Reconnaissance geological and geochemical studies of the Joe Mountain Formation, Joe Mountain region (NTS 105D/15), Yukon

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ABSTRACT

The Joe Mountain area of the Yukon contains Middle Triassic to Upper Triassic volcanic, sedimentary and intrusive rocks of the Stikine Terrane. The Ladinian (~237 to 228 Ma) rocks of the Joe Mountain Formation of Stikinia are divided into four units, including: 1) a lowermost mafic-ultramafic complex ($mTJM_4$); 2) a lower basalt-flow-dominated unit ($mTJM_3$); 3) a volcaniclastic- and sedimentary-rock-dominated unit; and 4) and uppermost unit of black pillow basalts and volcaniclastic rocks ($mTJM_4$). In the Joe Mountain Formation there is a general increase in the abundance of volcaniclastic and sedimentary material, and a decrease in flow material, away from Joe Mountain suggesting that Joe Mountain is a volcanic centre.

Hematite-magnetite iron formation was discovered in 2004 interlayered with unit $mTJM_3$ basalts. These iron formations have anomalous metal concentrations, but more importantly, have hydrothermal geochemical signatures (e.g., high Fe/Al ratios) similar to volcanogenic massive sulphide-associated iron formations globally.

RÉSUMÉ

La région du mont Joe, au Yukon, renferme des roches volcaniques, sédimentaires et intrusives du terrane de Stikine, datant du Trias moyen à supérieur. Les roches du Ladinien (~237 à 228 Ma) de la formation de Joe Mountain se divisent en quatre unités, comprenant : 1) à la base un complexe mafique-ultramafique ($mTJM_4$); 2) une unité inférieure dominée par une coulée basaltique ($mTJM_3$); 3) une unité à prédominance de roches volcanoclastiques et sédimentaires et 4) une unité supérieure formée de basalte noir en coussins et de roches volcanoclastiques ($mTJM_4$). De façon générale, l'abondance des matériaux volcanoclastiques et sédimentaires augmente, alors que la quantité de matériaux de coulées volcaniques diminue, à mesure qu'on s'éloigne du mont Joe, indiquant ainsi que ce dernier constituait un centre volcanique.

La formation de fer à hématite et magnétite, découverte en 2004, est interstratifiée de basaltes de l'unité $mTJM_3$. Ces formations de fer présentent des concentrations de métal anomales, mais, ce qui est plus important, elles présentent des signatures géochimiques hydrothermales (par ex. des rapports Fe/Al élevés) similaires à celles de formations de fer associées ailleurs dans le monde à des sulfures massifs volcanogènes.

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INTRODUCTION

The Stikine Terrane in the Whitehorse to Carmacks region of Yukon represents one of the largest accumulations of Mesozoic Stikine Terrane rocks in the Canadian Cordillera (Fig. 1). This accumulation of Stikine Terrane rocks has been termed the Whitehorse Trough (e.g., Wheeler, 1961) and consists of predominantly Mesozoic volcanic, intrusive and sedimentary rocks (Hart, 1997). In 2004, the author initiated a study of the field, tectonic and metallogenic setting of Mesozoic volcanic and volcano-sedimentary rocks of the Whitehorse Trough. This research project is a complement to other ongoing research aimed at assessing the mineral and petroleum potential of the Whitehorse Trough (e.g., Lowey, 2004; Lowey, this volume; Long, this volume; Colpron, this volume; Tizzard, this volume). In this paper, preliminary field and geochemical results of studies of the Middle Triassic (Ladinian) Joe Mountain Formation in the Joe Mountain region of southern Yukon are presented. In particular, this paper provides: 1) geological and facies relationships for volcanic, intrusive and sedimentary rocks of the Joe Mountain Formation; 2) a preliminary assessment of initial results from lithogeochemical studies of rocks from the Joe Mountain Formation; and 3) results from geological and geochemical analyses of hydrothermal iron formations discovered during the 2004 field season. The key initial results of this study are that the Joe Mountain region likely represents a volcanic centre (e.g., Hart, 1997) that formed within an ocean floor setting. Furthermore, the iron formations found during 2004 have hydrothermal signatures and suggest that this area has potential to host volcanogenic massive sulphide (VMS) mineralization.

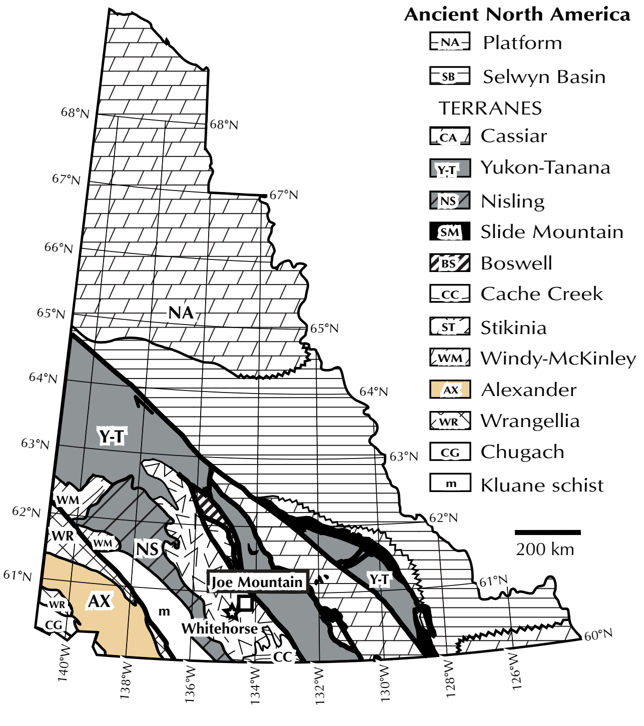

Figure 1. *Yukon terrane map, modified from Colpron (this volume).*

GEOLOGICAL RELATIONSHIPS IN THE JOE MOUNTAIN AREA

The Joe Mountain area is approximately 30 km northeast of the city of Whitehorse (Fig. 1). The area consists predominantly of Triassic to Jurassic volcanic, volcano-sedimentary and sedimentary rocks of the Stikine Terrane; Cretaceous volcanic rocks; and Cretaceous intrusive rocks of the Teslin, Whitehorse and Mount McIntyre plutonic suites (Fig. 2; Hart, 1997, and references therein). The Joe Mountain Formation is one of the lowermost units within the Stikine Terrane in the Whitehorse region. It stratigraphically overlies the Mississippian and older Takhini assemblage and underlies the Triassic-Jurassic Lewes River Group (Figs. 1, 2, 3; Tempelman-Kluit, 1984; Hart, 1997).

Legend, Figure 2 (facing page)

Middle Cretaceous

⊞ **mKdW:** Cap Creek pluton: medium grey-weathering, medium-grained, equigranular, biotite-hornblende granodiorite

▨ **mKgt:** M'Clintock granodiorite: white- to pale-weathering, recessive, leucocratic, equigranular biotite-hornblende granodiorite

Lower to Middle Jurassic
Laberge Group

▒ **JL:** brown- to tan-weathering sedimentary rocks including siltstone, greywacke, interbedded silt and sand couplets; minor conglomerate and limestone

▦ **JR: Richthofen formation:** dark weathering, black, finely laminated turbiditic mudstone and sandstone

Middle Triassic
Aksala formation

▤ **uTH: Aksala (undivided):** undifferentiated sedimentary rocks with siltstone, shale, sandstone, conglomerate and diamictite; locally limestone.

▥ **uTH: Hancock member:** white-weathering massive to poorly bedded, bioclastic limestone, marble and skarn; some sandy limestone

Middle Triassic (Ladinian)
Joe Mountain Formation

■ **mJM_4**: dark weathering cumulate gabbro, pyroxenite, anorthosite and diorite; locally, some diabase dykes

■ **mJM_3**: dark grey weathering pillowed basalts; minor diabase; pillows tubular and locally with radial, concentric and tortoise shell fracturing

▨ **mJM_2:** chaotic assemblage of volcaniclastic and sedimentary rocks; mostly turbiditic with significant volcanic and carbonate component

▒ **mJM_1 or mJM_2**

▥ **$mTJM_1$:** black- to grey-weathering pillowed basalts; some pyritee-quartz-calcite weathering

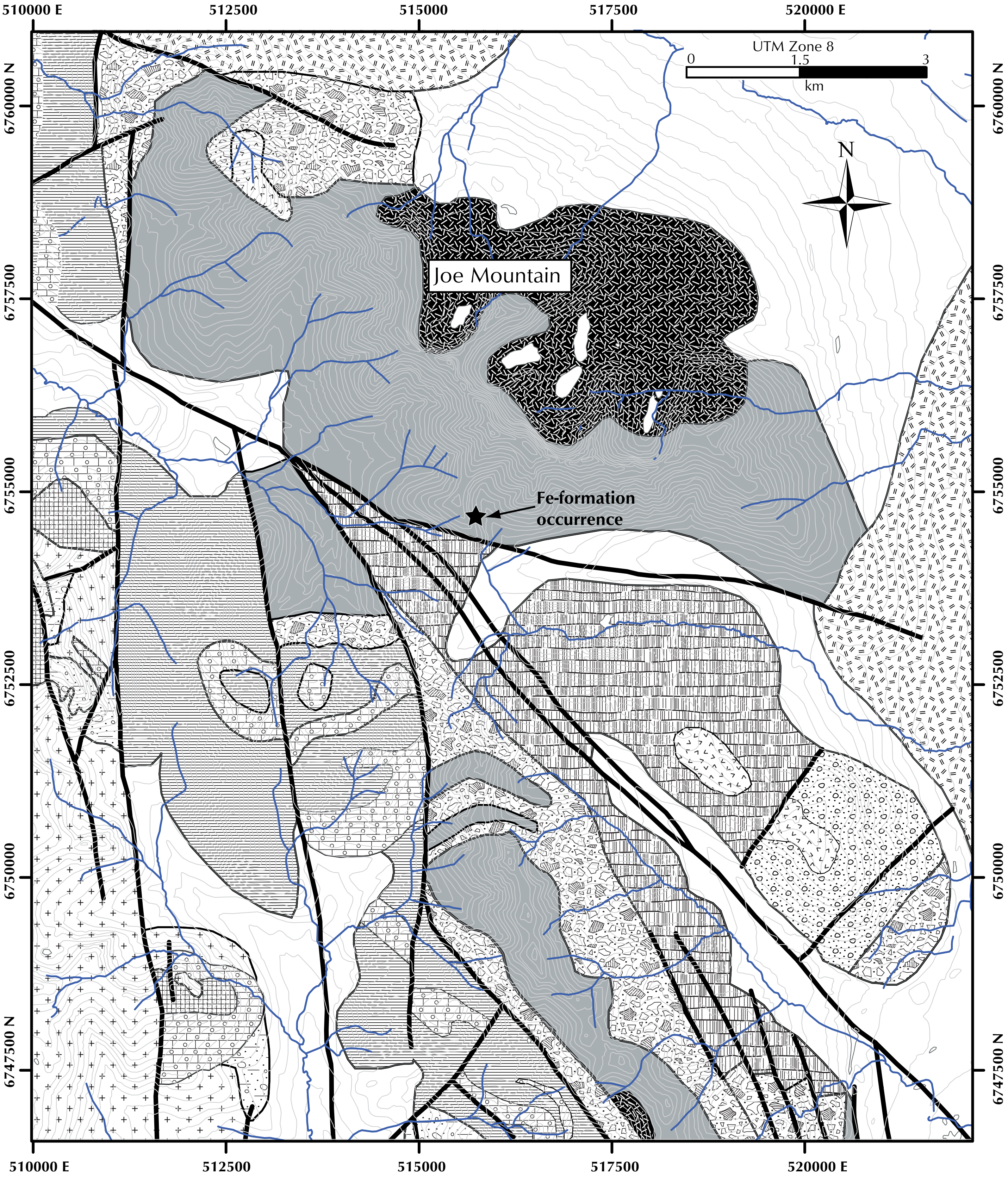

Figure 2. *Geological map of the Joe Mountain region. Map modified from Hart and Hunt (1997). Legend on previous page.*

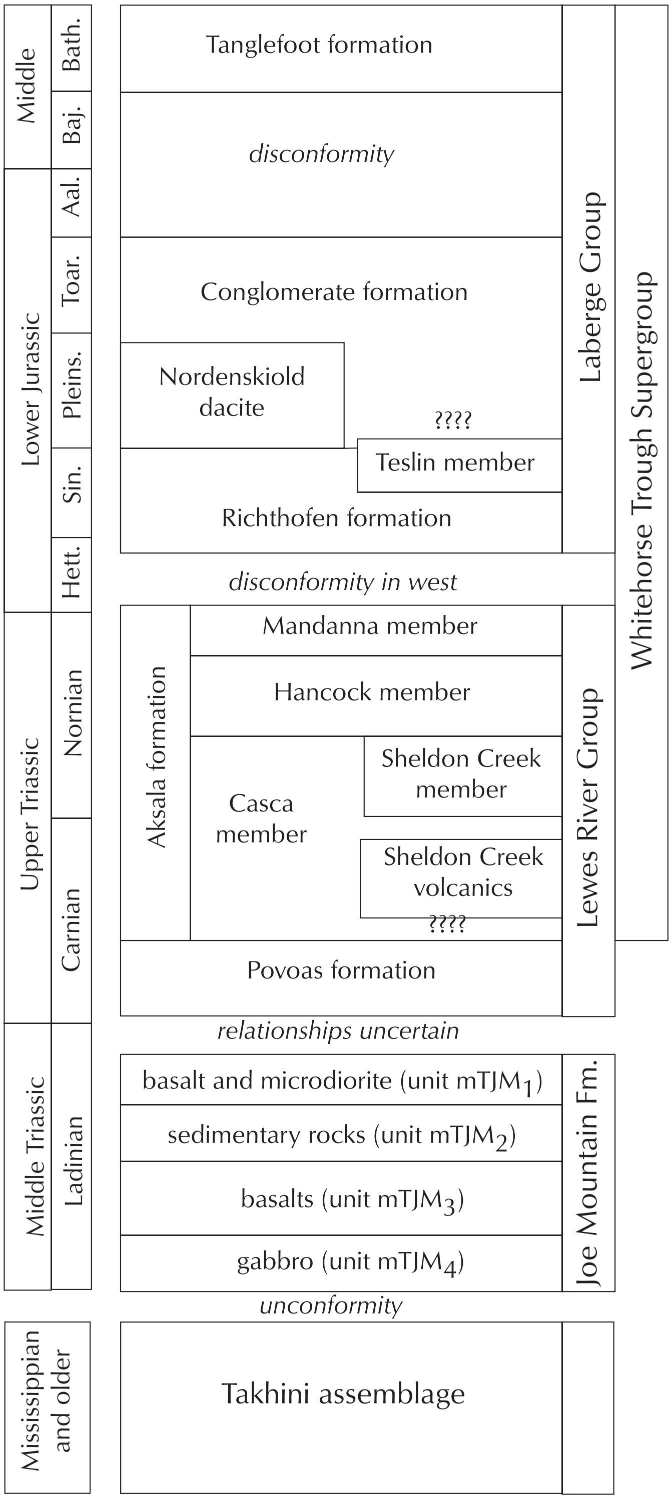

Figure 3. *Stratigraphic relationships of Stikinia within the Whitehorse Trough. Figure modified from Hart (1997). Abbreviations: Hett.=Hettangian, Sin.=Sinemurian, Pleins.=Pleinsbachian, Toar.=Toarcian, Aal.=Aalenian, Baj.=Bajocian, Bath=Bathonian, Fm=Formation.*

The Joe Mountain area is the type locality for the Joe Mountain Formation (Hart, 1997). The formation consists of Middle Triassic (Ladinian — 237 to 228 Ma; based on fossil ages in Hart, 1997 and the time scale of Gradstein et al., 2004) mafic volcanic, high-level subvolcanic (diabase/microdiorite), volcano-sedimentary, sedimentary, and mafic-ultramafic intrusive rocks. Hart (1997) erected the formational status of these volcanic and intrusive rocks as a distinctive stratigraphic entity from the younger Povoas Formation of the Lewes River Group (Fig. 3). He further suggested that the Joe Mountain Formation has some similarities to the Cache Creek Terrane, but depositional ties to Stikinia explain its inclusion within the Stikine Terrane.

In the Joe Mountain region, the Joe Mountain Formation is subdivided into four units: $mTJM_1$ through $mTJM_4$ (Hart, 1997). The first three units ($mTJM_1$-$mTJM_3$) consist predominantly of volcanic, volcaniclastic and sedimentary rocks, whereas the fourth ($mTJM_4$) is a mafic to ultramafic intrusive unit (Figs. 2 and 3).

Unit $mTJM_4$ intrusive rocks intrude the volcanic assemblages, but are interpreted to be synvolcanic intrusions coeval with the volcanic assemblages (Hart, 1997). This relationship is supported by geochemical relationships (see below). The intrusive rocks of unit $mTJM_4$ form the core of Joe Mountain (Fig. 2) and consist of gabbro, pyroxenite, leucogabbro and lesser anorthosite; diabase dykes cross-cut the gabbro in places. The bulk of intrusive rocks consist of coarse cumulate gabbro that contain coarse centimetre-scale pyroxene and plagioclase cumulate grains, and locally contain coarse pegmatoidal patches of pyroxene and plagioclase (Fig. 4a). Patches of leucogabbro, anorthosite and pyroxenite are commonly gradational with the cumulate gabbroic rocks. The rocks are fairly fresh and unaltered in places and are observed in thin section to contain very well-preserved intercumulus clinopyroxene and cumulate plagioclase. Most rocks, however, exhibit some degree of alteration and/or metamorphism. For example, most samples contain patches and millimetre- to centimetre-scale veinlets of calcite, epidote and quartz, with many pyroxene grains replaced by chlorite and actinolite, and feldspar grains replaced by minor sericite. Given the excellent textural preservation of these rocks (Fig. 4a,b), it is interpreted that these mineral assemblages represent hydrothermal alteration due to high-temperature seawater-rock interaction (e.g., Gillis and Thompson, 1993; Galley, 1993). Medium-grained, salt- and pepper-textured,

Figure 4. *Joe Mountain Formation:* ***(a)*** *cumulate gabbro with cumulate pyroxene and plagioclase from unit mTJM$_4$;* ***(b)*** *unit mTJM$_4$ gabbro cross-cut by unit mTJM$_4$ diabase dyke on Joe Mountain;* ***(c)*** *pillow basalt from unit mTJM$_3$ with radial cooling fractures;* ***(d)*** *pillow basalt from unit mTJM$_3$ with tortoise shell fracturing due to seawater-rock interaction.*

~045°-trending diabase dykes (Fig. 4b; sheeted dykes?) cross-cut the gabbroic rocks in a few localities. These diabase dykes are straight-walled and likely intruded into partly solidified gabbro. They contain similar hydrothermal alteration assemblages as the gabbro, however, which suggests that they are broadly coeval with the gabbroic rocks of unit mTJM$_4$.

Unit mTJM$_3$ is the lowermost volcanic unit within the Joe Mountain Formation and consists of a well preserved sequence of basaltic lava flows with lesser volcano-sedimentary rocks (Figs. 2 and 3). Well preserved pillow basalt flows are the predominant rock type throughout this unit. In general, the flows are greenish to grey-black, and aphyric to weakly plagioclase-phyric. The pillows are typically 50 to 60 cm in diameter but some are as large as 1.5 m in size and tubular in shape. Most pillows exhibit radial and concentric cooling fractures (Fig. 4c), which indicate rapid cooling in the presence of water, and have thin centimetre-scale rinds composed of calcite and chlorite. In most localities the pillows exhibit a tortoise shell fracturing on their outer surfaces (Fig. 4d) due to rapid quenching of the lavas upon interaction with seawater. In addition, some pillows exhibit pillow tube forms, with one lava tongue extruding through another pillow (Fig. 5a; McPhie et al. 1993). Notably, the pillows are very densely packed on a regional scale and there is very little reworked and resedimented volcanic rock between pillows. Collectively, these features indicate that high effusion rates were prevalent at the time of

Figure 5. *Joe Mountain Formation:* ***(a)*** *unit mTJM$_3$ pillow basalts illustrating pillow tubes, with one flow-tube coming out of an original pillowed flow;* ***(b)*** *unit mTJM$_2$ laminated marble turbidites with recessive carbonate layers and more resistant sandy layers;* ***(c)*** *unit mTJM$_2$ finely laminated volcanic sandstone turbiditic rocks with very fine ash (?) layers;* ***(d)*** *unit mTJM$_2$ heterolithic conglomerate.*

deposition, and that there was little or no quiescence in between volcanic episodes to allow for abundant hyaloclastite formation or resedimentation (McPhie et al., 1993; Gibson et al., 1999). Where there are volcaniclastic rocks, they consist of monolithic tuff breccias with angular fragments and have limited areal extent (metres to tens of metres). Styles of hydrothermal alteration affecting rocks of this unit include millimetre-scale veinlets of calcite and quartz; minor epidote; and replacement of original glass by minor chlorite, epidote and clays. Despite this minor hydrothermal alteration, these rocks are very well preserved, as illustrated by the results of the geochemistry described below.

Unit mTJM$_2$ consists of mixed sedimentary and volcaniclastic rocks and is very chaotic in nature (e.g., Hart and Hunt, 1997). The unit contains a variety of rock types but is dominated by carbonate (marble) turbidites, volcanic-derived turbidites and associated rocks, and heterolithic conglomerates. Within the formation, marble layers of the unit are conformable with unit mTJM$_3$. Marble units within the formation are grey to tan, and are recrystallized with grey recessive bands that alternate with more resistant tan, sandier bands (Fig. 5b). These layers may represent reworked and resedimented carbonate detritus in turbidite layers. Volcanic-derived turbidites are composed of glassy, ash-like material in sandy to silty black to grey-green sand-silt couplets (Fig. 5c). In some localities, mTJM$_3$ basalt flows and conglomerate layers of mTJM$_2$ are interlayered with coarse conglomerates made up of centimetre-scale fragments of marble, siltstone, chert and mudstone within a matrix of granule-sized sandy material. There are also pebble- to cobble-conglomerates in this unit that are matrix-supported and are composed of subrounded clasts of grey quartz porphyry dacite, white rhyolite, grey siltstone and chert (Fig. 5d). These conglomerates are commonly interlayered with granular sandstone that is composed of greenish detrital granules of potentially volcanic origin. Collectively, the rock types and textures in unit mTJM$_2$ suggest that this package formed from volcanic- and carbonate-rich debris flows.

Unit mTJM$_1$ is a second layer of basalts that are distinguished from those of mTJM$_3$ by their black weathering and mostly smaller pillow diameters. The pillowed flows are generally densely packed, range from very fine-grained (e.g., glassy) to medium-grained, and in places are recrystallized. Typically the pillows are black to dark grey with bulbous margins and are up to 1.5 m long, but are typically 30 to 80 cm in diameter (Fig. 6a). Most of the pillows have no rinds, but do have radial cooling fractures in places (Fig. 6b), and some are amygdaloidal. In some localities the fractures and amygdules in the pillows are filled with quartz and pyrite. Although not always present, the interpillow regions commonly contain angular hyaloclastite fragments. Interlayered with the pillows are matrix- to clast-supported pillow breccias that contain 1 to 2 cm rounded to angular basalt clasts. The association between the pillows and pillow breccias is consistent with a lobe and breccia volcanic facies association.

Hart (1997) suggested that Joe Mountain represents a volcanic centre, and results from regional facies relationships support this assertion. For example, in localities away from Joe Mountain, toward the south and southeast, the abundance of volcaniclastic rock and reworked sedimentary rock increases (e.g., unit uTJM$_2$) and the amount of flow material decreases. Furthermore, in the region of Joe Mountain, unit uTJM$_3$ is characterized by very large flows and little hyaloclastite and volcaniclastic rock, which suggests very high eruption rates with very little reworking in between flow events. The latter features are indicative of high effusion rates, which suggest closer proximity to their vent source (Gibson et al., 1999). In addition, the very large pillowed sequence near Joe Mountain is proximal to the mafic-ultramafic intrusive rocks and diabase dykes of unit uTJM$_4$ (Fig. 2). Combined with the geochemistry below, these relationships suggest that the rocks of unit uTJM$_4$ are synvolcanic intrusions to the volcanic rocks. The synvolcanic nature of the intrusions implies that the Joe Mountain region represents a volcanic centre or near-vent environment.

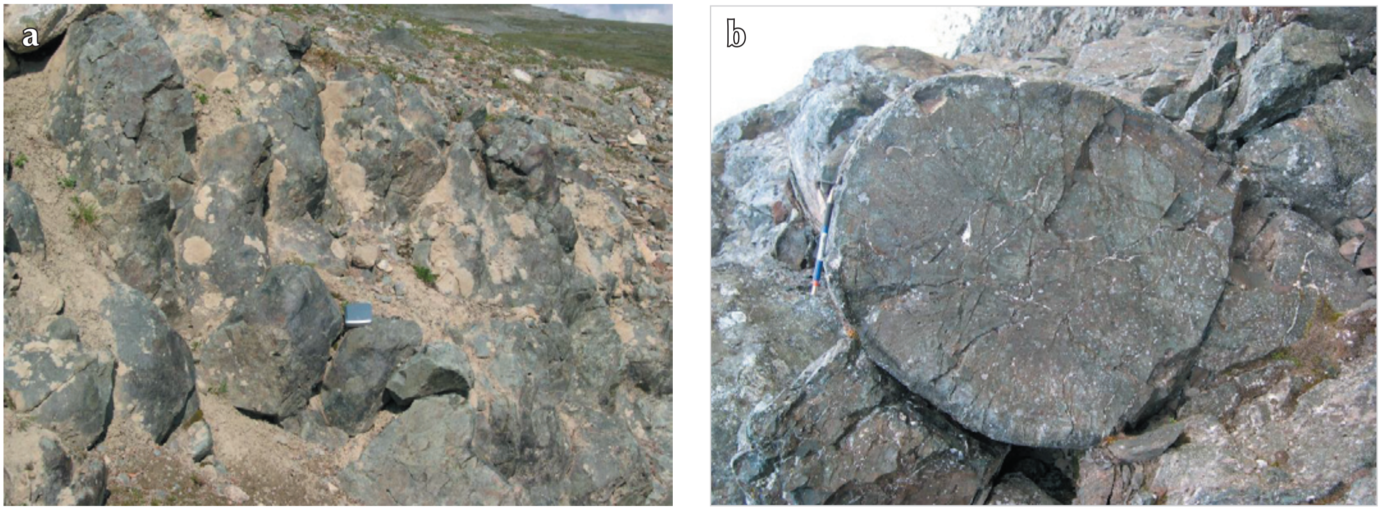

Figure 6. *Photos of the Joe Mountain Formation:* ***(a)*** *unit mTJM$_1$ black-coloured pillow basalts; and* ***(b)*** *unit mTJM$_1$ pillow basalt with radial cooling fractures.*

GEOCHEMISTRY: PRELIMINARY RESULTS

Samples from the Joe Mountain Formation were analysed at Activation Laboratories in Ancaster, Ontario. Major elements and material lost on ignition (LOI) were analysed by fused-disc X-ray fluorescence (XRF), whereas the trace elements Ni, Cr, V, Nb, Zr and Y were analysed by pressed-pellet X-ray fluorescence (XRF). During the course of the study, duplicate analysis and reference materials were analysed to test precision and accuracy. Precision for major elements is <5% of the reported values, and for the trace elements it is <10%, with most <7%. Accuracy, as measured from repeat analysis of reference materials, is <5% relative difference for most major elements, and is <10% relative difference for trace elements, with most <7% relative difference.

Preliminary results for the Joe Mountain Formation pillowed and massive volcanic rocks, and gabbro and diabase instrusive rocks are illustrated in Figure 7. Most of the samples from the Joe Mountain Formation have basaltic to andesitic SiO_2 contents (46 to 55%, average=50.5%), which is consistent with field calls for rocks of the formation. The rocks have relatively low Al_2O_3/Na_2O index values (<5.5; Spitz and Darling, 1978), moderate Na_2O values (Fig. 7a), and relatively low LOI values (average =2.9%), suggesting that the rocks are relatively fresh. Furthermore, on an alteration box plot, the samples have low Hashimoto alteration index (Saeki and Date, 1980) values and low chlorite-carbonate-pyrite index (Large et al., 2001) values, with most samples plotting in the field for least-altered andesites/basalts (Fig. 7b), which further suggests that the rocks are relatively fresh.

The immobile high field strength element (HFSE: Zr, Nb, Y) and transition element (TiO_2, V) systematics of the Joe Mountain Formation rocks are illustrated on Figure 7c-e. The bulk of the Joe Mountain Formation mafic rocks have sulbalkalic Nb/Y ratios (<0.7) and basaltic Zr/TiO_2 ratios (Fig. 7c), consistent with their SiO_2 content determinations. Most of the samples have Zr/Y ratios <4, indicative of a tholeiitic basaltic affinity (Fig. 7d; e.g., Barrett and MacLean, 1999). The Ti-V systematics of the Joe Mountain Formation basaltic rocks indicate a mid-ocean ridge basalt (MORB) or back-arc basin (BAB) affinity (Fig. 7e), which is also supported by elevated TiO_2 contents (0.52-3.08%, average 1.55%). Further rare-earth element and HFSE geochemical work will be required to further test and refine this tectonic discrimination.

It is also notable that there are no significant variations in the geochemical signatures of the mafic rocks from the different volcanic units of the Joe Mountain Formation (Fig. 7a-e). Furthermore, there is overlap between the trace element systematics of the volcanic rocks and intrusive rocks of the formation, which suggests that they are coeval and were derived from similar mantle source regions (Fig. 7a-e).

MINERAL OCCURRENCES AND ASSAY RESULTS

Numerous occurrences have been previously described from the Joe Mountain region, with most being gold occurrences (Hart, 1997). In 2004, the author discovered an iron formation occurrence south of Joe Mountain (UTM: 515584E, 6754534N, NAD83 Datum, Zone 8). The occurrence consists of Algoma-style iron formation (Peter, 2003) that occurs in a 2- x 2-m-wide outcrop and is approximately 2 m thick (Fig. 8a). Float from the occurrence trends approximately 1 to 2 km southwest of the occurrence, which suggests that the iron formation may have some lateral extent. The iron formation is reddish, is jasperoidal, and is interlayered with pillow lavas of unit $mTJM_3$. The iron formation is composed primarily of hematite with wispy 2- to 3-mm-wide magnetite layers and quartz (Fig. 8a). The unit does not contain significant sulphide minerals but is interpreted to represent a hydrothermal precipitate, based on the lateral extent of the unit, its occurrence as drapings around pillow lavas, and its geochemical characteristics (see below).

Reflected and transmitted light microscopy of the iron formations illustrate that they are made up primarily of hematite, magnetite, quartz, apatite and minor pyrite. Hematite and quartz are the dominant minerals in the iron formation. Quartz occurs as polycrystalline, rounded aggregates that are intergrown with the hematite. Hematite generally occurs in masses that contain ovoidal grains of hematite with deep red internal reflections and commonly contain inclusions of quartz and magnetite (Fig. 8b). Magnetite typically occurs as irregularly shaped, wispy aggregates in between the hematite masses (Fig. 9d). The magnetite is typically euhedral to subhedral, has lamellar twinning in places, and is commonly intergrown with apatite (Fig. 8c,d). Apatite also occurs as inclusions in the magnetite in some places. Pyrite is sparse in the iron formations, but is present as irregular, blebby-shaped inclusions in magnetite (Fig. 8d).

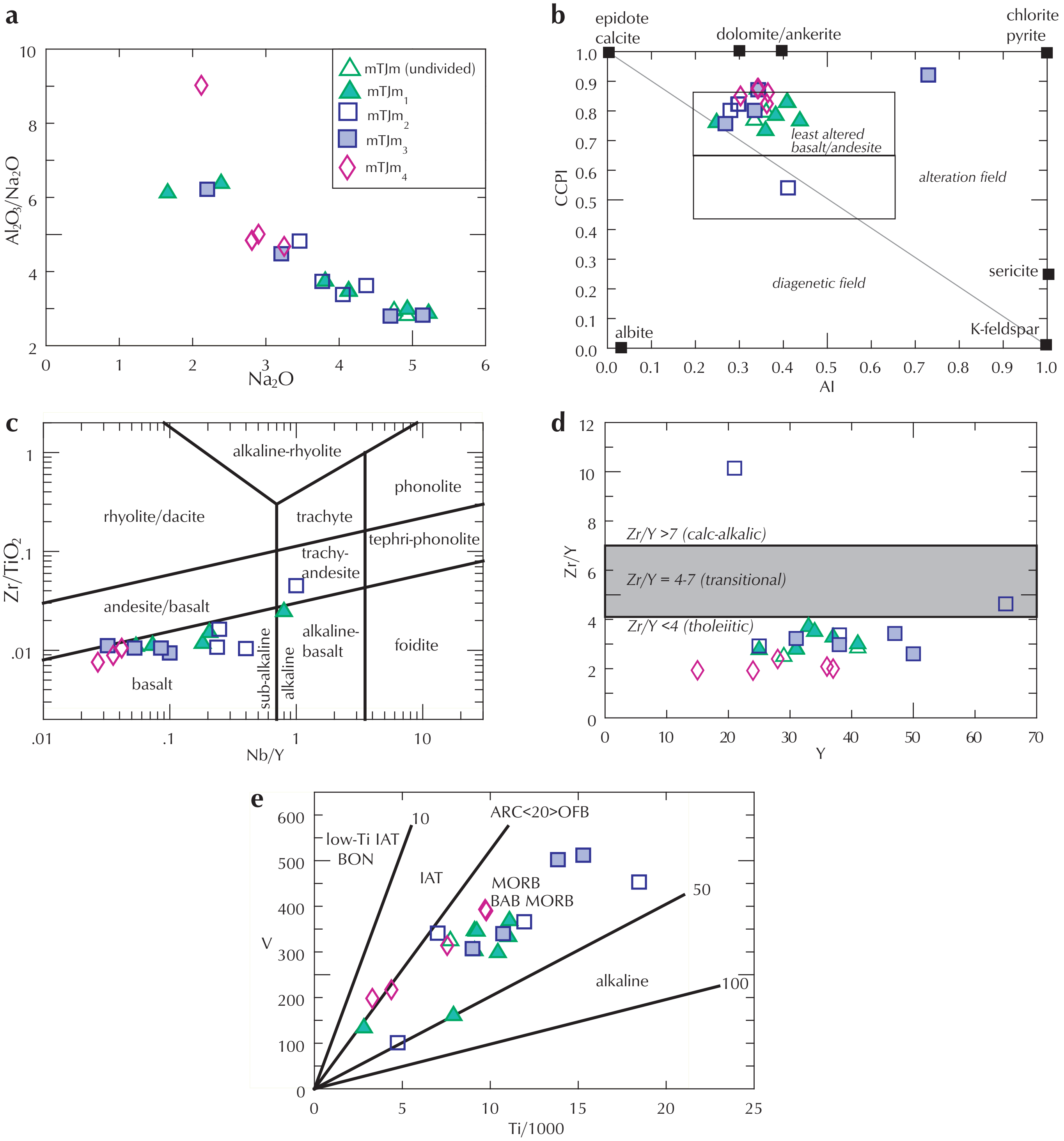

Figure 7. Plots of preliminary lithogeochemical data for the Joe Mountain Formation igneous rocks: ***(a)*** *Al_2O_3/Na_2O (Spitz-Darling index; Spitz and Darling 1978) versus Na_2O plot;* ***(b)*** *alteration box plot with chlorite-carbonate-pyrite index (CCPI) versus alteration index (AI). Modified from Large et al. (2001);* ***(c)*** *Pearce (1996) version of the Winchester and Floyd (1977) Zr/TiO_2 versus Nb/Y diagram;* ***(d)*** *Zr/Y versus Y diagram outlining tholeiitic versus calc-alkalic affinities, based on the concepts of Barrett and MacLean (1999); and* ***(e)*** *Ti versus V discrimination diagram of Shervais (1982). All samples from units mTJM (undivided), and $mTJM_1$ to $mTJM_3$ are extrusive rocks (e.g., flows, pillow lavas), whereas $mTJM_4$ is intrusive in nature (e.g., gabbro, diabase). Abbreviations: IAT=island arc tholeiites, BON=boninites; ARC=arc; BAB=back-arc basin; MORB=mid-ocean ridge basalt; OFB=ocean floor basalt.*

Two samples were taken from the outcrop and assayed with the Group 1F-MS package at Acme Analytical Laboratories. The samples were digested using an aqua regia digest and subsequently analysed using an inductively coupled plasma mass spectrometer (ICP-MS); the results are presented in Table 1 and Figure 9. There are anomalous metal abundances within the iron formation samples; however, the aqua regia digest likely underestimates the actual total metal content of the samples because it does not totally dissolve the sample, particularly material residing within silicate or oxide phases. Nonetheless, these geochemical results can be used to test whether the iron formations have a hydrothermal signature, and by association, if there was hydrothermal activity within the basin in which the Joe Mountain Formation and these iron formations were deposited.

Numerous workers have considered Algoma-type iron formations as potential vectors to volcanogenic massive sulphide (VMS) or seafloor vent-style mineralization (e.g., Peter, 2003, and references therein), and have devised chemical means of delineating hydrothermal versus detrital sedimentary signatures in these exhalative rocks. In general, the greater the hydrothermal component in the iron formation, the higher the iron content relative to aluminum and other detrital sedimentary components

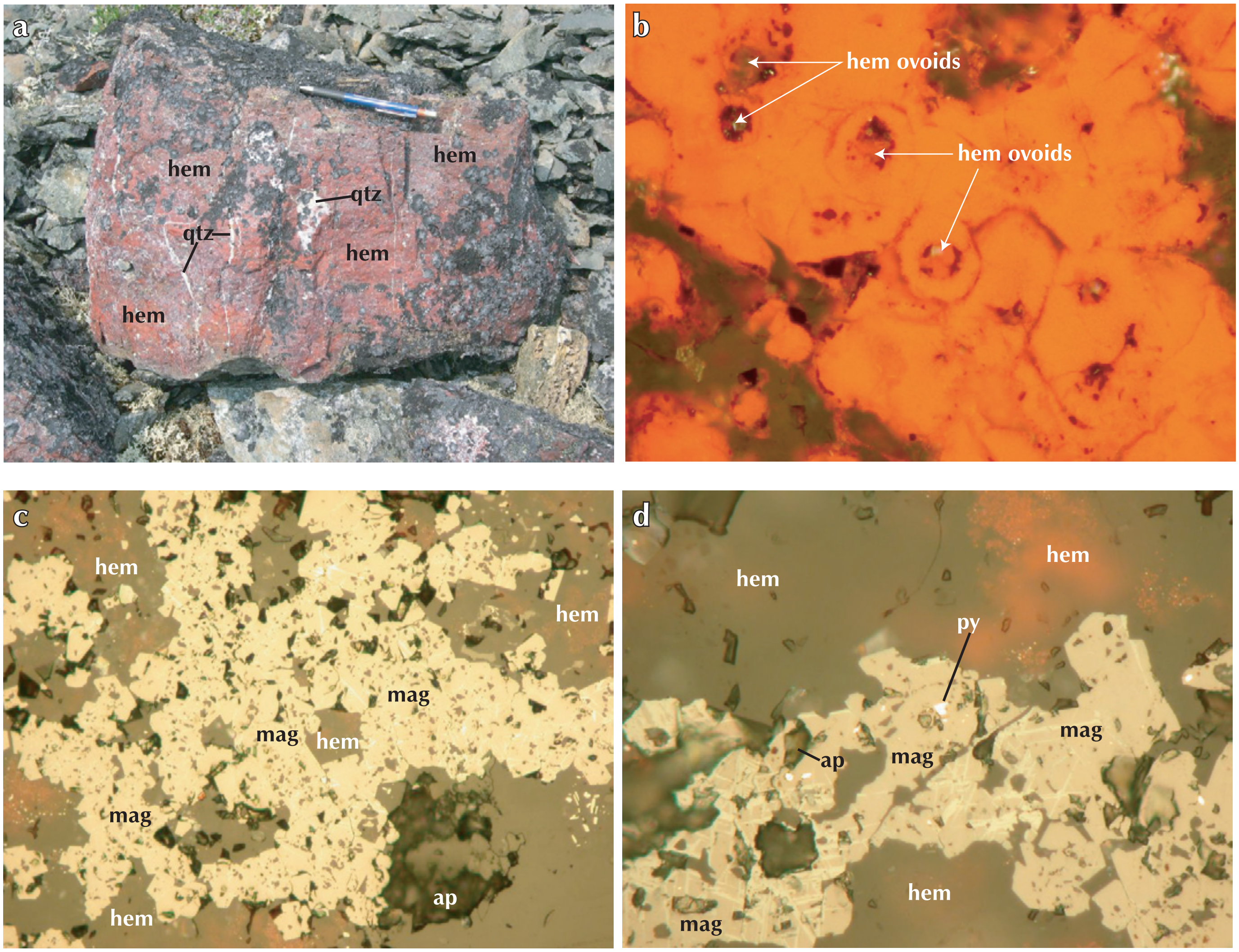

Figure 8. ***(a)*** *Outcrop of the hydrothermal iron formations on Joe Mountain. Photomicrographs of the iron formation:* ***(b)*** *ovoidal grains of hematite with internal reflections (field of view: 1.1 mm, transmitted light, crossed polars);* ***(c)*** *euhedral magnetite intergrown with hematite and apatite (field of view: 0.55 mm, transmitted light, plane light); and* ***(d)*** *intergrown magnetite and hematite with blebby inclusion of pyrite within magnetite (field of view: 0.22 mm). Abbreviations: qtz=quartz, hem=hematite, mag=magnetite, py=pyrite, ap=apatite.*

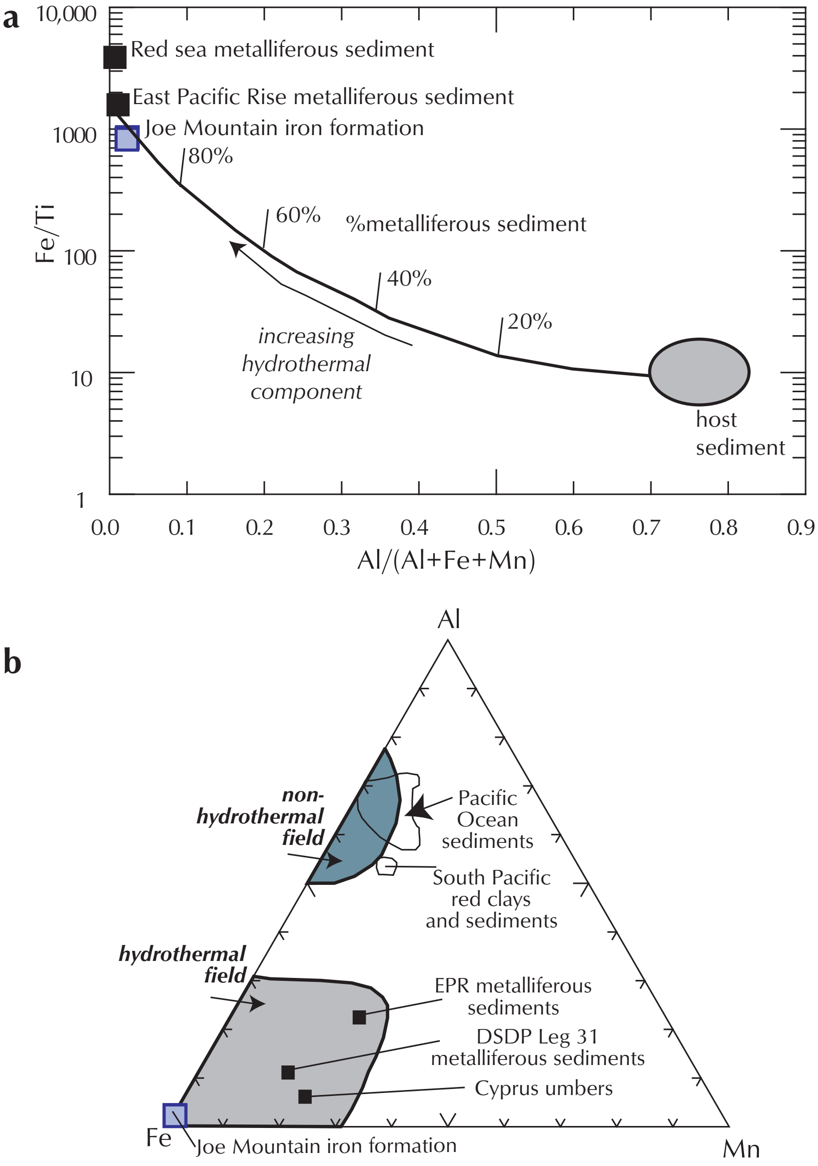

Figure 9. *Fe/Ti versus Al/(Al+Fe+Mn) plot* **(a)** *and Fe versus Al versus Mn plot* **(b)** *for iron formations in the Joe Mountain Formation. Note very high Fe/Al ratios that are similar to modern seafloor hydrothermal vent fluids. These data suggest that the Joe Mountain area may have potential to host volcanogenic massive sulphide mineralization. Abbreviations: EPR=East Pacific Rise; DSDP=Deep Sea Drilling Program. Figure modified from Peter (2003), and references therein.*

Table 1. *Assay results for two samples of Joe Mountain Formation iron formation.*

Sample	**04SJP570-2-2**	**04SJP570-2-3**
Easting	515584	515584
Northing	6754534	6754534
Fe (%)	6.81	7.41
Ca	0.71	0.84
P	0.015	0.017
Mg	0.21	0.21
Ti	0.008	0.009
Al	0.16	0.17
Na	0.003	0.004
K	<.01	<.01
S	0.02	0.02
Mo (ppm)	1.92	1.32
Cu	19.39	14.73
Pb	0.70	0.80
Zn	4.3	5.1
Ni	2.9	3.7
Co	2.0	1.7
Mn	183	219
As	1.5	1.3
U	0.1	0.1
Th	<.1	<.1
Sr	11.8	15.1
Cd	0.07	0.11
Sb	0.49	0.45
Bi	<.02	<.02
V	53	58
La	2.5	2.5
Cr	13.9	12.2
Ba	27.7	31.0
B	<1	1
W	0.3	2
Sc	0.9	1.0
Tl	<.02	<.02
Se	0.2	0.2
Te	<.02	<.02
Ga	1.0	1.0
Au (ppb)	1.3	1.3
Ag	27	23
Hg	<5	<5

such as titanium and manganese. Furthermore, the greater the hydrothermal component, the more proximal the rocks may be to the vent source that generated the hydrothermal fluids (Peter, 2003; Peter and Goodfellow, 1996).

The Joe Mountain iron formations have very high Fe/Al ratios (Fig. 10a-b), and have signatures similar to modern-day hydrothermal sediments associated with seafloor hydrothermal vents. These data suggest that seafloor hydrothermal activity existed within the basin that the Joe Mountain Formation formed in. Further work is required to ascertain whether this venting was of high enough temperature, was sustained for long enough, and if there were sufficient traps to form massive sulphide mineralized rock. Nonetheless, the occurrence of hydrothermal sedimentary rocks with strong hydrothermal signatures hints that there may be potential for VMS mineralization in the Joe Mountain Formation.

SUMMARY

The following points summarize the results of this preliminary research:

- The Joe Mountain Formation in the Joe Mountain area consists of a sequence of Ladinian (~237 to 228 Ma) volcanic, intrusive and sedimentary rocks that can be divided into four packages (Hart and Hunt, 1997): 1) unit $mTJM_4$ consists predominantly of cumulate mafic-ultramafic intrusive rocks and is interpreted to be synvolcanic with the overlying mafic volcanic rocks; 2) unit $mTJM_3$ consists predominantly of pillowed and massive basalt flows, lesser volcaniclastic rocks, and minor iron formation; 3) $mTJM_2$ consists of mixed sedimentary and volcano-sedimentary rocks that include heterolithic conglomerates, volcaniclastic and tuffaceous rocks, carbonates and marble, and some carbonate-rich turbidites; and 4) unit $mTJM_1$, the youngest basalt package, consists predominantly of black-weathering pillow lavas and lesser pillow breccia.
- In the Joe Mountain Formation there is a general increase in the abundance of volcaniclastic and sedimentary rocks, and a decrease in basalt flows with increasing distance from Joe Mountain proper. This regional variation in volcanic facies suggests that Joe Mountain proper may be the location of a volcanic centre (i.e., vent-proximal environment), as was previously suggested by Hart (1997).
- Preliminary lithogeochemical results from the Joe Mountain Formation indicate that these rocks are subalkalic with low Nb/Y (<0.7), moderate to high TiO_2 (0.52 to 3.08%), Ti/V ratios > 20 and tholeiitic Zr/Y ratios (<4). Collectively, these features are consistent with the rocks being subalkaline, tholeiitic rocks that likely formed in an oceanic environment. Whether this environment was a mid-ocean ridge spreading centre (e.g., mid-ocean ridge), an oceanic plateau (e.g., Ontong-Java plateau, Mahoney et al., 1993), or a back-arc basin (e.g., Japan Sea, Pouclet et al., 1995) requires further geochemical and isotopic work.
- A hematite-magnetite iron formation was discovered interlayered with basalts of unit $mTJM_3$ in 2004. This iron formation is ~2 m thick and extends in float for about 1 to 2 km from the occurrence. The iron formation consists of interlayered hematite and quartz, with wispy layers of magnetite, minor pyrite and apatite. Assays from this iron formation yielded anomalous metals, but more importantly, the iron formations have geochemical signatures (e.g., high Fe/Al ratios) consistent with derivation via deposition from hydrothermal fluids. These types of iron formations have been found in association with volcanogenic massive sulphide (VMS) mineralization in numerous massive sulphide camps worldwide (e.g., Cyprus, Bathurst, Finlayson Lake), and this suggests that the Joe Mountain Formation may have potential to host VMS-style mineralization.

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REFERENCES

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 Environments, C.T. Barrie and M.D. Hannington (eds.), Society of Economic Geologists, Reviews in Economic Geology, vol. 8, p. 101-131.

Colpron, M., 2005 (this volume). Preliminary investigation of the bedrock geology of the Livingstone Creek area (NTS 105E/8), south-central Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 95-107.

Galley, A.G., 1993. Characteristics of semi-conformable alteration zones associated with volcanogenic massive sulphide districts. Journal of Geochemical Exploration, vol. 48, p. 175-200.

Gibson, H.L., Morton, R.L. and Hudak, G.J., 1999. Submarine volcanic processes, deposits, and environments favorable for the location of volcanic-associated massive sulfide deposits. *In:* Volcanic-Associated Massive Sulfide Deposits: Processes and Examples in Modern and Ancient Environments, C.T. Barrie and M.D. Hannington (eds.), Reviews in Economic Geology, vol. 8, p. 13-51.

Gillis, K.M. and Thompson, G., 1993. Metabasalts from the Mid-Atlantic Ridge: New insights into hydrothermal systems in slow-spreading crust. Contributions to Mineralogy and Petrology, vol. 113, p. 503-523.

Gradstein, F.M., Ogg, J.G. and Smith, A.D., 2004. A Geological Time Scale 2004. Cambridge University Press, Cambridge, England.

Hart, C.J.R., 1997. A transect across northern Stikinia: geology of the northern Whitehorse map area, southern Yukon Territory (105D/13-16). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 8, 112 p.

Hart, C.J.R. and Hunt, J.A., 1997. Geology of Joe Mountain map area, southern Yukon (105D/15). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Geoscience Map 1997-6, 1:50 000 scale.

Large, R.R., Gemmell, J.B., Paulick, H. and Huston, D.L., 2001. The alteration box plot: a simple approach to understanding the relationships between alteration mineralogy and lithogeochemistry associated with VHMS deposits. Economic Geology, vol. 96, p. 957-971.

Long, D.G.F., 2005 (this volume). Sedimentology and hydrocarbon potential of fluvial strata in the Tantalus and Aksala Formations, northern Whitehorse Trough, Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 167-176.

Lowey, G. W. 2004. Preliminary lithostratigraphy of the Laberge Group (Jurassic), south-central Yukon: Implications concerning the petroleum potential of the Whitehorse Trough. *In:* Yukon Exploration and Geology 2003, D.S. Emond and L. L. Lewis (eds.), Yukon Geological Survey, p. 129-142.

Lowey, G.W., 2005 (this volume). Sedimentology, stratigraphy and source rock potential of the Richthofen formation (Jurassic), northern Whitehorse Trough, Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 177-191.

Mahoney, J.J., Neal, C.R., Petterson, M.G., McGrail, B.A., Saunders, A.D. and Babbs, T.L., 1993. Formation of an oceanic plateau: Speculations from field and geophysical observations of the Ontong Java Plateau. EOS, vol. 74, p. 552.

McPhie, J., Doyle, M. and Allen, R.L., 1993. Volcanic Textures: A guide to the interpretation of textures in volcanic rocks. Centre for Ore Deposit and Exploration Studies, University of Tasmania, Tasmania, Australia.

Pearce, J.A., 1996. A user's guide to basalt discrimination diagrams. *In:* Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration, D.A. Wyman (ed.), Geological Association of Canada, Short Course Notes, Volume 12, p. 79-113.

Peter, J.M., 2003. Ancient iron formations: their genesis and use in the exploration for stratiform base metal sulphide deposits, with examples from the Bathurst Mining Camp. *In:* Geochemistry of Sediments and Sedimentary Rocks: Secular Evolutionary Considerations to Mineral Deposit-Forming Environments, D.R. Lentz (ed.), Geological Association of Canada, GEOtext, vol. 4, p. 145-176.

Peter, J.M. and Goodfellow, W.D., 1996. Mineralogy, bulk and rare earth element geochemistry of massive sulphide-associated hydrothermal sediments of the Brunswick horizon, Bathurst mining camp, New Brunswick. Canadian Journal of Earth Sciences, vol. 33, p. 252-283.

Pouclet, A., Lee, J.-S., Vidal, P., Cousens, B.L. and Bellon, H., 1995. Cretaceous to Cenozoic volcanism in South Korea and in the Sea of Japan: Magmatic constraints on the opening of the backarc basin. *In:* Volcanism associated with extension at consuming plate margins, J.L. Smellie (ed.), Geological Society of London Special Publication 81, p. 169-181.

Saeki, Y. and Date, J., 1980. Computer application to the alteration data of the footwall dacite lava at the Ezuri Kuroko deposits, Akito Prefecture. Mining Geology, vol. 30, p. 241-250.

Shervais, J.W., 1982. Ti-V plots and the petrogenesis of modern and ophiolitic lavas. Earth and Planetary Science Letters, vol. 59, p. 101-118.

Spitz, G. and Darling, R., 1978. Major and minor element lithogeochemical anomalies surrounding the Louvem copper deposit, Val d'Or, Quebec. Canadian Journal of Earth Sciences, vol. 15, p. 1161-1169.

Tempelman-Kluit, D.J., 1984. Geology, Laberge (105E) and Carmacks (105I), Yukon Territory. Geological Survey of Canada, Open File 1101, 1:250 000 scale.

Tizzard, A. and Johnston, S., 2005 (this volume). Structural evolution of the Tally Ho shear zone (NTS 105D), southern Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 237-246.

Wheeler, J.O., 1961. Whitehorse map-area, Yukon Territory, 105D. Geological Survey of Canada, Memoir 312, Department of Mines and Technical Surveys, Canada, Ottawa, Ontario.

Wheeler, J.O. and McFeeley, P., 1991. Tectonic Assemblage Map of the Canadian Cordillera. Geological Survey of Canada, Map 1712A.

Winchester, J.A. and Floyd, P.A., 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chemical Geology, vol. 20, p. 325-343.