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THE STYLE AND ORIGIN OF ALTERATION ON THE LIMONITE CREEK PROPERTY, CENTRAL BRITISH COLUMBIA (93L/12)

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INTRODUCTION

This report summarizes the nature and mineralogy of alteration zones on the Limonite Creek Property in north central British Columbia. Research to date has included two field seasons involving extensive sampling of drill core, mineralogical classification of alteration, and limited geochemistry. Dating of intrusions that occur in the area of alteration has been initiated and one result is reported herein. Extensive deposits of exotic limonite also occur on and adjacent to the Limonite Creek property. These deposits are assumed to have been derived from the weathering and oxidation of extensive pyrite in the alteration zones. Research is also being directed towards the nature and origin of the limonite, but only a brief summary of these results is included in this paper.

Figure 1. Location of the Limonite Creek property within Stikinia, Central British Columbia.

The Limonite Creek property is located in Telkwa Pass, approximately 50 kilometres southwest of Smithers, in the Omineca Mining District of British Columbia. The property lies along a mountain ridge at an elevation of 1275 to 1400 metres, approximately one to two kilometres north of Limonite Creek, a tributary of the Zymoetz (Copper) River. Access is by helicopter only, although the Telkwa River logging road runs within seven kilometres south of the prospect.

The Limonite Creek property has been owned and explored by Telkwa Gold Corporation since 1994. Exploration activities have included over 6000 feet of diamond drilling, airborne geophysics, induced polarization and soil geochemical surveys. Previously, Cyprus Canada Inc. conducted geological mapping, rock, water and soil geochemical analyses, a transient electromagnetic (TEM) survey, and diamond drilling in 1992. Noranda Exploration Co. Ltd., Evergreen Explorations, and Pacific Petroleum Ltd. also evaluated the property in the 1960's.

REGIONAL GEOLOGY

The Limonite Creek property is located within the Stikine terrane (Figure 1) and is underlain by Lower to Middle Jurassic volcanic rocks of the Telkwa Formation. The Telkwa Formation consists of a varied assemblage of marine and non-marine calc-alkaline volcanic rocks, which form the basal part of the Hazelton Group. Five distinctive facies are recognized in the Telkwa Formation (Tipper and Richards, 1976). The Howson Subaerial Facies dominates the Telkwa Pass area, the Howson Range, and most of the Telkwa Range. This facies is described by Tipper and Richards (1976) as an assemblage of bright red, maroon, purple, pink, grey and green, well-bedded, slightly deformed pyroclastic flows and sedimentary rocks, dominantly of andesitic to dacitic composition.

Volcanic rocks of the Telkwa Formation are locally intruded by calc-alkaline stocks and batholiths of Early Jurassic age. These intrusions, termed Topley intrusions (Wordsworth et al., 1993), are thought to be contemporaneous with the Telkwa Formation and have K-Ar ages ranging from 173-205 Ma (Tipper and Richards, 1976). The intrusions form a series of bodies coincident with the Skeena Arch, of which the Howson Batholith is one of the largest. This batholith comprises mainly tonalite and granodiorite and has a K-Ar hornblende age of 193±8 Ma (recalculated from Wanless et al., 1974).
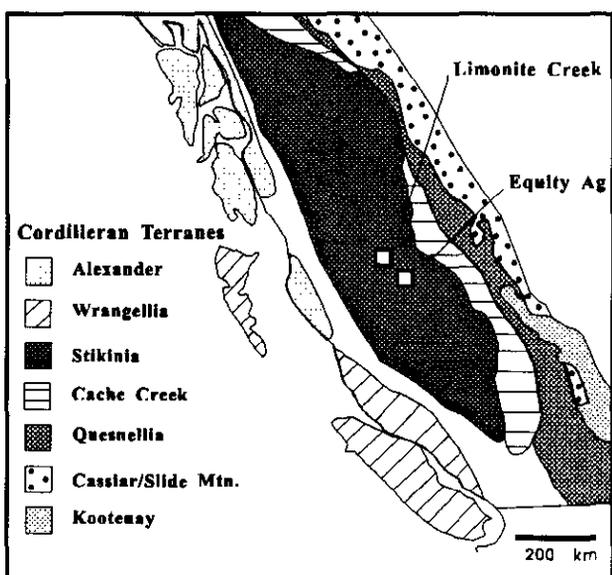
Younger intrusions in this region include the Late Cretaceous Bukley (ca. 70-88 Ma) and Eocene Nanika intrusive suites of the western Skeena Arch, as well as the Eocene Babine Igneous suite in the Babine Lake area to the east. Coeval Upper Cretaceous volcanic rocks of the Brian Boru Formation are locally preserved in the western Skeena Arch and Eocene volcanic rocks of the Ottsa Lake Formation are widespread across the west-central British Columbia region. Both Late Cretaceous and Eocene intrusive suites are associated with mineral deposits in the region. A quartz monzonite associated with the Equity Deposit (Cyr et al., 1984) gave an U-Pb age of 60.1±0.2 Ma, which is likely part of the Nanika intrusive suite. Prior to this study, U-Pb dating of rocks in the Telkwa Pass-Limonite Creek area has not been carried out.

PROPERTY GEOLOGY

The geology of the Limonite Creek property has been determined from mapping and drill core logging during exploration programs (Tompson (1997); Tompson and Cuttle (1994)) and fieldwork during this study.

The Limonite Creek prospect area is dominated by green and lesser maroon rhyodacitic, dacitic, and andesitic tuffs and flows which are interpreted to belong to the Telkwa Formation. The volcanic rocks are dominated by mafic to intermediate fragmental units with lesser massive and flow-banded units usually of more felsic composition. Bedding is difficult to recognize and most units exhibit a strong foliation trending 060-090°. As shown in Figure 2, these volcanic rocks are intruded by several stocks of dioritic to granodioritic compositions. An irregular body of porphyritic granodiorite occurs in the eastern part of the property, approximately 300 metres south of the camp. The intrusion is weakly altered with biotite partially replaced by chlorite and traces of disseminated pyrite. The intrusion was sampled for U-Pb dating (sample LC-08).

The Limonite Creek prospect is bounded to the east by a coarse to medium grained diorite to granodiorite and to the west by a weakly porphyritic granodiorite. The intrusion to the east shows weak to moderate propylitic alteration and abundant epidote veins close to the contact with the altered volcanic rocks. The majority of
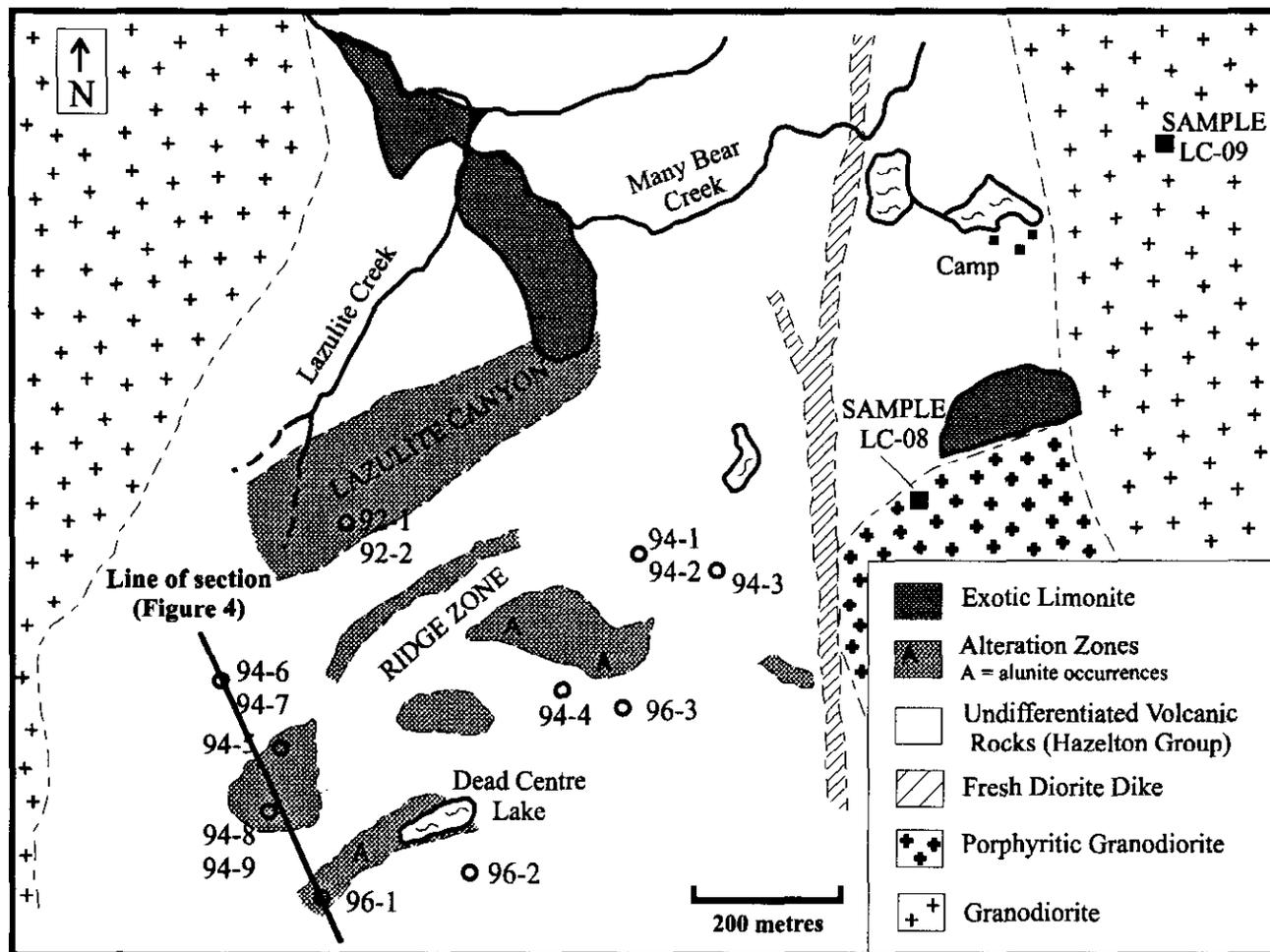
Figure 2: Generalized geological map of the Limonite Creek area showing intense alteration zones, exotic limonite occurrences, drill holes, sample sites for U-Pb dating, and line of section for Figure 4.

this intrusion displays only minor alteration but does contain rare milky white quartz veins with minor chalcopyrite. This intrusion was also sampled for U-Pb dating (sample LC-09), but results are not available at this time.

Both extrusive and intrusive rocks within the Limonite Creek prospect area are cross-cut by numerous late narrow basalt and diorite dike swarms. In the eastern part of the map, a prominent dike with northerly strike cuts across altered and unaltered volcanic rocks and various intrusive units (Figure 2).

GEOCHRONOLOGY

The sample of porphyritic granodiorite (sample LC-08) was prepared for U-Pb dating using standard mineral separation techniques. The sample yielded abundant, high quality, clear, colourless, stubby prismatic zircon with rounded cross sections and simple terminations. No cores or zoning were observed in these grains. The highest quality and coarsest nonmagnetic grains were selected for analysis and were air abraded to reduce the effects of surface-correlated Pb loss. These grains were split into three fractions which were dissolved, chemically separated and analyzed employing the techniques listed in Mortensen et al. (1995). All work was carried out at the Geochronology Laboratory of the Department of Earth and Ocean Sciences at the University of British Columbia.
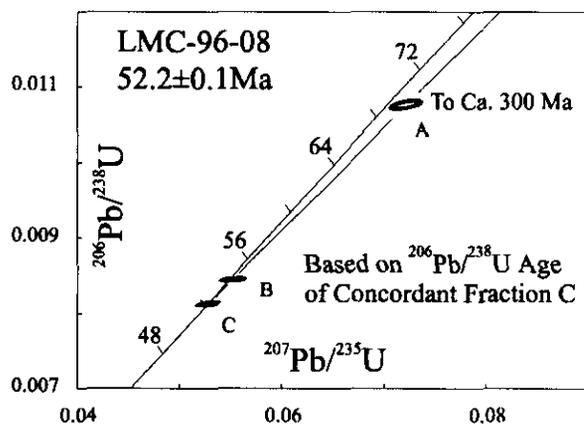
Figure 3: Concordia diagram for sample LC-08. Ellipses are plotted at the 2σ level of precision.

Three analyzed zircon fractions for sample LC-08 are plotted on Figure 3 and the U-Pb data are listed in Table 1. The best estimate for the age of the rock, 52.2±0.1 Ma, is based on the $^{206}Pb/^{238}U$ age for concordant fraction C. Fractions A and B give older Pb/U and Pb/Pb ages, which suggests the presence of minor inherited zircon. A regression line through the data give a poorly constrained upper intercept of ca. 300 Ma, which is interpreted as the average age of inherited zircon in fractions A and B.

ALTERATION

The characterization of alteration assemblages at Limonite Creek is based on drill core logging and petrography, as well as analyses by X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and a hand-held infra-red spectrometer (PIMA). Alteration zones identified on the property include intense acid sulphate and advanced argillic zones and widespread sericitic and propylitic assemblages. The mineralogy of each alteration type is given in Table 2.

The location of intense alteration at surface is shown on Figure 2. Relationships among alteration assemblages observed in drill core are complex (Figure 4) although based on the limited data, regions of strong alteration appear to form subvertical zones (the lightly shaded areas in Figure 4). In individual drill holes, intervals of siliceous and acid sulphate alteration are generally bound by advanced argillic alteration. This in turn grades to sericitic and finally propylitic-dominated assemblages. Alteration zones containing anhydrite (and/or gypsum) are generally confined to the periphery of the alteration system and are concentrated at depth.

Acid Sulphate Alteration (AS)

Acid sulfate alteration is characterized by the presence of alunite in the alteration assemblage. This alteration type is concentrated near the Ridge Zone, on the south side of the Limonite Creek property, and particularly in DH 94-5, 94-8, and 94-9. It also occurs at much greater depth (approximately 200 metres) in DH 96-2 but the relationship between these zones is unclear. AS altered rocks display a variety of textures from massive and sugary to fine-grained and distinctly foliated units. Original rock textures are rarely preserved and alunite crystals are found either in massive alunite-quartz (+/- pyrophyllite) clusters or concentrated in linear zones.

As noted in Table 2, alunite is always associated with quartz, in varying amounts, and very commonly with pyrophyllite. Simple to complex zoning patterns are evident in alunite crystals from both transmitted light petrography as well as detailed SEM examinations. Energy Dispersive Spectrometry (EDS) analyses show alunite compositions always have mixed K and Na contents and commonly may approximate natroalunite compositions. EDS analyses also show complex zoning patterns of Ca and Sr within individual alunite grains.

Accessory minerals associated with the AS assemblage are listed in Table 2. Pyrophyllite contents in AS altered rocks are highly variable, ranging from trace amounts to greater than 30 volume

Table 1: U-Pb Analytical data

Fraction[1]	Wt	U[2]	Pb*[3]	206Pb[4]	Pb[5]	206Pb[6]	Isotopic ratios (1σ,%)[7]			Apparent ages (2σ,Ma)[7]	
	mg	Ppm	ppm	204Pb	Pg	%	206Pb/238U	207Pb/235U	207Pb/206Pb	206Pb/238U	207Pb/206Pb
LMC-96-08											
A c,N1,p,s	0.117	173	1.9	198	77	13.3	0.01076 (0.27)	0.0722 (1.0)	0.04865 (0.88)	69.0 (0.4)	131 (41/42)
B c,N1,p,s	0.130	196	1.8	279	52	14.7	0.00845 (0.12)	0.0552 (0.97)	0.04741 (0.90)	54.2 (0.1)	70 (42/43)
C c,N1,p,s	0.128	160	1.4	259	43	15.5	0.00813 (0.14)	0.0528 (0.93)	0.04710 (0.84)	52.2 (0.1)	54 (40/41)

Notes: Analytical techniques are listed in Mortensen et al. (1995).

[1] Upper case letter = fraction identifier; All zircon fractions air abraded; Grain size, intermediate dimension: c= <180 μm and >134μm, m=<134μm and >104μm; Magnetic codes:Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1=nonmagnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: p=prismatic, s=stubby, t=tabular.

[2] U blank correction of 1pg ± 20%; U fractionation corrections were measured for each run with a double ^{233}U-^{235}U spike (about 0.005/amu).

[3] Radiogenic Pb

[4] Measured ratio corrected for spike and Pb fractionation of 0.0035/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 10-45pg ± 20%. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

[5] Total common Pb in analysis based on blank isotopic composition

[6] Radiogenic Pb

[7] Corrected for blank Pb, U and common Pb. Common Pb corrections based on Stacey Kramers model (Stacey and Kramers, 1975) at the age of the rock or the $^{207}Pb/^{206}Pb$ age of the fraction.

percent in zones transitional between AS and AA alteration. Minor kaolinite/dickite is locally associated with the AS assemblage. Where is does occur, it tends to form fine-grained aggregates and patches interstitial to the quartz-alunite assemblage. Occurrences of topaz are also noted, particularly in DH 94-8 and DH 94-5. Zoned woodhousite-svanbergite [CaAl3(PO4)(SO4)(OH)6 - SrAl3(PO4)(SO4)(OH)6] grains occur only in DH 94-4.

Sulphide minerals associated with the AS assemblage include pyrite and locally traces of chalcopyrite, covellite, colusite [Cu26V2(As, Sn, Sb)6S32], sphalerite, and enargite. Trace sphalerite and enargite are found at approximately 220 metres depth in DH 96-2 (Tompson, 1997). Colusite is slightly more abundant, but only occurs in this zone.

Advanced Argillic Alteration (AA)

Advanced argillic alteration is characterized by the presence of quartz and pyrophyllite with other accessory minerals (Table 2). This alteration type is concentrated roughly in the same area as AS alteration, but is also found locally north of the Ridge Zone in DH 94-7 and 94-2. AA zones are also found at greater depth in DH 96-2, as well as in DH 96-1 and 96-3. AA assemblages most commonly occur as massive to highly broken, mottled, pale white to cream-coloured units. Original rock textures are commonly destroyed, but where preserved, pyrophyllite commonly replaces plagioclase

phenocrysts. Pyrophyllite veinlets are also found locally cutting siliceous or AS assemblages.

Minor diapsore has been found in AA altered rocks from localities across the Limonite Creek property. Kaolinite/dickite occurrences are rare, and woodhousite-svanbergite grains have been recognized only in DH 94-4. Pyrite is the only common sulphide mineral found within this assemblage. Traces of covellite are noted in core from the 1996 drill holes. Hematite occurs locally in significant concentrations, forming a distinct dark grey to black, massive quartz-pyrophyllite-hematite rock.

Aluminous Alteration (AL)

Aluminous alteration is defined by the presence of aluminous minerals such as andalusite and lazulite. Lazulite is found only rarely in outcrop within Lazulite Canyon as well as locally in DH 94-6. Andalusite is much more common, although its distribution is limited to an area west of the Ridge Zone in DH 94-6 and 94-7. Quartz is always found associated with andalusite in this assemblage, with variable amounts of pyrophyllite and pyrite. Where associated with pyrophyllite, andalusite grains commonly exhibit ragged edges and are surrounded by masses of fine grained pyrophyllite. This may indicate retrograde reactions. Due to the range of accessory minerals associated with this assemblage, AL textures are highly variable.

Table 2 Alteration types and mineral assemblages at Limonite Creek

Alteration Type	Major Minerals	Associated minerals
Acid Sulphate (AS)	alunite-quartz	pyrophyllite, muscovite, rutile, pyrite, kaolinite/dickite, +/- topaz, zunyite, woodhousite-svanbergite, chalcopyrite, colusite, covellite, enargite
Advanced Argillic (AA)	pyrophyllite - quartz	alunite, muscovite, kaolinite/dickite, diaspore, pyrite, rutile, +/- covellite, woodhousite-svanbergite
Aluminous (AL)	quartz - andalusite +/- lazulite	pyrophyllite, muscovite, pyrite +/- kaolinite/dickite, diaspore, hematite, chalcopyrite, barite
Silicic (SL)	quartz	muscovite, alunite, pyrophyllite, pyrite, rutile +/- barite
Sericitic (SR)	muscovite-quartz	pyrite, hematite, anhydrite/gypsum +/- rutile, ilmenite
Anhydrite-Quartz (AQ)	anhydrite (+/- gypsum) – quartz	muscovite, pyrite, paragonite +/- pyrophyllite, topaz, kaolinite
Propylitic (PR)	chlorite and/or epidote – quartz	muscovite, albite, carbonate, anhydrite, pyrite +/- kaolinite, montmorillonite

Textures may range from massive and clay-rich to strongly foliated, usually soft and sericite-rich, to green, massive, and strongly veined rocks with chlorite-filled amygdules.

Silicic Alteration (SI)

Silicic alteration (SI) is defined by significant silicification and minor accessory minerals in the alteration assemblage. SI zones are concentrated in DH 94-5 and 94-7, and are also found locally in brecciated zones at surface in the Ridge Zone. Common accessory minerals in this assemblage include muscovite, found either concentrated in veins of goethite (after pyrite) or locally intergrown through the matrix. SI alteration is always partially to strongly oxidized and commonly cross-cut by extensive goethite-filled fractures; only trace amounts of fresh pyrite are preserved within quartz clasts. Locally, quartz breccia zones contain quartz grains and fine-grained clasts set in a goethite matrix.

Sericitic Alteration (SR)

Sericitic alteration is characterized by a muscovite-quartz assemblage with variable amounts of pyrite, chlorite and locally anhydrite/gypsum, paragonite, hematite, and ilmenite. SR alteration is widely distributed across the Limonite Creek property, commonly occurring in a zone transitional between AS, AA or SI zones and propylitic alteration. Texturally, the SR alteration assemblage is highly variable, ranging from massive muscovite-quartz to chlorite-rich zones with original porphyritic textures preserved. Where SR alteration is transitional to AS or AA alteration, minor amounts of alunite and/or pyrophyllite may occur associated with the muscovite-quartz assemblage. Paragonite, identified by XRD, is found only at depth in DH 96-1 and 96-2. The

presence of illite, as noted in Tompson (1997) and Tompson and Cuttle (1994), has not been confirmed.

Anhydrite-Quartz Alteration (AQ)

Anhydrite-quartz alteration is found distal to the most intense altered zones. The assemblage is concentrated at depth in DH 96-1 and near surface in the vicinity of DH 92-2 and DH 94-2. Where present, AQ alteration is intermediate between sericitic and propylitic assemblages. Significant amounts of montmorillonite occur in DH 92-2 (with lesser amounts in 94-2), associated with gypsum-muscovite-quartz alteration. At greater depths in DH 96-1, the AQ assemblage is found as massive zones intermixed with lesser SR alteration. Veins of anhydrite-quartz are also commonly found cross-cutting SR and/or PR assemblages in zones located to the east of the Ridge Zone, particularly in DH 92-1, 94-1 and 94-2.

Propylitic Alteration (PR)

Propylitic alteration assemblages are widely distributed peripheral to zones of more intense alteration and are commonly gradational into SR assemblages. The most common propylitic assemblage consists of chlorite with variable muscovite, quartz, and pyrite. Epidote-, carbonate-, and albite-rich assemblages occur locally. Secondary albite has only been recognized in narrow intervals from DH 94-4 and 94-9 where it is usually associated with abundant hematite. Epidote is a common accessory mineral in chlorite-rich propylitic alteration and locally forms massive zones in DH 92-2 and rarely in DH 94-2. Epidote is also a common constituent of quartz-rich veins which cross-cut propylitic and locally sericite-rich assemblages. Carbonate is present in only a few samples of epidote-bearing alteration from localities to the NE of the Ridge zone in DH 92-2 and DH 94-1.

NW   SE

94-5
94-7
        94-9 94-8   Metres
                                            ASL
    No Core   1400
    Recovered

                                            1350

                            96-1

                                            1300

                                            1250

                                            1200

        ALTERATION TYPES

        ■ Acid Sulphate

        ▨ Advanced Argillic   1150

        ▨ Aluminous

        ▥ Silicic

        ⬚ Sericitic
                                    1100
        ▤ Anhydrite-Quartz

        ☐ Propylitic
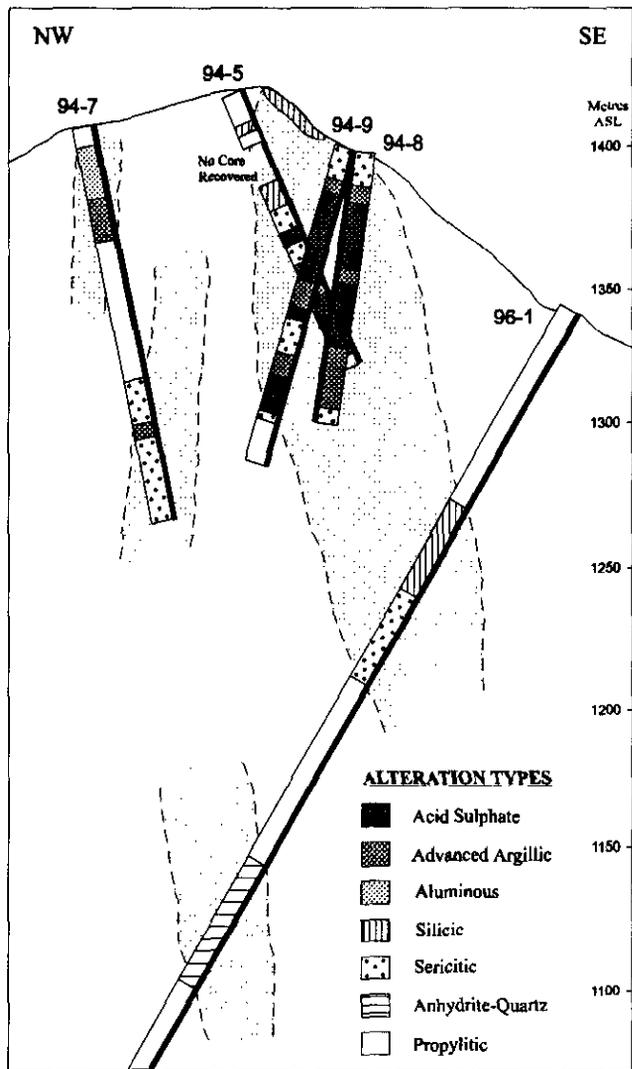
Figure 4: Cross-section through the southwest end of the Ridge zone showing the dominant alteration assemblage in each interval (see Figure 2 for location).

EXOTIC LIMONITE

Exotic limonites are defined by Blanchard (1968) as those that have "precipitated from iron-bearing solutions which have moved so far from their source that the source can no longer be identified specifically". The term is used at Limonite Creek for three major surface limonite deposits. The largest of these is exposed on the slopes north of Limonite Creek and covers an area of approximately 50 acres. It was reported to be up to 10.5 metres thick (British Columbia Minister of Mines, 1957). Drilling of this limonite zone during 1997 indicated a thickness of at least 7 metres. Two other limonite zones occur on the property to the north and south of the alteration zones (Figure 2). The 'Middle Deposit' is located near the camp and is actively forming from groundwater discharging along its northern edge. Drilling in 1997 determined a minimum thickness of 6 metres. The third deposit is exposed along the southern

banks of Many Bear Creek and appears to be a relatively thin blanket of limonite developed on coarse talus.

In all three of the exotic deposits, limonite is actively forming from acidic, iron-rich solutions as sheets, layers, and terraces parallel to the slope in each area. The measured pH of surface waters associated with the limonites ranges from 3.4 to 6.5. As the limonite precipitates, it commonly incorporates abundant organic matter in the form of pine needles, twigs, and leaves which remain trapped as successive layers accumulate. As a result, the limonite often consists of friable, very porous, light, relatively soft masses with abundant visible organic matter. Locally however, the limonite forms much denser, competent, and compact layers. Along the banks of Many Bear Creek, limonite also locally occurs as a matrix in masses of limonite-cemented pebbles and cobbles.

XRD analyses on selected limonite samples indicate that the exotic deposits are dominated by pure goethite. Sequential extraction techniques using a buffered ammonium oxalate solution (Schwertmann et al., 1982) however demonstrate that the limonite is precipitated from solution at surface initially as ferrihydrite, which over time transforms to crystalline goethite. Trace element analyses of limonite depth profiles have shown that limonites contain trace amounts of Cu, Zn and Mn (maximum of 518, 38 and 90 ppm respectively). Analyses of surface waters actively precipitating the limonitic material are currently in progress.

DISCUSSION

The alteration at Limonite Creek consists of irregular zones of acid-sulphate, advanced argillic, aluminous and silicic alteration within broader zones of sericitic and widespread propylitic alteration. These alteration mineral assemblages and their distribution are characteristic of high sulphidation systems (e.g., Arribas, 1995). Although significant mineralization has not been found to date on the Limonite Creek property, extensive pyrite and minor amounts of copper-rich sulphides and sulphosalts occur; these minerals are also characteristic of high sulphidation systems.

The presence of andalusite-rich aluminous alteration, and the predominance of pyrophyllite with only minor kaolinite, suggest that most of the alteration formed at temperatures above 250°C (Reyes, 1990; Hemley et al., 1980). This suggests that the alteration formed at greater depths than typical high sulphidation epithermal deposits. Alteration assemblages of these types occur in the upper parts of some porphyry deposits (e.g., El Salvador; Gustafson and Hunt, 1975) and are characteristic of parts of the Equity Silver deposit (Wojdak, 1974), which is located approximately 90 kilometres southeast of Limonite Creek (Figure 1). The presence of locally extensive anhydrite-quartz alteration at Limonite Creek, particularly

at depth in DH 96-1, is also consistent with a porphyry environment.

The U-Pb age for sample for the porphyritic granodiorite (LC-08) of 52.2±0.1 Ma is interpreted to be post-alteration, due to the lack of significant alteration within this intrusion. The age of alteration, therefore, is probably early or pre-early Eocene. The date of the major granodiorite intrusion to the east (sample LC-09), which shows moderate epidote alteration at the contact with the altered volcanic rocks, may constrain the age of the alteration more closely. At the Equity Silver deposit, the Eocene (ca. 50-52 Ma) intrusions are largely post-mineral but the 60 Ma intrusion appears to be related directly to mineralization. The alteration at Limonite Creek may be similar in age to Equity Silver, but a significantly older age cannot be ruled out. Direct dating of alunite is required to determine the actual age of alteration at Limonite Creek.

The alteration zones at Limonite Creek are extensively oxidized at surface with in-situ replacement of pyrite by goethite and local redistribution of goethite. Oxidation persists to at least 135 metres in structures intersected in drill holes. Surface oxidation generated low pH waters that transported dissolved iron to exotic limonites where iron was first precipitated as ferrihydrite subsequently converting to goethite. The extent and thickness of exotic limonites attests to the amount of pyrite in the Limonite Creek alteration zones and the efficiency of transport of iron in low pH waters. Mobilization of iron is a characteristic of the weathering of many high sulphidation alteration systems, which are dominated by pyrite-rich zones with negligible buffering capacity.

ACKNOWLEDGEMENTS

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