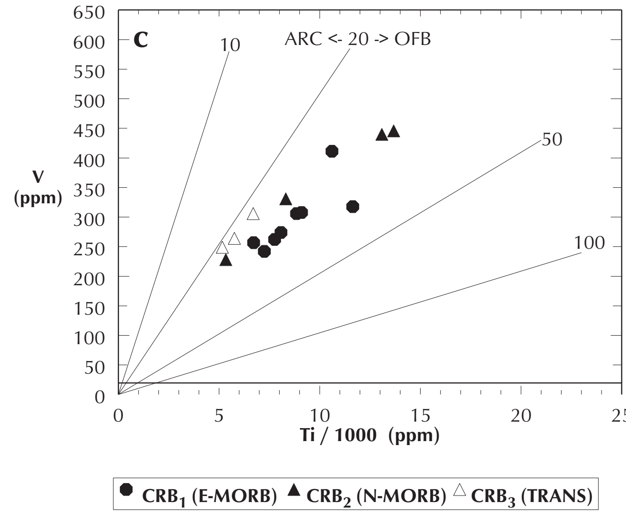


***Figure 7.** Discrimination diagrams of the Campbell Range belt mafic meta-volcanic rock. Fields in **a)** and **b)** from Winchester and Floyd (1977), and in **c)** modified from Shervais (1982).*

***Table 3.** Selected elemental concentrations and ratio ranges for the Campbell Range belt mafic meta-volcanic rocks. Values in brackets are the average values.*

Subgroup	CRB_1	Average	CRB_2	Average	CRB_3	Average
Mg#	51.37-65.84	(57.68)	45.81-59.30	(52.02)	61.07-71.11	(66.32)
SiO_2	42.69-50.63	(47.64)	47.72-49.41	(48.53)	49.84-51.68	(50.57)
TiO_2	1.08-1.86	(1.39)	0.84-2.17	(1.61)	0.86-1.12	(0.98)
Ce/Yb_N	0.98-1.77	(1.28)	0.84-2.17	(0.78)	2.83-3.56	(3.12)
Zr/Y	2.51-3.15	(2.74)	2.10-2.95	(2.51)	3.95-4.77	(4.30)
Zr	61-104	(77.63)	44-130	(93.75)	65-89	(77.67)
Nb	2-10	(5.75)	1-4	(2.75)	5.8-11.2	(8.40)
Ni	0-118	(62)	0-105	(35)	65-170	(131)
Cr	36-402	(263)	60-282	(151)	224-586	(445)

HFSE contents (Figs. 4b, 4e, 8c and 8f; Tables 1 and 2). These rocks are typed as LREE-enriched tholeiites and are somewhat transitional between arc and non-arc affinities (Fig. 7c); these characteristics will be addressed in the discussion.

DISCUSSION: SIGNIFICANCE OF GEOCHEMICAL DATA AND EXPLORATION IMPLICATIONS

The meta-volcanic rocks from the Finlayson Lake region have been subdivided into geochemical suites with a wide range of lithogeochemical signatures. However, certain consistencies arise between each of the stratigraphic units and these consistencies have implications for metallogenic models for the YTT in this region.

UNIT 2 MAFIC META-VOLCANIC ROCKS

The low-Ti rocks in unit 2 (suite 2a) are chemically similar to rocks found in forearc regions of both modern and ancient intraoceanic arc environments (Crawford et al., 1989; Pearce et al., 1992; Bloomer et al., 1995; Piercey et al., 1997; Bédard et al., 1998; Giaramita et al., 1998). The co-existence of suite 2a boninitic rocks with N-MORB (2c) and transitional tholeiitic (2b) rocks in unit 2 may seem somewhat disconcerting considering the latters' similarities to many ocean/back-arc basin environments; however, both MORB- and OIB-like magmatism have been documented together in arc environments (e.g., Coish et al., 1982; Johnson and Fryer, 1990; Kostopoulos and Murton, 1992; Piercey et al., 1997; Giaramita

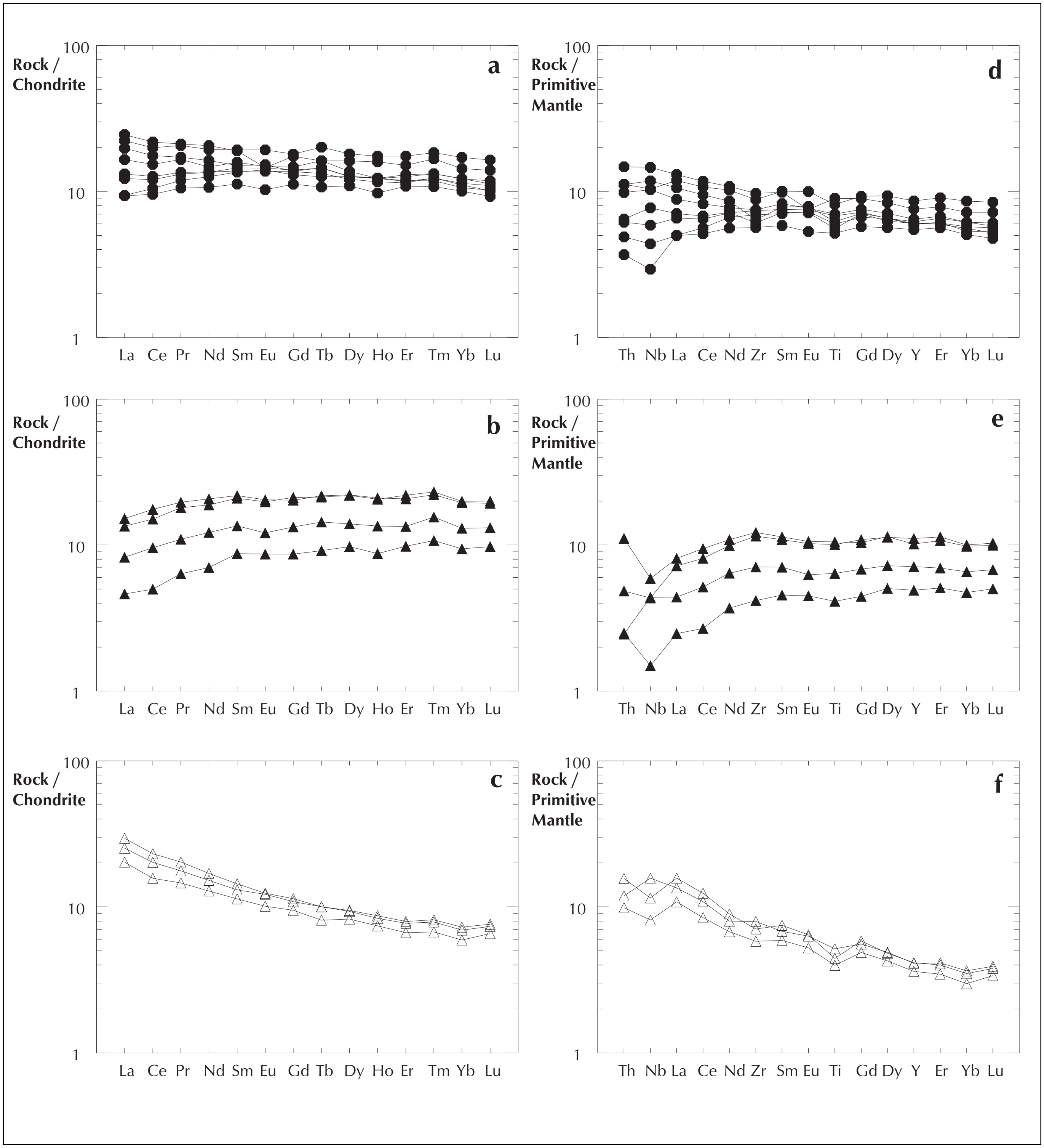


Figure 8. *Chondrite-normalized REE and primitive-mantle-normalized multi-element plots for the Campbell Range belt mafic meta-volcanic rocks:* ***a)*** *and* ***d)*** *– CRB_1 suite;* ***b)*** *and* ***e)*** *– CRB_2 suite; and* ***c)*** *and* ***f)*** *– CRB_3 suite. Chondrite normalization values from Taylor and McLennan (1985) and primitive mantle values from Sun and McDonough (1989).*

et al., 1998). These non-arc signatures may be a function of intra-arc or back-arc basin formation (e.g., Coish et al., 1982), forearc rifting/spreading (Bédard et al., 1998), and/or OIB and/or MORB source components involved in arc-tholeiite genesis (e.g., Faloon and Crawford, 1991; Kostopoulos and Murton, 1992). Clearly, our present low level of understanding of the region precludes inferences about any of the above processes; however, this will be a focus of our continuing research.

Unit 2 hosts volcanogenic massive sulphide mineralization near Fire Lake (Fyre Lake deposit). All three suites of mafic meta-volcanic rocks in unit 2 occur at Fyre Lake and it is not clear if mineralization is preferentially associated with a specific suite (see Sebert and Hunt, this volume). Petrological processes typically associated with this type of magmatism provide a rationale for this association. The low-Ti tholeiitic and boninitic rocks are likely melts of a mantle source from which at least one MORB-type melt has been previously extracted (e.g., Hickey and Frey, 1982; Crawford et al., 1989; Pearce et al., 1992). This in itself imparts a requirement for high-heat flow in order to induce a second melting (e.g., ~1200-1300^{o}C; Umino and Kushiro, 1989), which could act as the heat source for driving a hydrothermal system (cf. Swinden, 1991, 1996; Piercey et al., 1997). Furthermore, an extensional stress regime is a requirement for models for both boninite genesis in the plate overlying the subduction zone (Stern and Bloomer, 1992) and the genesis of MORB and transitional lavas in intra-arc/back-arc settings; such extensional regimes would provide the needed ground preparation required for the percolation of hydrothermal fluids. Although all unit 2 suites have potential to host VMS mineralization, we suggest that rocks of 2a suite are the most prospective due to the required high heat flow and extensional stress required in their formation.

UNIT 3 FELSIC META-VOLCANIC ROCKS

Unit 3 felsic meta-volcanic rocks have broadly calc-alkalic continental arc signatures; however, there are marked differences between the two sub-suites. The subtle divergence in the chemistry of the two felsic meta-volcanic suites and the SRPS is likely a function of the nature of melting. The flat HREE, low Zr/Y and Ce/Yb_N ratios, and relatively high Zr contents of suite 3a (Table 2, Fig. 6) are all features consistent with melting of a source in which amphibole or garnet was not stable (or fractionated out en-route to the surface; Rollinson, 1993; Lentz, 1998). Furthermore, the very low Eu contents (Eu/Eu* in Table 2, Fig. 6d) suggest either plagioclase fractionation en-route to their present position, or plagioclase as a restite phase in the source region (e.g., Campbell et al., 1982; Lesher et al., 1986; Barrie et al., 1993; Lentz, 1998). In contrast to suite 3a, suite 3b and SRPS show very minimal Eu anomalies and have higher Eu/Eu* values (Fig. 6, Table 2) suggesting that plagioclase fractionation has not been as important as in suite 3a. Furthermore, the steeper total REE patterns and HREE distribution, coupled with higher Zr/Y ratios are consistent with melting in a source whereby amphibole (± garnet) was stable as a restite phase, or was fractionated en-route to the surface (e.g., Lentz, 1998).

Suite 3a has a number of similarities to felsic meta-volcanic rocks in many world-class volcanogenic massive sulphide camps. For instance, Campbell et al. (1982), Lesher et al. (1986) and Barrie et al. (1993) showed that ore-bearing Archean felsic volcanics in the Superior Province (and the Abitibi Belt of the latter) had signatures with low La/Yb_N (~Ce/Yb_N), Zr/Y and Eu/Eu* values and suggested that this signature was a function of shallow-level fractionation in subvolcanic sills and magma chambers (e.g., suite 3a). In contrast, ore-barren or weakly mineralized rocks had higher La/Yb_N, Zr/Y and Eu/Eu* values. They attributed this signature to magma generation at deeper depths with lesser subvolcanic chamber fractionation (op cit; e.g., suite 3b and SRPS). Similarly, Lentz (1998), in a detailed petrotectonic study of Phanerozoic VMS camps worldwide, also showed a similar distribution of La/Yb_N, Zr/Y and Eu/Eu* distributions.

We suggest that although all of the felsic volcanic rocks have the potential to host mineralization, suite 3a is the most prospective on a regional scale. Our reasons for this arise primarily from the petrological characteristics. In particular, the evidence for shallow-level genesis and fractionation in suite 3a suggests that they are likely associated with shallow-level subvolcanic intrusions. This itself provides a potential heat source to drive hydrothermal circulation cells required to form related VMS deposits (e.g., Campbell et al., 1981; Galley, 1995, 1996). Furthermore, the chemical signature of suite 3a also suggests an extensional setting (e.g., Fig. 5c) and this may have resulted in ground preparation required for VMS formation (for details see Lentz, 1998).

CAMPBELL RANGE BELT META-BASALT

The geochemistry of Campbell Range belt meta-basalt is consistent with generation in an ocean basin (and/or back-arc/marginal) basin environment (e.g., Plint and Gordon, 1997; this study). The three different suites in the CRB likely represent varying degrees of depleted mantle (CRB_1) versus plume/hot spot influence (CRB_2 and CRB_3). The typical N-MORB chemistry of suite CRB_1 is consistent with its formation from a depleted mantle source (McKenzie and Bickle, 1988); whereas, the progressive LREE and LFSE enrichments in the CRB_2 and CRB_3 suites indicate increased plume- (OIB-like) type mantle being involved in their genesis (e.g., Langmuir et al., 1992).

VMS mineralization in the CRB is associated with generic MORB-type magmatism; no distinctive chemical signature is apparent. This association is not unreasonable considering that temperatures associated with this type of magmatism are likely on the order of 1300-1500^{o}C (McKenzie and O'Nions, 1991; Langmuir et al., 1992). Furthermore, spreading centres associated with the aforementioned magmatism would provide fractures and faults that could act as conduits for hydrothermal fluids. In contrast, suite CRB_3 likely represents off-axis magmatism, and in contrast, would have lower heat flow and likely be displaced from favourable conduits for upwelling (and downwelling) hydrothermal fluids. Hence, we suggest that suites CRB_1 and CRB_2 are the most prospective hosts within the CRB from a regional exploration program viewpoint.

SUMMARY AND CONCLUSIONS

The preliminary work presented in this paper illustrates the chemostratigraphic complexity that exists in Yukon-Tanana Terrane of the Finlayson Lake region. The key preliminary findings of our research include:

1) Unit 2 mafic meta-volcanic rocks consist of three suites: a) a low Ti tholeiitic to boninitic suite (2a); b) a transitional (OIB) tholeiite suite (2b); and c) and N-MORB suite (2c). These suites have signatures consistent with formation in an island arc setting, similar to forearcs in the modern southwest Pacific (e.g., Bonin-Marianas, Tonga-Kermadec). Suite 2a meta-volcanic rocks are likely the most prospective hosts for VMS mineralization as they are associated with high heat flow and extensional stress (rifting?) regimes.

2) Unit 3 felsic meta-volcanic rocks and coeval plutonic rocks of the Simpson Range Plutonic Suite have calc-alkalic continental arc signatures. The meta-volcanic rocks can be divided into two suites: a) a low Ce/Yb_N, Zr/Y and Eu/Eu* suite (3a); and 2) a higher Ce/Yb_N, Zr/Y, and Eu/Eu* suite (3b). Suite 3a is likely the most prospective for volcanogenic massive sulphide mineralization as it exhibits evidence for generation at shallow crustal levels and shallow-level crystal fractionation, possibly in subvolcanic intrusive complexes. Shallow-level intrusions would provide the necessary heat pumps required for hydrothermal fluid circulation and VMS genesis (e.g., Campbell et al., 1981; Galley, 1996).

3) The Campbell Range belt contains three suites, all of which appear to be of ocean basin and/or marginal (back-arc?) basin affinity: a) a slightly LREE-enriched suite of enriched mid-ocean ridge basalts (CRB_1); b) a suite of normal mid-ocean ridge basalts (CRB_2); and c) a high Mg#, LREE-enriched tholeiitic basalt suite (CRB_3). Suites CRB_1 and CRB_2 are associated with spreading centres and high heat flow and are the most prospective hosts for VMS mineralization in the Campbell Range belt. This setting would provide not only a heat source for fluid circulation, but spreading would also provide faults and fracture conduits for upwelling and downwelling hydrothermal fluids.

Although there have been new insights into the geological evolution of YTT in the Finlayson Lake district over the past several years (e.g., Murphy, 1998; Hunt, 1998a, b; Murphy and Piercey, this volume), the results presented here, and by the above authors, have enlightened us to the complex geological, geochemical and tectonic relationships in this region. With continuing multidisciplinary field, geochemical, geochronological and isotopic studies we shall obtain a clearer picture of this enigmatic terrane of the Canadian Cordillera.

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