# The Heff Prospect at Heffley Lake, South-Central B.C. (092INE096): An Unusual Example of a Mafic-ultramafic-related Cu-Au-REE-Bearing Magnetite Skarn

By G.E. Ray and I.C.L. Webster

**KEYWORDS:** *Heff Prospect, Heffley Lake, Magnetite-Cu-Au-REE skarn, Garnet-pyroxene skarn, Alaskan-type mafic-ultramafic pluton, Heffley Creek Pluton, Candelaria-Ernest Henry-Fe oxide deposits, Geochemistry, Economic geology.*

## INTRODUCTION AND LOCATION

The Heff prospect (also known as Iron Range, Hal and Mesabi claims, B.C. MINFILE No. 092INE096) is located on the north side of Heffley Lake, approximately 26 kilometres northeast of Kamloops. It lies within the Intermontane Belt and is hosted by calcareous metasediments of the Quesnel Terrane (Figure 1) and younger mafic intrusive rocks. The road between the township of Heffley Creek and the Sun Peaks ski resort passes immediately south of the property (Figure 2).

In the summer of 1999 the authors spent 15 days mapping and sampling the property and its surrounding area (Figure 2). Previous sampling had revealed anomalous quantities of REE's in the Heff magnetite skarn (Ray and Webster, 1997); the recent seasons' study was part of a program to investigate the potential for Fe-oxide-Cu-Au-REE mineralization of the Candelaria-Ernest Henry types (Hitzman *et al.*, 1992; Ryan *et al.*, 1995; Marschik and Fontboté, 1996; Williams, 1999; Ray and Lefebure, 2000) in British Columbia. Work included geological mapping at 1:5 000 scale of a 2.5 $km^2$ area containing the skarn alteration and mineralization, using a previously cut exploration grid. In addition, a 30 $km^2$ area surrounding the property was mapped at a scale of 1:20 000 (Ray and Webster, 2000)

This report presents the preliminary conclusions of the mapping program together with assay results of mineralization and whole rock chemical data of some intrusive rocks. An Alaskan-type mafic-ultramafic pluton and several Cu occurrences were discovered (Figure 2; Ray and Webster, 2000). The results of on-going work to extract conodont microfossils from the limestones and complete microprobe analyses of the skarn mineralization and alteration will be published at a later date.

## PREVIOUS WORK

Past exploration and drilling have been concentrated in a poorly exposed area that lies at the base of a series of northwest trending limestone cliffs, immediately north of Heffley Lake (Figure 2). Since the early part of this century the property has undergone several name changes, and there are discrepancies in the records regarding some past exploration and drilling.

Copper mineralization was first noted in 1915 (MMAR, 1916) when the lake was then known as "Hefferly Lake". The Lake View and Monarch claims were staked and trenched, and samples containing up to 51 percent Fe and trace Cu and Au were noted. By the 1940's, more trenches had been cut on the "Iron Range Group" property. In the early 1960's the prospect was known as the HAL group. At least four diamond drillholes totalling 250 metres were completed in 1966 but only one hole was reportedly sampled and assayed (Casselman, 1980; Arseneau, 1997). Two additional holes apparently did not hit bedrock and were abandoned. The drilling intersected over 10 metres of massive magnetite and another 4.5 metres thick zone of semi-massive magnetite with chalcopyrite; the latter zone graded 1.67 percent Cu and 0.48 g/t Au. From this work, a resource of 63 Mt grading 30 percent Fe was calculated (Northern Miner, 1967; B.C. MINFILE). Federal Government records also note that in 1976 (when the property was registered as the Freda 1 claim), diamond drilling totalling 72 metres was completed in deepening a pre-existing drillhole.

In 1980, Cominco conducted a mapping and soil sampling program over the "Heff Lake" property (Casselman, 1980). This identified a broad, 600 metres-long Cu soil anomaly but no samples were apparently assayed for Au (Arseneau, 1997). In 1985, a single 58 metres long hole intersected 16 metres of semi-massive magnetite, one 6 metre interval of which assayed 25 percent Fe and 0.5 g/t Au (Arseneau, 1997).

In 1994, the property was sampled as part of a project to examine skarn occurrences throughout British Columbia (Ray and Webster, 1997). This work revealed that the Heff magnetite skarn, unlike the large Fe skarn deposits on the west coast of British Columbia, contained anomalous quantities of REE's (up to 570 ppm La and 490 ppm Ce). Subsequently, Echo Bay Mines optioned the claims in 1997 (which they called the Mesabi property). A geophysical and soil sampling program was conducted over east-west orientated grid lines spaced 100 metres apart. This outlined several magnetic anomalies with coinci-

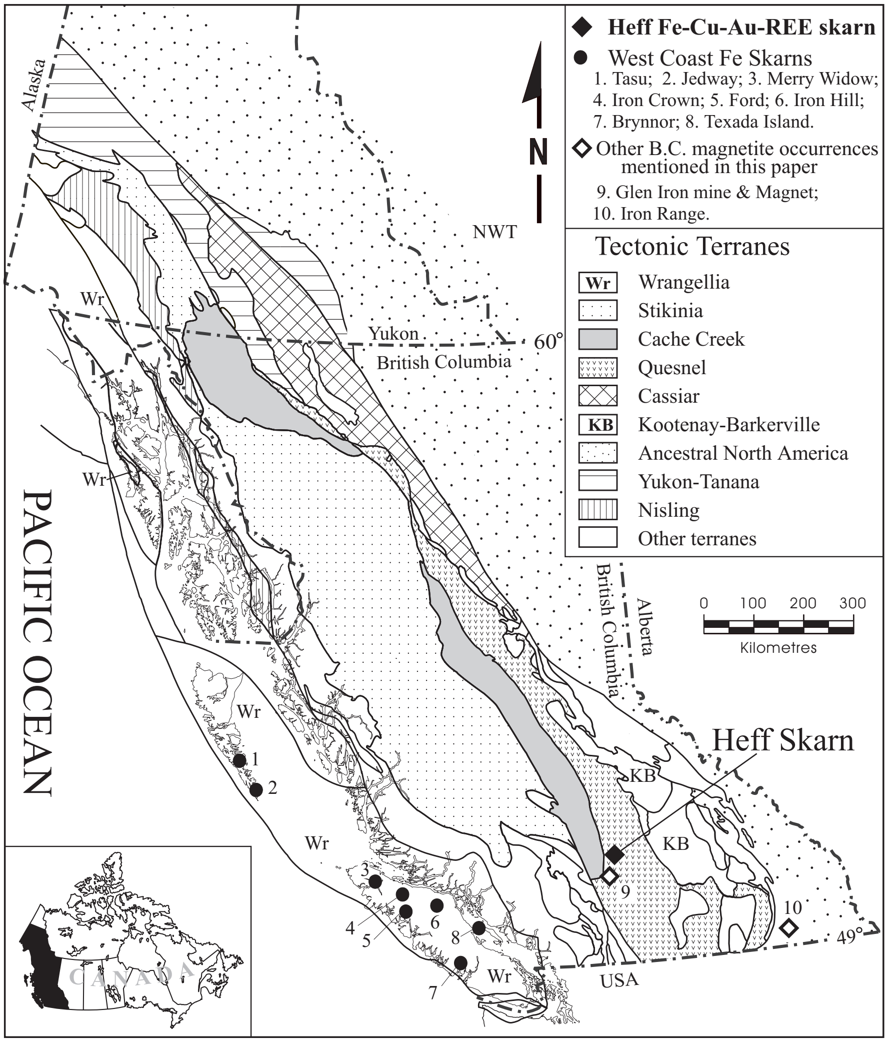


Figure 1. Simplified terrane map of the Canadian Cordillera showing the locations of the Heff skarn and some other Fe-oxide-rich properties in British Columbia. Terrane map modified after Wheeler *et al.* (1991).

dent soil geochemistry marked by values exceeding 1200 ppm Cu and 1000 ppb Au; these anomalies lay adjacent to magnetite-rich skarn. Drilling was recommended but not completed (Arseneau, 1997).

In 1999, whilst this mapping was in progress, a magnetometer and VLF geophysical survey was completed by one of the present property owners.

Previous government mapping of the area includes early work by Cockfield (1944, 1947) and, more recently, a 1:250 000 scale geological map of the district has been published (Monger and McMillan; 1989).

## GENERAL GEOLOGY OF THE HEFFLEY LAKE AREA

### Stratified Rocks

The 30 $km^2$ area mapped is extensively covered with superficial glacio-fluvial deposits and is estimated to have < 1 percent rock exposure. The stratified rocks were originally mapped as Cache Creek Group (Cockfield, 1944, 1947) but more recently they are considered to belong, in part, to the Harper Ranch Group of the Quesnel Terrane (Monger and McMillan, 1989). They mainly comprise steeply dipping, northwest striking argillites and calcareous siltstones with lesser andesitic ash and lapilli tuff and some limestone. These rocks were intruded by the Heffley Creek Pluton and then folded and overprinted by lower to sub-greenschist metamorphism producing slatey and phyllitic fabrics. Bleached marbles and calc-silicate-rich metasediments are developed where hydrothermal or thermal alteration has occurred. The magnetite-bearing garnet-pyroxene skarn alteration comprising the Heff property is hosted by calcareous metasediments and a suite of dioritic minor intrusions; it is best exposed in a number of overgrown trenches that lie 200 to 300 metres north of the Heffley Creek-Sun Peaks road (Figure 2).

The southern part of the area includes units of blue-grey crinoidal limestone and black argillites whilst

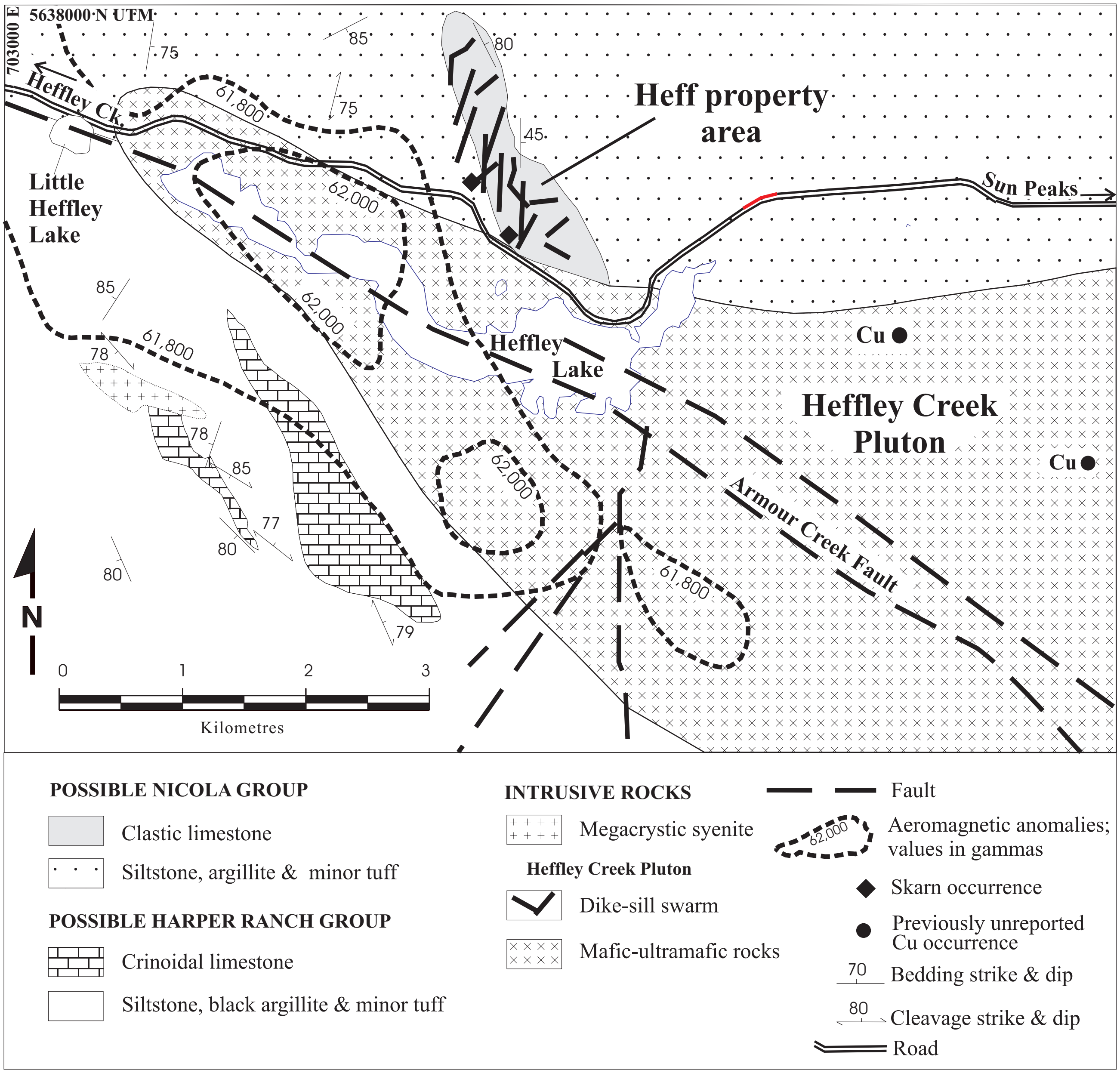


Figure 2. Geology of the Heffley Lake area, south central British Columbia.

the coarsely clastic to conglomeratic limestones in the vicinity of the Heff skarn, north of Heffley Lake, lack crinoids and the argillites are less organic-rich. This and other lithological differences suggest that the supracrustal rocks may be separated into northern and southern packages; these are tentatively believed to represent the Nicola and Harper Ranch groups respectively. The northwest trending contact between these packages is thought to pass under the Heffley lakes and continue south-eastwards along Armour Creek. This original stratigraphic contact has been intruded by the mafic-ultramafic Heffley Creek Pluton and has subsequently been the locus of brittle movement along the Armour Creek Fault (Figure 2).

## INTRUSIVE ROCKS

### Introduction

Two intrusive phases are recognised. The oldest, largest and most economically important of these is the Heffley Creek Pluton and its marginal dike-sill swarm (Figure 2), which is genetically related to the Heff skarn. This either predates or was coeval with the district-wide folding, and it was also affected subsequently by younger brittle movement along the Armour Creek Fault. A younger generation, which post-dates the folding, resulted in bodies of distinctive megacrystic, feldspar-porphyry syenites; these occur mainly 2 km southwest of Heffley Lake (Figure 2).

## Heffley Creek Pluton and its Related Dike-Sill Swarm

Most of the pluton lies south and southeast of Heffley Lake, where small, scattered outcrops of the intrusion are traceable over a 10 $km^2$ area. The true size and shape of the pluton are unknown because its southern, eastern and north-western margins have not been fully mapped (Figure 2). The pluton probably forms an elongate body that intruded the Nicola and Harper Ranch groups. It contains a variety of rock types, including early ultramafics, younger mafic and felsic gabbros, diorites and quartz diorites, and minor amounts of late leucocratic monzodiorite. In addition, a strongly altered swarm of sills and dikes on the Heff property, north of Heffley Lake, is probably related to both the pluton and the magnetite skarns.

The ultramafic rocks, which include pyroxenites and hornblendites, appear to lie in the central part of the pluton They are dark, coarse grained (up to 0.5 centimetres) and massive rocks that commonly contain up to 2 percent disseminated pyrite and up to 10 percent disseminated magnetite. The latter mineral produces an elongate magnetic anomaly outlined by a 1:25 000 scale government aeromagnetic survey (Map 4411G) that extends 6 km south-eastwards from Little Heffley Lake (Figure 2).

The late felsic monzodiorite is an extremely minor part of the pluton. It forms irregular and narrow dikes, between 1 cm and 1.5 metres wide, that cut the ultramafics to produce intrusive breccias comprising sharply angular clasts of ultramafite in a matrix of felsic monzodiorite.

Thin sections reveal that the ultramafic rocks are dominated by either cumulate clinopyroxene or inter-cumulate hornblende, both of which are variably altered to chlorite or light coloured secondary amphibole. The pyroxene includes both colourless and highly pleochroic varieties. Minor amounts of highly altered olivine were tentatively identified in a few outcrops but its presence has not been verified in thin section. Other cumulate minerals include sphene and euhedral to subhedral crystals of magnetite. Secondary minerals include chlorite, epidote, pyrite, phlogopite, talc and trace serpentine, chalcopyrite and plagioclase.

Major and trace element analytical data for the various rock types in the Heffley Creek Pluton are presented in Table 1 and the chemical plots are shown in Figure 3. The data can be subdivided into four compositional groups, namely the ultramafic rocks, the gabbroic to quartz-dioritic intrusives, the late felsic monzodioritic phase, and the swarm of strongly altered sills and dikes on the Heff skarn property. The two ultramafic samples (GR99-30A and 51) are notable for their high Fe, Ca and Mg contents, and one of these magnetite-bearing samples contains more than 23 percent total iron (Table 1). The gabbroic and dioritic samples from the main body range from highly altered microdiorite on the margin of the pluton (GR99-24A), to felsic quartz diorite (GR99-27A) to more mafic gabbro-diorite (GR99-26A and 29A). The total alkali content of the latter group indicates a weak alkalic affinity (Figure 3A). However, other plots, including ones using less mobile trace elements (Figure 3D and E) suggest that these rocks are calc-alkaline and that their higher alkali content is due to hydrothermal alteration. The relatively low Fe and high Ca and Na contents of the one felsic monzodiorite sample (GR99-52; Table 1) reflects the plagioclase-rich nature of this rock-type.

The limestone unit exposed in cliffs on the Heff property are cut by a variety of minor intrusives, the most common and economically important of which occur as a swarm of strongly altered dioritic sills and dikes (Figure 2). Individual bodies are usually less than 10 metres wide but a few exceed 50 metres in thickness. Due to the ubiquitous presence of up to 6 percent disseminated, fine-grained pyrite, these rocks are rusty-weathering. However, fresh samples are generally light grey coloured and are weakly to moderately enriched (Table 1) in Si, Ca and Na which reflects silicification with carbonate and albitic plagioclase alteration. The relatively high loss on ignition content also reflects the presence of carbonate in these rocks.

Hydrothermal alteration in the sills and dikes varies in intensity over short distances; some bleached and strongly altered dikes contain rounded small (less than 1m diameter) remnants of dark coloured and less altered igneous rock. The widespread overprinting has caused difficulties in identifying the original composition of these minor intrusions which, due to their siliceous appearance, have been mapped previously as “dacites” (Arseneau, 1979). However, plots using immobile trace elements (Figure 3D and E) show they are dioritic in composition; they are believed to be related to both the Heffley Creek Pluton and the hydrothermal event that produced the Heff Fe-Cu-Au-REE skarn.

The dike-sill swarm includes equigranular and porphyritic varieties; the latter are more common and contain euhedral to anhedral, corroded phenocrysts of plagioclase, clinopyroxene and hornblende up to 0.5 centimetres long. The north to north-northwest trending swarm can be traced for 2 kilometres on the Heff property (Figure 2). These intrusions are much more common in the limestones than in the adjoining tuffaceous and siltstone-argillite units. Most of the sills and dikes strike north to northeast, but some of the more irregularly orientated intrusions bifurcate or intersect one another. Their margins are lobate and highly irregular, and many dikes are folded and overprinted by a fracture cleavage. Whilst the hosting limestones have undergone ductile deformation, boudinage has produced brittle rupturing in the more competent intrusions.

## Megacrystic Syenite

These are the youngest intrusives in the area and they are believed to post-date the major folding event, although they have undergone brittle faulting. They are best seen south of Heffley Lake; in this area a single, 500

**TABLE 1**
**MAJOR AND TRACE ELEMENT ANALYSES OF THE HEFFLEY CREEK PLUTON, HEFFLEY LAKE, B.C.**

| | Altered pyritic dikes & sills | | | | Samples from the main pluton | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | GR99 24 | GR99 46 | GR99 47 | GR99 48 | GR99 24A | GR99 26A | GR99 27A | GR99 29A | GR99 30A | GR99 51 | GR99 52 |
| $SiO_2$ | 57.50 | 57.11 | 46.61 | 49.32 | 49.76 | 58.12 | 63.19 | 49.57 | 47.07 | 40.13 | 55.57 |
| $TiO_2$ | 0.59 | 0.55 | 0.81 | 0.78 | 1.00 | 0.83 | 0.34 | 0.78 | 0.61 | 1.29 | 0.46 |
| $Al_2O_3$ | 17.46 | 15.87 | 15.71 | 14.74 | 18.51 | 16.23 | 16.61 | 16.91 | 4.61 | 5.25 | 17.58 |
| $Fe_2O_3$ | 5.66 | 6.11 | 9.24 | 8.36 | 7.95 | 7.44 | 3.73 | 9.26 | 10.14 | 23.47 | 4.57 |
| MnO | 0.06 | 0.05 | 0.09 | 0.12 | 0.17 | 0.14 | 0.09 | 0.15 | 0.14 | 0.19 | 0.10 |
| MgO | 1.92 | 2.44 | 5.50 | 6.24 | 3.48 | 2.57 | 1.21 | 5.15 | 14.87 | 10.06 | 2.13 |
| CaO | 5.72 | 5.14 | 11.35 | 10.83 | 11.71 | 5.99 | 3.95 | 8.02 | 20.13 | 16.82 | 9.28 |
| $Na_2O$ | 4.34 | 5.40 | 2.02 | 3.09 | 3.89 | 4.47 | 4.69 | 3.69 | 0.26 | 0.33 | 6.05 |
| $K_2O$ | 2.23 | 3.84 | 3.13 | 2.09 | 1.09 | 2.74 | 4.17 | 1.77 | 0.10 | 0.16 | 0.75 |
| $P_2O_5$ | 0.18 | 0.29 | 0.35 | 0.30 | 0.30 | 0.21 | 0.16 | 0.44 | 0.03 | 0.04 | 0.32 |
| LOI | 3.66 | 1.98 | 3.83 | 2.68 | 1.21 | 0.60 | 1.12 | 2.88 | 1.05 | 1.33 | 2.48 |
| TOTAL | 99.32 | 98.78 | 98.64 | 98.55 | 99.07 | 99.34 | 99.26 | 98.62 | 99.01 | 99.07 | 99.29 |
| K2O/Na2O | 0.51 | 0.71 | 1.55 | 0.68 | 0.28 | 0.61 | 0.89 | 0.48 | 0.38 | 0.48 | 0.12 |
| Ba | 1300 | 1665 | 1865 | 1030 | 310 | 1415 | 1890 | 760 | 75 | 140 | 495 |
| Rb | 56 | 66 | 80 | 64 | 28 | 56 | 100 | 46 | 12 | 16 | 18 |
| Sr | 588 | 1040 | 846 | 1025 | 842 | 650 | 966 | 630 | 38 | 980 | 1020 |
| Nb | 8 | 8 | 2 | 6 | 8 | 10 | 8 | 6 | 4 | 6 | 18 |
| Zr | 96 | 111 | 63 | 78 | 84 | 132 | 105 | 60 | 27 | 51 | 90 |
| Y | 20 | 24 | 20 | 18 | 22 | 24 | 20 | 20 | 12 | 8 | 12 |
| F | 270 | 460 | 1300 | 1200 | 640 | 300 | 410 | 500 | 50 | 80 | 170 |
| Hg (ppb) | 50 | 10 | 10 | <10 | 10 | <10 | 10 | 10 | <10 | <10 | <10 |
| Rb/Sr | 0.10 | 0.06 | 0.09 | 0.06 | 0.03 | 0.09 | 0.10 | 0.07 | 0.32 | 0.02 | 0.02 |
| Ba/Sr | 2.21 | 1.60 | 2.20 | 1.00 | 0.37 | 2.18 | 1.96 | 1.21 | 1.97 | 0.14 | 0.49 |

Oxides in percent; Hg in ppb; other trace elements in ppm.

Sample description:

GR99-24 & 46 Moderately silicified, rusty weathering, pyritic and albite-altered intrusion.
GR99-47 & 48 Pyritic and carbonate-altered intrusion.
GR99-24A Altered, hornblende-microdiorite with minor pyrite.
GR99-26A Medium grained gabbro with 60% mafics and 2% pyrite.
GR99-27A Felsic diorite with 12% mafics and 1% pyrite. Minor quartz veining.
GR99-29A Coarse, horblende porphyry gabbro with 15% mafics and 1% pyrite.
GR99-30A Coarse grained pyroxenite with 5% magnetite & trace pyrite.
GR99-51 Coarse grained hornbende-pyroxene ultramafic with 10% magnetite.
GR99-52 Pale, feldspathic monzodiorite agmatite cutting ultramafics.

Analyses completed at Chemex Labs Ltd., 212 Brookbank Ave., North Vancouver, B.C.
Methods: Major & minor oxides = XRF; Au = Fire assay and AA finish;
Ba, Rb, Sr, Nb, Zr, Y = XRF; Hg = Atomic Absorption Specroscopy (AAS)
F = Specific Ion Electrode

metre-long syenitic body has been inferred from the sporadic small outcrops (Figure 2). However, north of Heffley Lake, the limestones and the altered dioritic dike-swarm are cut by a few syenitic dikes that are generally less than 3 metres thick.

These syenites appear as leucocratic, buff coloured rocks; some contain up to 7 percent remnant mafic amphibole and biotite, both of which are extensively chloritized, as well as trace to minor glassy quartz. Many outcrops are cut by parallel veins of white quartz up to 1 cm thick. The syenites are characterised by abundant (up to 30 percent) elongate euhedral to subhedral feldspar laths that are generally between 2 and 4 cm long, although some crystals exceed 15 cm in length. Some of these pale brown phenocrysts have thin, light coloured margins and are partially resorbed. Many crystals show a pronounced parallel orientation due to igneous flow. Intrusive contacts between the syenites and the sedimentary country rocks were seen both north and south of Heffley Lake. No chilled margins were observed, although thin (less than 0.5 m wide) zones of silicification and hornfels occur adjacent to some dikes.

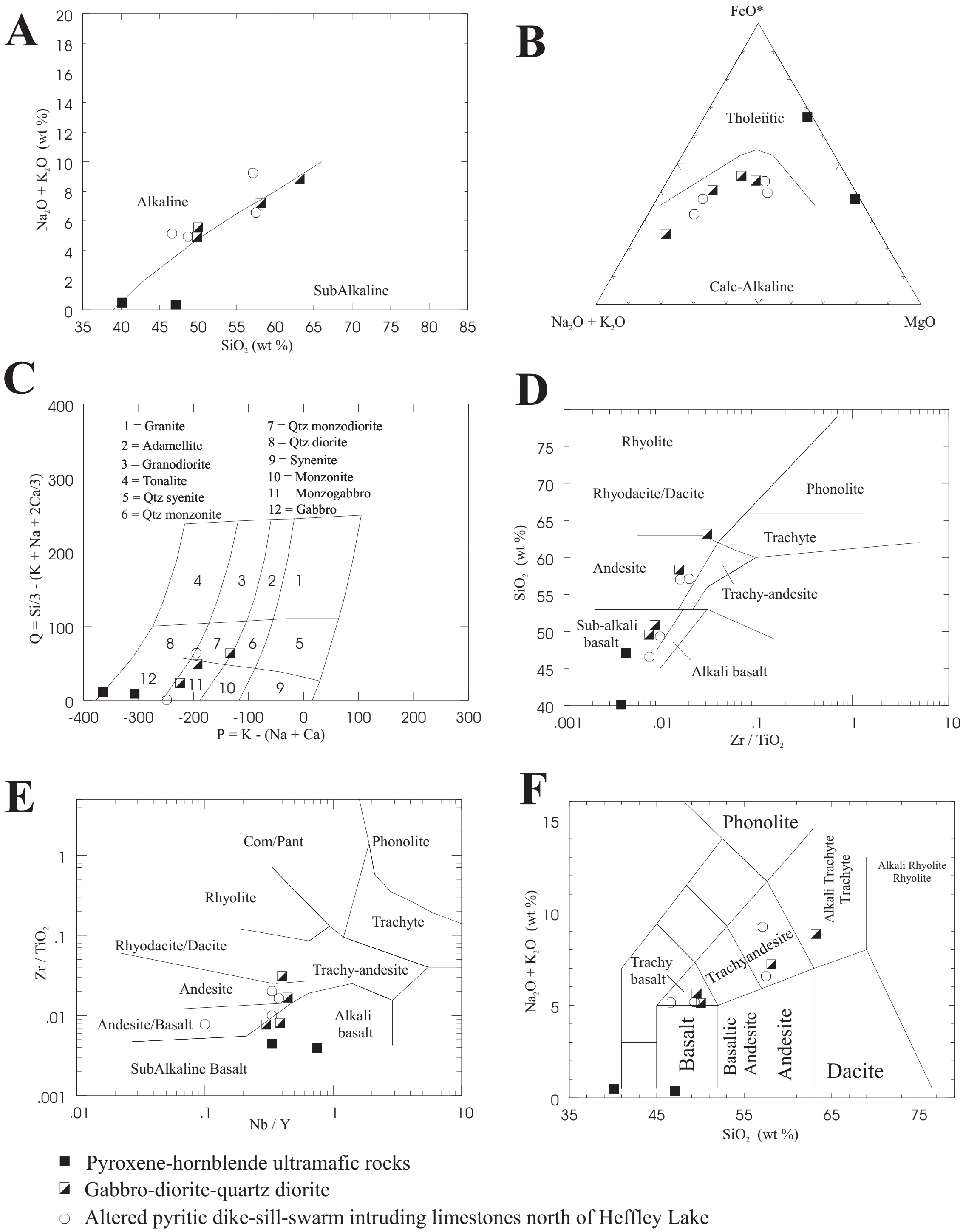


Figure 3. Plots showing the major and trace element geochemistry of the Heffley Creek Pluton.

(A) Alkali-silica plot (after Irvine and Baragar, 1971

(B) AMF plot (after Irvine and Baragar, 1971)

(C) Q - P plot (after Debon and Le Fort, 1983)

(D) Silica versus Zr/titanium plot (after Winchester and Floyd, 1977)

(E) Zr/titanium versus Nb/Y plot after Winchester and Floyd, 1977)

(F) Alkali versus silica plot (after Le Maitre *et al*., 1989).

## ALTERATION RELATED TO THE HEFF SKARN

Most of the limestones on the Heff property show little or no signs of thermal or hydrothermal overprinting, despite the presence of the pervasively altered dike-sill-swarm. Varying degrees of pyritic, albitic, carbonate and silica alteration are seen in all the dioritic dikes and sills on the Heff property and this alteration overprints the intrusions for at least 1.5 km north of the Heff skarn occurrences. There is a progressive southerly change in the intensity and style of alteration in the dikes, and, to a lesser extent, in the limestones. This change reflects increasing proximity to the mineralised Heff skarn occurrences and the northern margin of the Heffley Creek Pluton, which is presumed to either underlie Heffley Lake or its northern shore (Figure 2).

In the north part of the Heff property grid, the sills and dikes are characterised by up to 3 percent by volume pyrite, which is fine grained and disseminated. Further south, however, in the vicinity of line 6700N and 6800E (this and the following locations refer to the cut grid illustrated in Map 1, Arseneau, 1997), the pyrite content increases; in addition to the disseminated sulphide, the margins of some sills and dikes contain haloes, up to 7 centimetres thick, of massive, coarse grained pyrite. Still further south (close to line 6400N and 6950E), endoskarn alteration is first recognised; the dikes are still pyritic but they also contain trace amounts of magnetite together with pyroxene, epidote and silica. The limestones in this area have also undergone a recognisable colour-change. To the north they are unaltered and dark to medium grey in colour but further south they become pervasively paler. Coinciding with the first southern appearance of pyroxene-endoskarn, the pale grey limestones are cut by irregular veins and stringers, up to 4 centimetres thick, of white marble. These fracture-controlled bleached veins in the limestones represent the more distal effects of hot, metal-poor fluids from the Heff skarn hydrothermal system.

Immediately to the south of this area, on line 6400N and 6850E, coarse garnet-dominant skarn is first recognised with massive to semi-massive magnetite and lesser pyroxene and pyrite and trace chalcopyrite. Some of this garnet-rich alteration appears to be endoskarn, although in the majority of cases the alteration is so intense that the protolith is unidentifiable. In this area, the fracture controlled bleaching in the carbonates is so intense that some rocks comprise mostly white, fine grained marble that enclose small dark relicts of original limestone. In the coarser skarns, the euhedral garnet crystals are intergrown with calcite. Thin section studies show that the garnets are moderately birefringent and they form anhedral to euhedral crystals up to 1 centimetre in diameter. Many contain small inclusions of pyroxene, calcite and opaque Fe oxides; some garnet crystals are skeletal, consisting of alternating growth zones of garnet-rich and calcite-rich material. Other minerals identified in thin section in the skarns include epidote, chlorite, quartz, albitic plagioclase, zoisite and ilmenite.

## MINERALIZATION AND GEOCHEMISTRY

At least two types of Cu-bearing mineralization are recognised in the area. These are: (1) magnetite-rich chalcopyrite ± Au ± REE garnet-pyroxene skarns which occur on the Heff property north of Heffley Lake, and (2) disseminations and veins of chalcopyrite ± magnetite-pyrite mineralization in the Heffley Creek Pluton south of Heffley Lake (Figure 2).

Unlike the Cu-showings in the Heffley Creek Pluton, the Heff skarns have had a long history of exploration. The more extensive pyroxene ± garnet skarn horizons reach up to 50 metres thick but most are generally less than 2 metres wide. Surface mineralization in the skarn consists of pods and massive lenses of magnetite with lesser amounts of pyrite and pyrrhotite and trace of chalcopyrite. The sulphides occur as disseminations and veinlets, and pyrite is generally dominant to pyrrhotite. Magnetite lenses up to 1 metre wide crop out on surface but massive magnetite zones over 10 metres thick have been intersected by drilling (Casselman, 1980). Mineralization occurs locally in the intrusions and in what is believed to be the adjacent exoskarn. On a local scale, many of the calc-silicate layers are mineralogically zoned with a central core of coarser grained garnet-dominant skarn and a wider outer halo of finer grained pyroxene-dominant skarn. Magnetite-sulphide mineralization tends to be better developed in the garnet-dominant skarn.

Assay results of grab samples of mineralised Heff property skarn are shown in Table 2. Many samples contain > 25 percent Fe which reflects the abundant magnetite, and some are weakly anomalous in Au (up to 445 ppb), Cu (up to 1195 ppm), Co (up to 467 ppm) and Mo (up to 14 ppm) as well as being sporadically enriched in REE's (up to 490 ppm Ce and 570 ppm La) and P (up to 1560 ppm).

Assay data for pyrite-bearing grab samples from the Heffley Creek Pluton and its dike-sill swarm are presented in Table 3. Two samples of magnetite-bearing ultramafic pyroxenite were assayed for PGE's but they contained only 15 ppb Pt and 4 ppb Pd. However, there are unconfirmed reports that Pt geochemical soil anomalies are present in the area (Roed, 1988).

Samples collected from the altered pyritic dike-sill swarm on the Heff property contain no economic quantities of Cu and Au, although one sample (GR99-24; Table 3) is weakly anomalous in Au (145 ppb) and some are moderately anomalous in F (up to 1300 ppm F; Table 1). Disseminated cumulate magnetite is common throughout the main Heffley Creek Pluton but locally some pyrite ± chalcopyrite ± secondary Cu oxides are also seen. Many of these sulphide-rich zones are characterised by silicification and plagioclase veining and they appear to be fault-related. One chalcopyrite-malachite-K feld-

## TABLE 2
## ASSAY RESULTS OF MINERALIZED SKARN, HEFF PROPERTY, HEFFLEY LAKE, B.C.

| SAMPLE No. | GR94-217 | GR94-219 | GR94-220 | GR94-223 | GR94-224 | GR99-19 | GR99-25A | GR99-27 | GR99-28 | GR99-29 | GR99-32A | GR99-32 | GR99-33 | GR99-34 | GR99-37 | GR99-40 | GR99-42 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Au | 96 | 55 | 49 | 176 | 445 | 36 | <5 | 75 | 160 | 55 | 20 | 35 | 25 | 40 | 205 | 20 | 25 |
| Hg | 15 | 10 | 15 | 20 | 25 | <10 | 40 | <10 | 60 | 10 | 50 | <10 | 10 | <10 | 20 | 10 | 50 |
| Sb | 3.1 | 0.1 | 1.5 | 1 | 1.4 | 1.3 | 0.7 | 7 | 0.5 | 0.9 | 0.7 | 1.2 | 1 | 0.6 | 0.5 | 2.1 | 0.8 |
| Ba | >10 | >10 | >10 | 61 | 92 | 270 | 170 | 560 | <10 | 30 | 10 | <10 | 50 | 40 | 60 | 70 | 60 |
| Be | 1 | 4 | 1 | 4 | 1 | 0.35 | 9.65 | 0.85 | <0.05 | 0.3 | 0.4 | 0.55 | 1 | 0.4 | 0.5 | 0.4 | 0.25 |
| Bi | <4 | <4 | <4 | <4 | <4 | 0.13 | 0.16 | 1.5 | 0.91 | 0.07 | 0.19 | 0.1 | 0.14 | 0.75 | 0.14 | 0.18 | 0.15 |
| Cd | 0.8 | 3 | 3.2 | 3.2 | 1.2 | 0.1 | 0.22 | 0.22 | 0.02 | 0.02 | 0.06 | 0.02 | 0.02 | 0.1 | 0.22 | 0.08 | 0.3 |
| Ce | 9 | 490 | 86 | 6 | 6 | 1.41 | 13.7 | 62.4 | 0.62 | 6.26 | 2.2 | 1.58 | 1.03 | 0.75 | 1.15 | 12.65 | 3.92 |
| Cs | >1 | >1 | >1 | 1 | 1 | 5.1 | 0.2 | 0.25 | <0.05 | 0.7 | 0.35 | 0.15 | 0.9 | 3.95 | 5.8 | 2.2 | 0.75 |
| Cr | 130 | 48 | 38 | 120 | 120 | 30 | 71 | 61 | 3 | 27 | 54 | 16 | 23 | 7 | 27 | 35 | 80 |
| Co | 79 | 63 | 45 | 54 | 48 | 67 | 77.1 | 68.3 | 467 | 40.2 | 61.6 | 44.6 | 46.8 | 135 | 33.8 | 68.5 | 42.4 |
| Cu | 511 | 769 | 393 | 495 | 352 | 392 | 754 | 439 | 243 | 350 | 718 | 377 | 363 | 822 | 679 | 905 | 1195 |
| Ga | - | - | - | - | - | 12.7 | 7.2 | 11.4 | 0.4 | 14.3 | 10.1 | 9.1 | 15.4 | 9.4 | 6.7 | 8.9 | 6.1 |
| Ge | - | - | - | - | - | 0.6 | 3.2 | 1.2 | 0.3 | 0.6 | 0.9 | 0.7 | 1 | 0.8 | 0.5 | 1 | 0.9 |
| La | 7.2 | 570 | 100 | 2.8 | 2.9 | 0.5 | 6.5 | 47.5 | <0.5 | 6 | 1.5 | 1 | 0.5 | <0.5 | 0.5 | 9.5 | 2.5 |
| Pb | 4 | 4 | 4 | 4 | 4 | 3.5 | 20 | 8.5 | 6.5 | 3 | 3 | 2.5 | 6.5 | 5 | 2 | 3.5 | 2 |
| Li | - | - | - | - | - | 0.6 | 23 | 2.4 | <0.2 | 1.2 | 1.6 | 1.6 | 0.8 | 1.6 | 1 | 1.2 | 1 |
| Mn | 2738 | 571 | 896 | 2456 | 2721 | 1530 | 2730 | 1245 | 180 | 890 | 1770 | 1045 | 1560 | 1355 | 1205 | 2080 | 3060 |
| Mo | 8 | 2 | 2 | 10 | 14 | 0.2 | 0.6 | 0.4 | 0.4 | <0.2 | 0.2 | <0.2 | 0.2 | 0.2 | 1.6 | <0.2 | 0.6 |
| Ni | 43 | 25 | 21 | 48 | 53 | 16.8 | 32.8 | 75.3 | 144.5 | 13.2 | 27.6 | 14 | 21.2 | 57.5 | 19.6 | 32.2 | 20 |
| Nb | 4 | 2 | 2 | 2 | 3 | 0.6 | 13.8 | 1.6 | <0.2 | 0.2 | 0.8 | 0.2 | 0.4 | 0.2 | <0.2 | 0.8 | 1.2 |
| P | 1500 | 700 | 300 | 1200 | 1000 | 670 | 760 | 1210 | 120 | 420 | 910 | 700 | 890 | 800 | 570 | 730 | 1560 |
| Rb | >5 | 7 | 10 | >5 | 8 | 14.8 | 25.4 | 9.4 | 0.2 | 2.2 | 1 | 0.8 | 3.8 | 23.2 | 18.6 | 5.2 | 2.2 |
| Ag | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.75 | 0.95 | 0.5 | 2.25 | 0.45 | 0.9 | 0.4 | 0.85 | 0.85 | 0.9 | 1 | 1.3 |
| Sr | 42 | 50 | 31 | 52 | 146 | 174.5 | 474 | 605 | 8.8 | 29.6 | 86.5 | 30.6 | 41.8 | 65.6 | 77.5 | 55.9 | 110.5 |
| Ta | - | - | - | - | - | <0.05 | 0.05 | 0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.05 | 0.05 |
| Te | 0.3 | 0.4 | 0.2 | 0.3 | 0.2 | 0.2 | 0.05 | 0.15 | 4.15 | 0.25 | 0.55 | 0.3 | 0.3 | 0.75 | 0.3 | 0.35 | 0.4 |
| Tl | - | - | - | - | - | 0.02 | 0.14 | 0.08 | <0.02 | <0.02 | 0.02 | <0.02 | 0.02 | 0.18 | 0.16 | 0.08 | 0.02 |
| Th | 1 | 1.4 | 0.6 | 1 | 1.1 | 0.6 | 0.8 | 2.4 | <0.2 | <0.2 | 0.2 | 0.2 | <0.2 | 0.2 | 0.4 | 0.8 | 0.4 |
| W | 8 | 2 | >1 | >1 | >1 | 1.1 | 0.2 | 0.8 | 0.1 | 0.3 | 1.8 | 0.3 | 1 | 0.3 | 0.1 | 0.9 | 2.7 |
| U | 2.8 | 0.5 | 2.3 | 3.6 | 3.8 | 1 | 3.8 | 2.6 | <0.2 | 0.8 | 1.2 | 0.4 | 0.8 | 0.4 | 0.6 | 1.4 | 1.8 |
| V | 134 | 37 | 40 | 95 | 112 | 80 | 151 | 233 | 3 | 71 | 92 | 57 | 65 | 59 | 155 | 164 | 109 |
| Y | 18 | 4 | 3 | 13 | 15 | 5.1 | 12.3 | 10.7 | 0.3 | 2.8 | 7.5 | 1.3 | 2.4 | 2.4 | 1.6 | 9.5 | 13.9 |
| Zn | 24 | 31 | 30 | 30 | 20 | 20 | 126 | 36 | <2 | 26 | 24 | 28 | 32 | 16 | 32 | 30 | 32 |
| As | 6.4 | 28 | 8 | 6.6 | 9.1 | 9 | <1 | 79 | <1 | <1 | <1 | <1 | <1 | <1 | 2 | <1 | 2 |
| F | 500 | 240 | 210 | 270 | 260 | 100 | 240 | 360 | 40 | 100 | 150 | 160 | 170 | 260 | 140 | 180 | 270 |
| Total S | 5.5 | 3.75 | 3.46 | 3.14 | 3.82 | - | - | - | - | - | - | - | | | | | |
| Al | 3.32 | 0.7 | 0.7 | 2.62 | 2.76 | 1.88 | 2.34 | 8.05 | 0.21 | 0.95 | 1.78 | 0.75 | 1.38 | 0.79 | 1.09 | 2.5 | 3.41 |
| Ca | 14.27 | 3.53 | 5.07 | 12.43 | 15.94 | 7.93 | 10.25 | 11.95 | 0.75 | 3.85 | 11.7 | 6.77 | 6.84 | 5.35 | 3.39 | 9.19 | 17.75 |
| Fe | 16.3 | 49.5 | 39.5 | 28 | 18.1 | >25.0 | 15.9 | 7.2 | >25.0 | >25.0 | >25.0 | >25.0 | >25.0 | >25.0 | >25.0 | >25.0 | 13.85 |
| Mg | 1.09 | 1.31 | 2.61 | 1.1 | 1.16 | 0.53 | 1.49 | 2.73 | 0.14 | 0.55 | 1.48 | 2.81 | 1.51 | 1.23 | 1.04 | 1.2 | 1.93 |
| K | 0.07 | 0.07 | 0.1 | 0.07 | 0.09 | 0.32 | 1.54 | 0.69 | 0.06 | 0.15 | 0.08 | 0.11 | 0.11 | 0.53 | 0.59 | 0.22 | 0.11 |
| Na | 0.06 | 0.1 | 0.12 | 0.05 | 0.05 | 0.24 | 1.73 | 0.89 | 0.15 | 0.23 | 0.09 | 0.18 | 0.13 | 0.17 | 0.19 | 0.15 | 0.11 |
| Ti | 0.18 | 0.04 | 0.05 | 0.12 | 0.12 | 0.07 | 0.14 | 0.42 | <0.01 | 0.07 | 0.11 | 0.05 | 0.06 | 0.05 | 0.05 | 0.13 | 0.2 |

Au and Hg in ppb
Total S, Al, Ca, Fe, Mg, K, Na, & Ti in wt %
Other elements in ppm
Analyses completed at Chemex Labs Ltd., 212 Brookbank Ave., North Vancouver, B.C.
Methods:
Au = Fire assay and AA finish; F = Specific Ion Electrode; As = AAS; other elements = ICP-MS

**TABLE 2 CONTINUED**
**ASSAY RESULTS OF MINERALIZED SKARN, HEFF PROPERTY,**

| | |
|---|---|
| For sample locations *see* Ray and Webster (2000) | |
| GR94-217, 219 & 220 | Garnet-pyroxene-magnetite skarn with pyrite and trace chalcopyrite |
| GR94-223 & 224 | Drill core: magnetite-garnet skarn with pyrite and trace chalcopyrite |
| GR99-19 | Pyroxene-magnetite-pyrite skarn; UTM 10 7067 80E; 56 365 18N |
| GR99-25A | Magnetite-pyrite-garnet skarn |
| GR99-27 | Ganet-pyroxene skarn with pyrrhotite, pyrite and trace chalcopyrite |
| GR99-28 & 29 | Pyrite-magnetite skarn with trace garnet and chalcopyrite |
| GR99-32A | Magnetite-garnet-proxene skarn |
| GR99-32 | Magnetite-pyroxene skarn with pyrite and trace chalcopyrite |
| GR99-33 | Magnetite skarn with trace garnet, pyrite and chalcopyrite |
| GR99-34 | Magnetite vein with minor pyrite |
| GR99-37 | Massive magnetite with pyrite and trace garnet |
| GR99-40 | Magnetite-garnet-pyrite skarn with trace chalcopyrite |
| GR99-42 | Garnet-pyroxene-pyrite skarn with minor chalcopyrite |

spar-bearing occurrence was seen in a new road cut at NAD 83, UTM location 11 2 89 285E; 56 34 320N. A grab sample from this occurrence (sample GR 99-53; Table 3) contained 0.8 percent Cu as well as anomalous Mo, Co and Ag. This sample also contained the highest quantity of Hg (250 ppb) recorded during this survey. The pyritic mineralization in both the pluton and its related dike-sill swarm are weakly anomalous in P and possibly Ce (Table 3).

## THE HEFF SKARN COMPARED TO OTHER Fe SKARNS IN B.C.

In some respects, the Heff skarn resembles the calcic Fe skarns on the west coast of British Columbia, such as the Merry Widow, Tasu and Texada Island deposits (Sangster, 1969; Meinert,1984; Ray 1995; Ray and Webster, 1997). Similarities include:

(a) the presence of abundant massive magnetite with variable amounts of Fe sulphides that are associated with sporadic Cu and Au-rich mineralization;

(b) the presence of dark-coloured (probably Fe-rich) garnet and pyroxene assemblages; and,

(c) the proximal development of magnetite skarn in calcareous rocks adjacent to mafic, Fe-rich intrusions.

However, the Heff mineralization is significantly different from that in the west coast deposits which suggests it is not a typical island arc Fe skarn. These differences include:

(a) its location in the central part of the province where it is hosted by Quesnel Terrane rocks whereas the major Fe skarn deposits lie further west in Wrangellia (Figure 1);

(b) unlike the west coast Fe skarns, the Cu-Au mineralization at the Heff skarn lacks enrichment in Co, Ni, and As (Table 2);

(c) the Heff mineralization contains more Ti, REE's, P, Sr and Ba than the west coast Fe skarns (Figs. 4A, B and C); the higher P content is probably related to the presence of apatite, although this mineral has not been identified on the Heff property;

(d) unlike the west coast Fe skarns, there are positive correlations between Ti and P, Ba and Sr, and La and Ce in the Heff mineralization (Figure 4); the latter has a higher average Cu content (Figure 4D) but contains less Ag (Figure 4E and F); and,

(e) there is a moderate to good positive correlation between Cu and Ag in the west coast Fe skarns (Ray and Webster, 1995); this correlation is less obvious at the Heff property (Figure 4E).

## DISCUSSION

Previously, the Heff mineralization has been considered to be either a skarn or to have resulted from syngenetic submarine fumerolic activity (Casselman, 1980). We believe it is a skarn that formed by the infiltration of hydrothermal fluids from the Heffley Creek Pluton. The latter probably represents an Alaskan-type intrusion, similar to the Tulameen body and other late Triassic to Jurassic mafic-ultramafic complexes that intrude rocks of the Quesnel and Stikinia terranes elsewhere in British Columbia (Taylor, 1967; Nixon *et al.*, 1997).

The Heffley Creek Pluton is one of several major Fe-rich intrusive bodies in the district that include the alkalic and dioritic Iron Mask Batholith, located 33 km southwest of Heffley Lake. The batholith is related to the Ajax and Afton Cu-Au porphyry deposits (Ross *et al.*, 1995) and, like the Heffley Creek Pluton, it is controlled along a southeast trending structure (Carr and Reed, 1976). Parts of the batholith contain detectable amounts of Pd (Kwong, 1987) as well as some magnetite-apatite vein mineralization, as seen

## TABLE 3
## ASSAY RESULTS OF MINERALIZED INTRUSIVE ROCKS, HEFFLEY LAKE, B.C.

| | Altered pyritic dikes & sills | | | Heffley Creek Pluton | | |
|---|---|---|---|---|---|---|
| SAMPLE No. | GR99-23 | GR99-24 | IW99-9 | GR99-28A | GR99-30A | GR99-53 |
| Au | <5 | 145 | 5 | <5 | 8 | 15 |
| Sb | 1.3 | 0.9 | 2.2 | 1.8 | 0.3 | 1.8 |
| Ba | 230 | 430 | 290 | 300 | 20 | 150 |
| Be | 0.5 | 0.7 | 1.2 | 0.75 | 0.1 | 0.8 |
| Bi | 0.2 | 0.06 | 0.12 | 0.28 | <0.01 | 0.52 |
| Cd | 0.02 | 0.08 | 0.1 | 0.16 | 0.08 | 1.3 |
| Ce | 16.85 | 17.45 | 24 | 22.9 | 5.44 | 21.3 |
| Cs | 1.1 | 0.6 | 0.8 | 0.45 | 0.1 | 0.6 |
| Cr | 162 | 40 | 43 | 116 | 556 | 65 |
| Co | 21.8 | 21.4 | 30.6 | 26 | 46 | 83.8 |
| Cu | 116 | 85 | 141 | 144 | <1 | 8230 |
| Ga | 12.5 | 14.7 | 20.6 | 13.4 | 7 | 12.6 |
| Ge | 1.3 | 1.2 | 1.5 | 1.5 | 1.5 | 0.8 |
| La | 7.5 | 8 | 10.5 | 9.5 | 1.5 | 10.5 |
| Pb | 3.5 | 5 | 7 | 8.5 | 2 | 9.5 |
| Li | 10.8 | 4.2 | 12.4 | 6.6 | 7.6 | 5.2 |
| Mn | 830 | 365 | 690 | 1525 | 875 | 300 |
| Mo | 1.4 | 0.6 | 2 | 20.2 | <0.2 | 16.8 |
| Ni | 29.8 | 6.6 | 26 | 27.6 | 85.2 | 5.2 |
| Nb | 1.6 | 2.8 | 2.6 | 1 | <0.2 | 3.8 |
| P | 1130 | 760 | 1460 | 1630 | 80 | 1170 |
| Rb | 34.2 | 37 | 64 | 25.6 | 1.2 | 100 |
| Ag | 0.95 | 0.65 | 0.5 | 0.45 | 0.2 | 14.4 |
| Sr | 811 | 591 | 789 | 834 | 58.8 | 331 |
| Ta | 0.05 | 0.2 | 0.05 | 0.05 | <0.05 | 0.05 |
| Te | 0.2 | 0.15 | 0.2 | 0.05 | <0.05 | 0.6 |
| Tl | 0.42 | 0.26 | 0.36 | 0.18 | <0.02 | 0.54 |
| Th | 2 | 2.6 | 2.6 | 1.4 | <0.2 | 2.6 |
| W | 0.7 | 1.1 | 1.6 | 0.9 | 0.1 | 22.5 |
| U | 1 | 1.2 | 1.6 | 0.8 | <0.2 | 1.8 |
| V | 274 | 121 | 232 | 356 | 215 | 121 |
| Y | 12.3 | 11.9 | 16.3 | 17.8 | 7.7 | 11.4 |
| Zn | 30 | 16 | 22 | 64 | 30 | 122 |
| As | 1 | 1 | 6 | 20 | 1 | 20 |
| F | 930 | 270 | 550 | 480 | 50 | 310 |
| Hg | <10 | 50 | <10 | <10 | <10 | 250 |
| Al | 7.09 | 8.76 | 9.1 | 6.41 | 2.1 | 5.98 |
| Ca | 7.37 | 4.06 | 6.67 | 7.07 | 11.2 | 0.83 |
| Fe | 5.79 | 3.62 | 5.05 | 7.46 | 5.5 | 5.49 |
| Mg | 3.64 | 1.1 | 2.55 | 3.95 | 7.81 | 0.83 |
| K | 1.46 | 1.7 | 2.08 | 0.82 | 0.05 | 3.25 |
| Na | 1.53 | 3.27 | 2.06 | 1.47 | 0.2 | 1.43 |
| Ti | 0.49 | 0.32 | 0.42 | 0.47 | 0.33 | 0.2 |

Au and Hg in ppb
Al, Ca, Fe, Mg, K, Na, & Ti in wt %
Other elements in ppm
Analyses completed at Chemex Labs Ltd., 212 Brookbank Ave., North Vancouver, B.C.
Methods:
Au = Fire assay and AA finish; F = Specific Ion Electrode; As = AAS; other elements in ICP-MS

Sample Descriptions, Heff Skarn
GR99-23 2m wide pyrite-bearing dike, 7100N-6775E
GR99-24 5m wide pyritic and sicified dike adjacent to garnet-pyroxene skarn, 5700N-7600E
IW99-9 15 cm-wide hornblende-pyroxene-porphyry dike with pyrite-pyrrhotite veinlets.
GR99-28A Altered, silicified mafic diorite with 10% pyrite and quartz veins.
GR99-30A Dark, clinopyroxenite with 5% cumulate magnetite and trace pyrite.
GR99-53 Silicified, altered and malachite-stainedgabbro with pyrite & chalcopyrite. UTM 11 2 89 285E; 56 34 320N
GR99-51 Dark, pyroxene-hornblende ultramafic with 10% cumulate magnetite and trace pyrite. UTM 10 7 08 482; 56 33 287

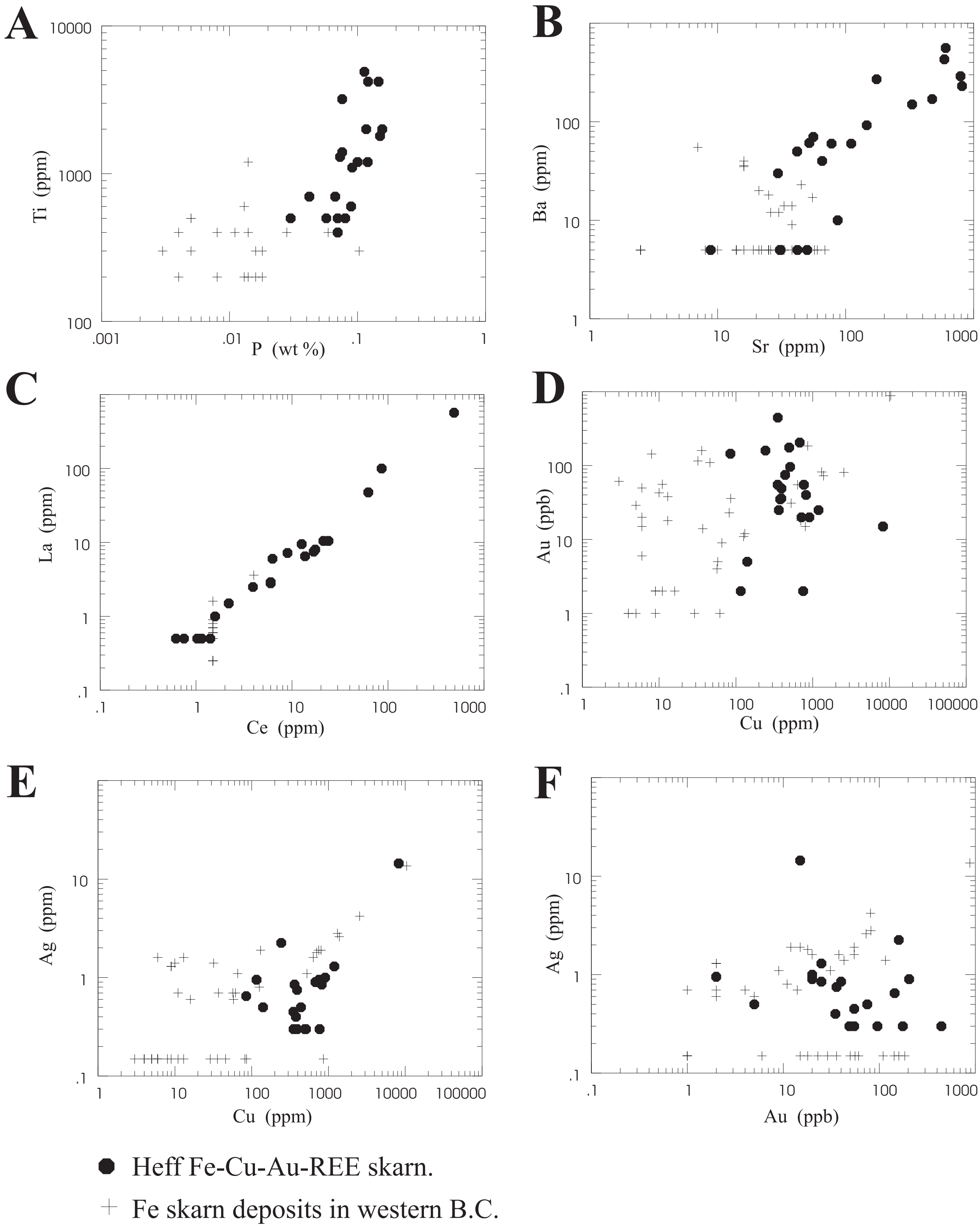


Figure 4. Plots comparing the chemistry of magnetite-rich mineralization at the Heff property with the Fe skarn deposits in western British Columbia. The plots include 21 samples from the Heff skarn and a total of 43 samples from the Merry Widow, Texada Island and Iron Crown deposits (*see* Figure 1).

at the Glen Iron mine and the Magnet occurrence (Figure 1; MINFILE Nos. 092INE 025 and 022 respectively; Hancock, 1988). The latter includes several southeast-trending veins of massive magnetite that reach up to 10 metres in thickness and 400 metres in strike length. The coarse crystalline magnetite is intergrown with coarse pale apatite crystals up to 3 centimetres long; some veins also include very coarse amphibole crystals over 5 centimetres in length. A magnetite-apatite-rich grab sample from the Magnet occurrence contained low quantities of Au, Cu and Ag, but the mineralization is anomalous in P (over 1 percent) and some REE's and trace elements, containing 172 ppm Ce, 20 ppm Ga, 76 ppm La, 57 ppm Y and 1775 ppm V.

A few REE ± U-rich skarns have been identified in the Yukon (e.g. Yukon MINFILE Nos. 116B 056 and 117A 020), but skarns containing both magnetite and anomalous quantities of REE's similar to the Heff property are extremely rare in the Canadian Cordillera. One exception is the Guano skarn (Yukon MINFILE 105F 081), a magnetite-U-REE-F-bearing occurrence. The Heff skarn may have resulted from an Fe-oxide-Cu-Au-REE-P-rich hydrothermal system similar to those responsible for deposits in the Ernest Henry (Australia)-Kiruna (Sweden)-Candelaria (Chile)-Wernecke Breccias (Canada) spectrum. These systems, which have been described by Laznicka and Gaboury (1988), Einaudi and Oreskes (1990), Hitzman *et al.* (1992), Oreskes and Hitzman (1990; 1993), Bookstrom (1977, 1995), Ryan *et al.* (1995), Jenkins *et al.* (1998), Williams (1998; 1999) and Ray and Lefebure (2000), have the following characteristics, some of which are seen at the Heff property:

(a) they are associated with large volumes of pervasive, massive hematite and/or magnetite; the latter mineral tends to have a lower Ti content than primary magmatic-related magnetite;

(b) they occur along major, long-lived brittle structures that were deep enough to tap mantle-derived intrusions;

(c) they occur in a variety of tectonic environments and rock types, ranging from rifts in intercratonic granitic basement (e.g. Olympic Dam) to mafic volcanic arcs (e.g. the Chilean Fe belt examples, including the Candelaria deposit);

(d) the orebody-morphology is highly variable; mineralization may occur as veins, breccia sheets, breccia pipes, tabular bodies or stockworks. Structure is the dominant regional and local control, but mineralization may also be strongly influenced by stratigraphy and host-rock lithology;

(e) they range in age from Proterozoic (e.g. Ernest Henry) to Cretaceous (e.g. Candelaria) (Marschik and Fontboté, 1996; Marschik *et al.*, 1996; Jenkins *et al.*, 1998; Williams, 1998; 1999);

(f) they may contain elevated values of U, REE's and trace elements (La, Ce, Nd, Pr, Sm, Y, Gd); the latter elements are commonly concentrated in mineral phases such as allanite, monazite or epidote;

(g) many represent low-sulphur Fe-oxide systems and are uneconomic for base metals. However, deposits such as Olympic Dam, Ernest Henry and Candelaria are more sulphide-rich and are an economic source of Cu and Au;

(h) the intrusions may be a critical source of the heat, fluids and metals in these systems (Oreskes and Hitzman, 1993), but in many deposits there is a poor spatial relationship between the deeper-level plutons and the mineralization, which tends to form at higher structural levels;

(I) where associated plutons are identified, they range in composition from syenite to granodiorite to mafic gabbro-diorite; and,

(J) many of these deposits world-wide lack skarn. However, where calcareous protoliths are present (e.g. Candelaria in Chile, Osborne and Mount Elliot in Australia), garnet-pyroxene-scapolite skarn assemblages may develop (Ryan *et al.*, 1995; Adshead *et al.*, 1998; Garrett, 1992; Williams, 1999).

## CONCLUSIONS AND RECOMMENDATIONS

The Heffley Lake area contains two types of chalcopyrite-bearing mineralization, namely: (1) magnetite-rich garnet-pyroxene skarns on the Heff property, and (2) pyrite ± magnetite disseminations and veins south of Heffley Lake in the Heffley Creek Pluton.

The Heff skarn represents an unusual Cu ± Au ± REE ± P-bearing magnetite skarn whose location and distinctive chemistry (Figs. 1 and 4) suggests it differs from the typical Fe skarns occurring along the west coast of British Columbia. It possibly resulted from a Fe-oxide ± Cu ± Au ± REE ± P-bearing hydrothermal system similar to those responsible for deposits in the Ernest Henry-Candelaria-Wernecke Breccias spectrum. Structurally-controlled Fe oxide mineralization of this type is recorded at the Iron Range occurrences east of Creston, British Columbia (Figure 1; MINFILE Nos. 82FSE 014-028; Brown *et al.*, 1994; Stinson and Brown, 1995). However, the Heff skarn lacks the extensive brecciation and widespread Na ± K metasomatism that characterises many deposits of the Ernest Henry-Candelaria-Wernecke Breccias spectrum.

The Heff skarn is genetically related to the Heffley Creek Pluton, a pyroxene and magnetite-bearing mafic-ultramafic body that exceeds 10 $km^2$ in outcrop area. The pluton, which contains several Cu occurrences, is thought to represent an Alaskan-type body, similar to the Tulameen and other Triassic-Jurassic complexes in British Columbia.

A proposed model for the Heff skarn involves the emplacement of the elongate Heffley Creek pluton and the related skarns along a structure that may have marked the original Harper Ranch-Nicola unconformity. Subsequently, large-scale folding resulted in the north-easterly tilting of the skarn, the pluton, and its hostrocks. No skarns or minor intrusions are seen along the southern border of the pluton, perhaps because this was the basal margin of the body. Instead, late, Fe-rich hydrothermal fluids from the pluton were channelled upwards along a swarm of minor intrusions into overlying Nicola Group limestones. Thus, the skarns and the dike-sill swarm seen north and northeast of Heffley Lake are believed to have formed along, and close to, the upper margin of the pluton. The dominance of pyrite over pyrrhotite and the abundance of magnetite suggests the presence of an oxidised, low sulphur hydrothermal system.

Recommendations for further work in the area include:

(a) map the remainder of the Heffley Creek Pluton to accurately determine its distribution and margins;

(b) prospect the interior of the Heffley Creek Pluton for Cu, Au, Cr and PGE mineralization, and explore its margins for Cu-Au-REE skarns similar to the Heff property;

(c) future exploration for blind skarn orebodies on the Heff property should include a geophysical survey along the presumed margin of the Heffley Creek Pluton, in the poorly exposed area immediately north of, and under Heffley Lake. The southerly change in mineral alteration recognised in this survey, supported by the very high Au and Cu soil anomalies previously outlined, suggests that an economic skarn orebody could underlie Heffley Lake and its alluvium-covered northern shore;

(d) the Heff skarns and their host rocks are strongly folded; thus, future exploration for orebodies on the property should commence with an attempt to determine the structural controls; and finally,

(e) the recognition of a large Alaskan-type pluton in this highly accessible part of southern British Columbia indicates that the entire district needs to be re-mapped and evaluated for its skarn, porphyry and PGE-potential.

## ACKNOWLEDGMENTS

The ideas and scientific opinions of the following persons were helpful to this program: D. A. Brown, M.S. Cathro, D.V. Lefebure, R.H. McMillan, G.T. Nixon, and V.A.G. Preto.

## REFERENCES

Adshead, N.D., Voulgaris, P., and Muscio, V.N. (1998): Osborne copper-gold deposit, NW Queensland; *Australasian Institute of Mining and Metallurgy,* Monograph 22, p. 793-798.

Arseneau, G.J. (1997): Geological, geochemical and geophysical report on the 1997 field work, Mesabi property; Unpublished report for Echo Bay Mines, October 1997, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 25203, 79 pages.

Bookstrom, A.A., (1977): The magnetite deposits of El Romeral, Chile, *Economic Geology*, Volume 72, pages 1101-1130.

Bookstrom, A.A. (1995): Magmatic features of iron ores of the Kiruna type in Chile and Sweden; ore textures and magnetite geochemistry; discussion. *Economic Geology*. 90; 2, Pages 469-473.

Brown, D.A., Bradford, J.A., Melville, D.M., Legun, A.S., and Anderson, D. (1994): Geology and mineral deposits of the Purcell Supergroup in the Yahk map area, south-eastern British Columbia (82F/1); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1993, Paper 1994-1, pages 129-151.

Carr, J.M., and Reed, A.J. (1976): Afton; *In* Porphyry deposits of the Canadian Cordillera. (A. Sutherland Brown, ed.). *Canadian Institute of Mining and Metallurgy;* Special Volume 15, pages 376-387.

Casselman, M.J.(1980): Assessment report of line-cutting and geological, soil geochemical and magnetometer surveys on the Heff Lake Property; *Cominco Limited*.

Cockfield, W.E. (1944): Nicola map area, British Columbia, Paper 44-20. Map with descriptive notes, *Geological Survey of Canada*, Ottawa, 1944.

Cockfield, W.E. (1947): Nicola, Kamloops and Yale districts, British Columbia, *Geological Survey of Canada*, Map 886A, scale 1:253 440.

Debon, F., and Le Fort, P., 1983, A chemical-mineralogical classification of common plutonic rocks and associations: *Royal Society of Edinburgh*, Transactions, Earth Sciences 73 (for 1982), p. 135-149.

Einaudi, M.T., and Oreskes, N. (1990): Progress towards an occurrence model for Proterozoic iron oxide deposits - a comparison between the ore provinces of South Australia and southeast Missouri. *In* The Mid-continent of the United States - Permissive Terranes for an Olympic Dam Deposit?, *U.S. Geological Survey,* Bulletin 1392.

Garrett, S.J.M. (1992): The geology and geochemistry of the Mt. Elliott Cu-Au deposit, northwest Queensland; Unpublished MSc thesis, Hobart, *University of Tasmania*.

Hancock, K.D. (1988): Magnetite occurrences in British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1988-28, 153 pages.

Hitzman, M.W., Oreskes, N., and Einaudi, M.T. (1992): Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits; *Precambrian Research*, Volume 58, pages 241-287.

Irvine, T.N., and Baragar, W.R.A. (1971): A guide to the chemical classification of the common volcanic rocks; *Canadian Journal of Earth Sciences*, Volume 8, pages 523-547.

Jenkins, R.A., Leveille, R.A., and Marin, W. (1998): Discovery and geology of the Candelaria deposit, Chile. Pathways ’98, extended abstract volume*, B.C. & Yukon Chamber of Mines and Society of Economic Geologists*. Pages 78-79.

Kwong, Y.T.J. (1987): Evolution of the Iron Mask Batholith and its associated copper mineralization; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 77, 55 pages.

Laznicka, P., and Gaboury, D. (1988): Wernecke Breccias and Fe, Cu, U mineralization: Quartet Mountain-Igor area (NTS 106E); *in* Yukon Exploration and Geology, *Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, pages 42-50.

Le Maitre, R.W., Bateman, P., Dudek, A., Keller, J., Lameyre, J., Lebas, M.J., Sabine, P.A., Schmid, R., Sorensen, H., Streckeisen, A., Woolley, A.R., and Zanettin, B., Eds., (1989): A classification of igneous rocks and glossary of terms: recommendations of the International Union of Geological Sciences Subcommission on the systematics of igneous rocks, *Oxford Blackwell Scientific Publications*, 193 pages.

Marschik, R., and L. Fontboté ( 1996): Copper (-iron) mineralization and superposition of alteration events in the Punta Del Cobre Belt, northern Chile; *In* Andean copper deposits: new discoveries, mineralization, style and metallogeny, *Society of Economic Geologists Special Publication No. 5*, Camus, F., Sillitoe, R.H., and Peterson, R., eds. 1996, pages 171-190.

Marschik, R., Singer, R., Munizaga, F., Tassarini, C., and Fontbote, L. (1996): Age of the Cu(-Fe) mineralization and Cretaceous to Paleocene thermal evolution of the Punta del Cobre district, northern Chile. *In* Proceedings of the XXXIX Brazilian Geological Congress, Bahia. Anais 7, pages 306-309.

Meinert, L.D., 1984, Mineralogy and petrology of iron skarns in western British Columbia, Canada: *Economic Geology*, v. 79, p. 869-882.

MMAR (1916): Hefferly Lake, Minister of Mines, *Province of British Columbia*, Annual Report for the Year Ended 31st December 1915, page K222.

Monger, J.W.H. and McMillan, W.J. (1989): Geology, Ashcroft, British Columbia*; Geological Survey of Canada,* Map 42-1989, sheet 1, scale 1:250 000.

Nixon, G.T., Hammack, J.L., Ash, C.H., Cabri, L.J., Case, G., Connelly, J.N., Heaman, L.M., Laflamme, J.H.G., Nuttall, C., Paterson, W.P.E., and Wong, R.H. (1997): Geology and platinum-group element mineralization of Alaskan-type ultramafic-mafic complexes in British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 93, 142 pages.

Oreskes, N. and Einaudi, M.T. (1990): Origin of rare earth-enriched hematite breccias at the Olympic Dam deposit, Roxby Downs, South Australia; *Economic Geology*, Volume 85, Number 1, pages 1-28.

Oreskes, N., and Hitzman, M.W., (1993): A model for the origin of Olympic Dam-type deposits. *In*, Mineral deposit modeling: *Geological Association of Canada*, Special Paper No. 40, pages 615-633.

Ray, G.E. (1995): Fe skarns; *In* Selected British Columbia Mineral Deposit Profiles, Volume I - Metallics and Coal, editors D.V. Lefebure and G.E. Ray. *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1995-20, pages 63-65.

Ray, G.E. and Webster, I.C.L. (1995): The geochemistry of mineralized skarns in British Columbia; Geological Fieldwork 1994, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 371-383.

Ray, G.E. and Webster, I.C.L. (1997): Skarns in British Columbia, *B.C. Ministry of Employment and Investment, Geological Survey Branch,* Bulletin 101, 260 pages.

Ray, G.E. and Lefebure, D.V. (2000): A synopsis of iron oxide-Cu-Au-U-P-(REE) deposits of the Candelaria-Kiruna-Olympic Dam Family; *B.C. Ministry of Energy and Mines*, Paper 2000-1 (this volume).

Ray, G.E. and Webster, I.C.L. (2000): Geology and mineral occurrences in the Heffley Lake Area, south-central B.C.; *B.C. Ministry of Energy and Mines,* Open File Map.

Roed, M.A. (1988): Geological exploration of the Hawk 1 to 4 mineral claims, 1987, Heffley Lake, B.C.; Unpublished report for Redbird Gold Corp., *B.C. Ministry of Energy, Mines and Petroleum,* Assessment report 17147, 40 pages.

Ross, K.V., Godwin, C.I., Bond, L., and Dawson, K.M. (1995): Geology, alteration and mineralization of the Ajax East and Ajax West copper-gold alkalic porphyry deposits, southern Iron Mask batholith, Kamloops, British Columbia; *In* Porphyry Deposits of the Northwest Cordillera of North America. (T.G. Schroeter, ed.). *Canadian. Institute of Mining, Metallurgy and Petroleum.* Special volume 46, pages 565-608.

Ryan, P.J., Lawrence, A.L., Jenkins, R.A., Matthews, J.P., Zamora, J.C., Marino, E.W. & Diaz, I.U. (1995): The Candelaria copper-gold deposit, Chile; *In* Porphyry Copper Deposits of the American Cordillera, editors Pierce, F.W. and Bolm, J.G, *Arizona Geological Society Digest*, 20, 625-645.

Sangster, D.F. (1969): The Contact metasomatic magnetite deposits of British Columbia; *Geological Survey of Canada*, Bulletin 172, 85 pages.

Stinson, P, and Brown, D.A., (1995): Iron Range Deposits, southern British Columbia (82F/1); *B.C. Ministry of Energy, Mines and Petroleum,* Paper 1995-1, pages 127-134.

Taylor, H.P., Jr. (1967): The zoned ultramafic complexes of southeastern Alaska; *In* Ultramafic and related rocks, editor Wyllie, P.J., *John Wiley and Sons Inc*., New York, pages 97-121.

Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W. and Woodsworth, G.J. (1991): Terrane map of the Canadian Cordillera; *Geological Survey of Canada,* Map 1713a, Scale 1:2 000 000.

Williams, P.J. (1998): Metalliferous economic geology of the Mount Isa Eastern Succession, northwest Queensland. *Australian Journal of Earth Sciences*, Volume 45, pages 329-341.

Williams, P.J. (1999): Fe oxide-copper-gold deposits. Shortcourse notes, *James Cook University Economic Geology Research Unit and Mineral Deposits research Unit*, University of B.C., Vancouver, 11 th March 1999.

Winchester, J.A., and Floyd, P.A. (1977): Geological discrimination of different magma series and their differention products using immobile elements. *Chemical Geology*, Volume 20, pages 325-343.