Sedex and Broken Hill-Type Deposits, Northern Monashee Mountains, Southern British Columbia

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INTRODUCTION

The existence of a number of stratabound zinc-lead-silver deposits has long been known within high grade metamorphic rocks in the Monashee Mountains of southern British Columbia (Figure 1). A number of these, including Big Ledge south of Revelstoke, and Jordan River, Cottonbelt and Ruddock Creek to the north, have been moderately explored, but none have had any production. The deposits typically comprise thin layers of massive to semi-massive sulphides that have strike lengths of several kilometres. They are intensely deformed and metamorphosed and locally invaded by extensive zones of pegmatite.

The purpose of this paper is to describe a number of these deposits within the northern Monashee Mountains north of Revelstoke and to compare them with both Broken Hill-type and classical sedex deposits. Age constraints on these deposits are also reviewed. Four weeks were spent in the field, mapping the Kneb and eastern exposures of Ruddock Creek. Several days were spent at both Cottonbelt and Jordan River examining the host stratigraphy in order to attempt detailed correlations and to identify key assemblages or units that are characteristic of Broken Hill successions elsewhere.

The Broken Hill-type deposit (BHT) is named after Broken Hill, a large lead-zinc-silver massive sulphide deposit in highly metamorphosed metasedimentary rocks of Paleoproterozoic age in New South Wales, Australia. As it is the largest and best studied of this type of deposit, it is described below.

BROKEN HILL-TYPE DEPOSITS

Many authors regard Broken Hill-type deposits as metamorphosed equivalents of more classical sedex deposits (cf. Gustafson and Williams, 1981; Sangster, 1990). Others, however, argue that they represent a distinct class of sediment-hosted massive sulphides containing unique chemistry and occurring within distinct sequences (Plimer, 1986; Walters, 1995; Parr, 1994; Parr and Plimer, 1993).

Broken Hill-type deposits are stratiform base metal orebodies hosted by thick accumulations of clastic and minor volcanic rocks that typically have undergone multiphase deformation and high grade regional metamorphism. The best known examples are within Proterozoic rocks, and include the world-class Broken Hill deposit in New South Wales, Australia, the Aggeneys and Gamsberg deposits in South Africa (Rozendal, 1986; Ryan et al, 1986) and deposits of the Bergslagen district, Sweden (Hedström *et al.*, 1989).

Broken Hill, New South Wales

The Broken Hill deposits in southeastern Australia contain approximately 300 million tonnes of ore extending over a strike length of 7 kilometres. They are within the Willyama Supergroup, a sequence of deformed Paleoproterozoic schists and gneisses, unconformably overlain by Neoproterozoic sedimentary rocks and minor basalt. Due to generally intense deformation and metamorphism, the protoliths to some of the metamorphic rocks of the Willyama Supergroup have been and continue to be the focus of considerable debate. However, it is generally agreed that they represent mainly metasedimentary rocks, some possible rhyodacitic volcanics, a minor component of mafic volcanics, and migmatites derived from partial melting of these rocks. Calcsilicates, banded iron formations and “lode” rocks - quartz-gahnite and garnet quartzite - are minor components.

The Willyama Supergroup has been interpreted to have been deposited as a rift, rift fill and cover sequence, developed on continental crust (Willis *et al.*, 1983; Stevens *et al.*, 1988). The Broken Hill and underlying Thackaringa groups host most of the main Broken Hill-type massive sulphide bodies, some stratabound tourmaline-rich rocks, stratabound scheelite occurrences, and the banded iron formations and other “lode” rock types. These groups are interpreted to record a rift stage, overlain by rift fill of the Sundown Group and platformal deposits of the Paragon Group.

The age of the Willyama Supergroup and contained sulphide deposits is now well known due to recent zircon U-Pb SHRIMP geochronological studies. A maximum age is afforded by 1710-1700 Ma detrital zircons within the Thackaringa Group while a date of 1704±4 Ma on the intrusive Alma Gneiss provides a minimum age (Page *et al.*, 2000). Gneisses within the Broken Hill Group, in-

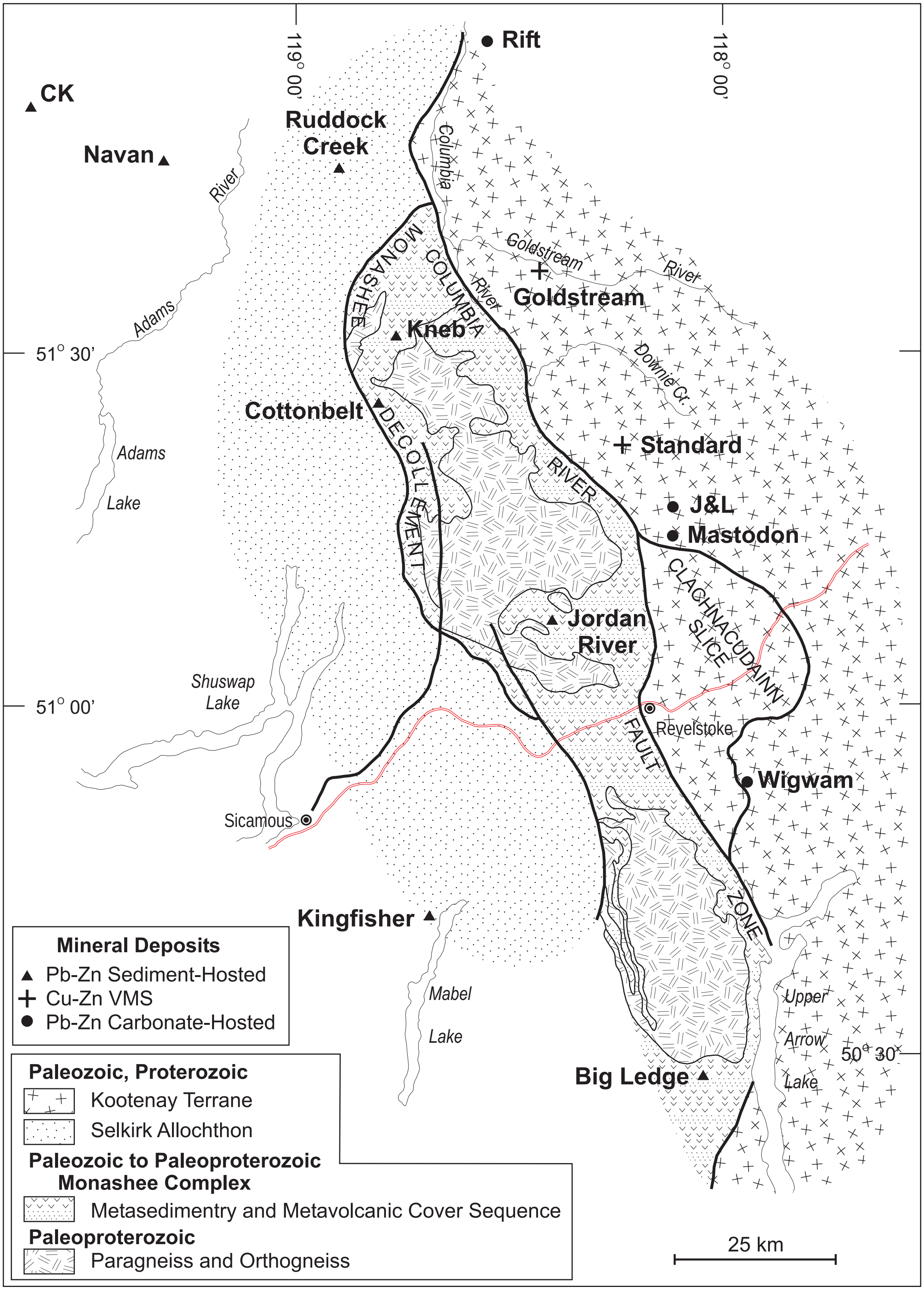

Figure 1. Setting of stratabound massive lead-zinc deposits of the Monashee Complex, southern British Columbia.

cluding the Potosi and Hores gneisses, have been interpreted to be felsic volcaniclastics and intrusive rocks. These have yielded dates of 1693±5 to 1686±3 Ma and therefore provide depositional ages for the Broken Hill deposit host rocks (Page and Laing, 1992; Page *et al.*, 2000). The overlying Sundown Group contain detrital zircons as young as 1690-1700 Ma, but most are derived from ca. 1790 and 1820-1860 Ma terrains. Tuffaceous siltstones in the Paragon Group, the upper part of the Willyama Supergroup, have yielded 1656±5 Ma zircons that are interpreted to be a depositional age. In summary, the rift sequence of the Willyama Supergroup was deposited in a relatively short time span, from ca. 1710 to 1690 Ma; overlying platformal cover rocks continued deposition until ca. 1642 Ma.

The Broken Hill orebodies occur in the upper portions of the Hores gneiss at the top of the Broken Hill Group. They are described by numerous workers; the following is largely summarized from Parr and Plimer (1995) and Walters (1995). The deposits are zoned on a regional scale with more zinc-rich lodes occurring at lower stratigraphic levels and in more southern exposures. Host rocks are variable, reflecting both sedimentary deposition and alteration. The siliceous zinc-rich deposits are within quartz-rich psammopelitic metasedimentary rocks that contain variable but minor amounts of gahnite, spessartine, orthoclase, sulphides, sillimanite and biotite; individual orebodies are typically separated by blue quartz, quartz-spessartine and quartz-gahnite rocks. The lead lodes are more carbonate or calcsilicate rich, and may be enveloped by quartz, garnet, or plagioclase-rich rocks. Sulphide-silicate contacts are usually sharp.

The garnet-rich lithologies are conspicuous units within, adjacent to or as strike equivalents to the lead lodes. Garnetites, comprising greater than 80 percent spessartine grains, are considered to be original manganiferous chemical sediments (Spry and Wonder, 1989). Quartz-garnet rock, containing minor gahnite and sulphides, commonly surrounds lead lodes and may be a hydrothermal alteration envelope. Spessartine-quartz rich envelopes, containing variable but minor sericite, plagioclase, fluorapatite, fluorite and sulphides, are more common where host rocks are pelitic or psammopelitic.

Broken Hill deposits are commonly characterized by close association with a number of unusual lithologies, mainly dominated by Si-Fe-Mn-Ca, and generally regarded as exhalites or possibly alteration zones (Plimer, 1986). The most conspicuous of these are the various iron formations, dominated by either sulphide or magnetite phases, quartz-rich zones with minor spessartine or gahnite, the gahnite-quartz layers, barite, calcareous units that may appear as skarn-like assemblages and quartz-tourmalinites.

These "enrichment" zones are important exploration guides. With closer proximity to deposits or camps, the diversity and number of these zones increase. Furthermore, the enrichment of Fe, Si, Mn, Ca, P, F, K and carbonate not only signifies closer proximity to deposits or camps, but may also characterize deposits size or grade. Walters (1995) concludes that the extreme Ca-Mn-F enrichments, or calcsilicate associations, are restricted to significant, proximal zones of larger, "more evolved" systems more likely to be associated with high-grade mineralization whereas Fe-Si-(Mn) dominant systems characterize the majority of "less evolved" proximal systems associated with numerous smaller occurrences in BHT districts.

In summary, some significant regional features of Broken Hill deposits include (after Walters, 1995):

- association with diverse suites of generally thin exhalite marker units such as quartzites, quartz-gahnites, tourmalinites or banded iron formations
- numerous, small, base metal occurrences
- diversity of other deposit types, including veins and skarns.

Camp or deposit-scale features include:

- rapid lensing and stacking of exhalite lenses
- association with significant magnetite in some lenses
- wallrock alteration involving silicification, magnetite, garnet, K-feldspar and sillimanite
- dominant galena-sphalerite mineralization, with low pyrite or pyrrhotite
- strong zoning from siliceous Zn-rich to carbonate-calcsilicate Pb-Ag rich
- low S:base metal ratios, with lead-zinc enrichment in numerous silicate and oxide facies
- association with minor elements, Cu, Au, Bi, Sb, W, Co and As
- "skarn-like" mineralogies, involving carbonates, fluorite, apatite, garnets, pyroxenes, and pyroxenoids
- high levels of manganese.

Many of these features are also common to more classical sedex deposits (Goodfellow *et al.*, 1993). However, differences include the abundance of a variety of forms of exhalite mineralization, possible association with volcanic rocks, and in deposits themselves, occurrence of magnetite and unusual chemistry that includes high F, Mn, P, Ca and Mg and low iron sulphide content.

Other features are common to sedex deposits, or to their metamorphosed equivalents. The following descriptions of some of the massive sulphide deposits of the Northern Monashee Mountains emphasize features in common with Broken Hill-type deposits. Some, such as Cottonbelt, are unusual and share many similarities while others, such as Jordan River, appear to be more similar to metamorphosed sedex deposits.

MASSIVE SULPHIDE DEPOSITS OF THE NORTHERN MONASHEE MOUNTAINS

Introduction

The deposits of the Monashee Mountains (Figure 1) are within the Monashee Complex, a 2-3 kilometre thick succession of mainly platformal rocks that unconformably overlies crystalline basement. This basement is exposed in two structural culminations, the Frenchman Cap dome in the north (Wheeler, 1965; Höy and Brown, 1980) and Thor-Odin dome in the south (Reesor and Moore, 1971; Read, 1980). Granitic orthogneiss in these basement exposures range in age from ca. 1.87 Ga to 2.27 Ga (Armstrong *et al.*, 1991; Parkinson, 1991; Crowley, 1997). However, the age of the overlying Monashee Complex, and contained deposits, is known with less certainty, and may range from Paleoproterozoic to Paleozoic.

The northern Monashee Mountains are located west of the Columbia River and north of the Trans Canada Highway. The Jordan River, Cottonbelt, Kneb and Ruddock Creek deposits are all above timberline in relatively rugged terrane; however, traversing by foot on most of the showings is relatively easy. They are accessible by helicopter from a base at Revelstoke.

Regional Geology

The Jordan River deposit is located within the Monashee complex in a large structural embayment on the southern margin of Frenchman Cap dome (Figure 2). Cottonbelt and Kneb are on the northwestern and northern margin of the dome. The complex is exposed within a tectonic window beneath a crustal-scale thrust fault, the Monashee decollement (Read and Brown, 1981; Brown *et al.*, 1986). The Monashee complex comprises basement gneisses, referred to as the core gneisses, and an unconformably overlying succession of mainly metasedimentary rocks, termed the cover sequence.

Core Gneiss

Core gneisses in the northern Frenchman Cap area have been subdivided into three structural units (Journeay, 1986). The lowest consists of intercalated biotite paragneiss, pelitic schist and quartzofeldspathic gneiss that is intruded by K-feldspar augen gneiss. A middle orthogneiss complex, structurally above the paragneiss, includes feldspar augen gneiss, overlain by well layered amphibolites, syenitic gneisses, and homogeneous biotite quartzofeldspathic gneisses. It is in turn overlain by a heterogeneous paragneiss succession that includes quartz-feldspar schist, biotite schist, hornblende gneiss, amphibolite and feldspar gneiss with variable orthogneiss and granitic intrusive component (Höy, 1987).

Age Constraints: Core Gneisses

The age of the core gneisses is reasonably well constrained. Armstrong *et al.* (1991) summarize and present Rb-Sr model dates that suggest core gneiss ages of ca. 2200 Ma. In the Thor-Odin dome, 1.93 and 1.86 Ga U-Pb dates have been obtained from orthogneisses (Parkinson, 1991) and in the Malton Complex near Valemont north of Frenchman Cap dome, ages of 1.87, 1.99 and ca. 2.1 Ga are reported (McDonough and Parrish, 1991). Paleoproterozoic intrusive ages for orthogneisses in Frenchman Cap dome, summarized in Table 1, range from ca. 1862±1 Ma (Crowley, 1997) to 2103±16 Ma (Armstrong *et al.*, op. cit.). The older intrusive age from within the lower core gneiss unit (Unit 1) restricts the paragneiss component of that succession to pre 2.1 Ga.

Detrital zircon data from the basal part of the overlying cover sequence (Unit 3, Figure 3) are also summarized in Table 1. These dates, 1.99-2.00 Ga (n=12), 2.02 Ga (n=1), 2.17 Ga (n=1) and 2.04-2.05 Ga (n=2) (Crowley, 1997; Ross and Parrish, 1991) suggest that the core complex, including Unit 2, is older than 1.99 Ga; younger detrital zircon dates (<1.99 Ga) only occur in units higher in the Monashee cover sequence (Table 1, Figure 3). The undeformed, postkinematic nature of the 1951±8 Ma granite (Table 1, Figure 3) indicates that, at least in the central and eastern part of the dome, the most intense deformation is PreCambrian in age, with only "modest disturbance during Late Cretaceous-Eocene time" (Parrish, op. cit., p. 1628). Hence it is probable that a ca. 1.9 Ga metamorphism that is recorded in the core gneisses (Armstrong *et al.*, 1991; Crowley and Schaubs, 1994; Parrish, 1995) may record a metamorphic-tectonic event separating core gneiss Unit 2 from the cover sequence.

In summary, paragneisses in the lower structural unit within the core gneiss complex (Unit 1) are older than 2.1 Ga and the overlying, dominantly paragneiss succession of Unit 2 is probably older than 1.99 Ga. The hiatus between core gneisses and the overlying cover sequence may be a regional tectonic event that is recorded by the 1.9 Ga metamorphic and 1.95 Ga intrusive dates (Figure 4). A number of zircons with Archean ages (2.88 Ga; 2.95-2.94 Ga: Crowley, 1997) indicate an Archean source terrane for at least part of the cover sequence, and lend support to the conclusion of Duncan (1984) that basement gneiss, at least in Thor-Odin dome, may contain an Archean component.

Monashee Cover Sequence

The Monashee cover sequence is a succession of dominantly metasedimentary rocks that unconformably overlies the core gneisses. The cover sequence of Frenchman Cap also includes a number of thin amphibolite layers interpreted to be mafic volcanics or intrusions, and a regionally extensive carbonatite tuff, the Mount Grace carbonatite (McMillan, 1973; McMillan and Moore, 1974; Höy and Kwong, 1986; Höy and Pell, 1986). It also hosts the Jordan River, Cottonbelt and Kneb deposits. It is intruded by a variety of meta-igneous rocks, including

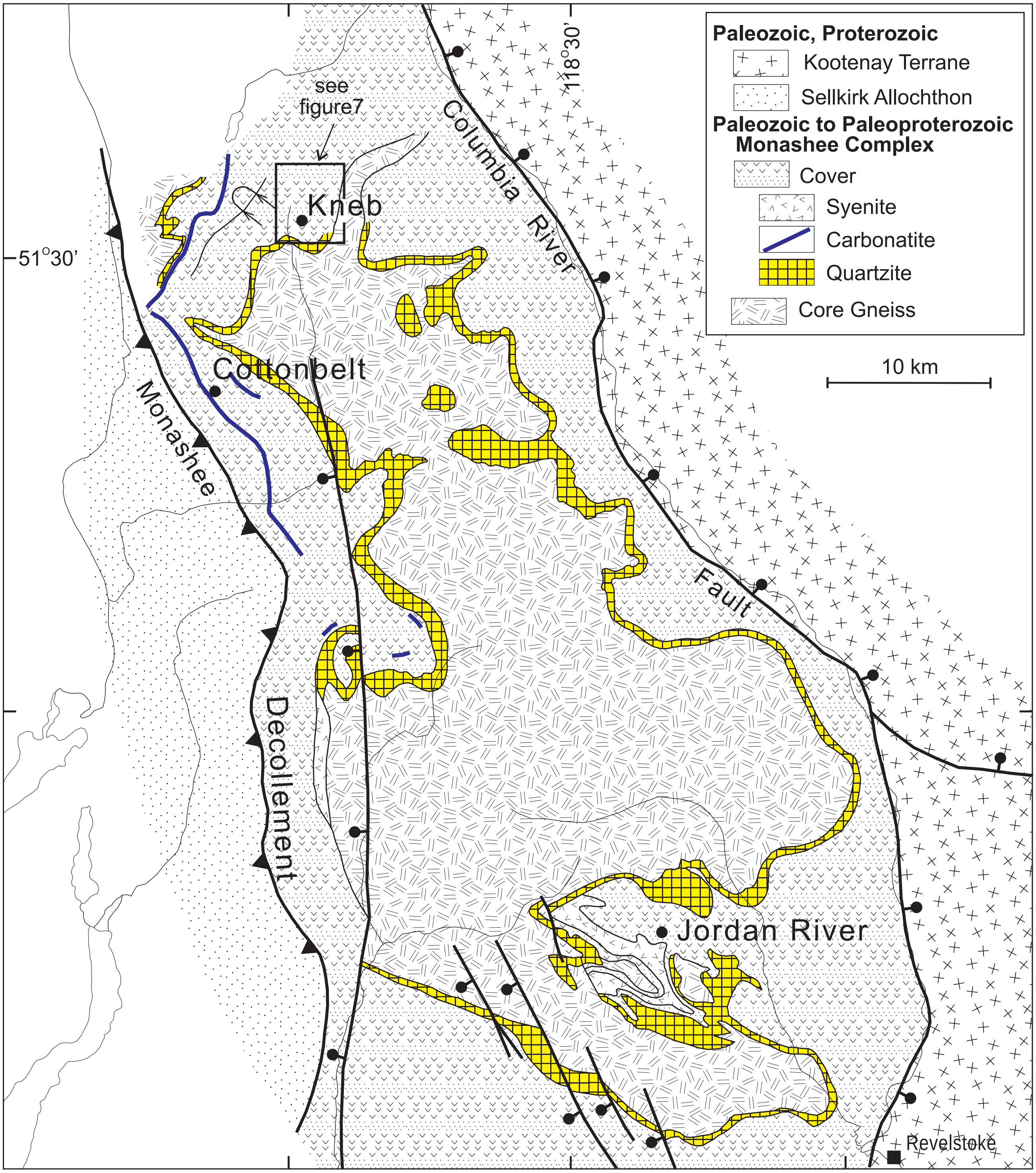

Figure 2. Geological map of Frenchman Cap dome showing distribution of tectonic elements, main lithologic units, dated intrusions, and massive lead-zinc deposits (from Höy and Brown, 1981, and references therein).

TABLE 1
SUMMARY OF U-PB DETRITAL AND MAGMATIC ZIRCON DATA, NORTHERN MONASHEE MOUNTAINS

Reference	*Field No.*	*Source*	*Description*	*Date(s)*	*Note*
1	RS-4	Parrish, 1995	amphibolite	541 ± 11 Ma (magmatic) 57 + 1 Ma (metamorphic)	adjacent to mafic pyroclastic unit, unit 6, cover sequence
2	207	Crowley, 1997	Mt. Grace syenitic orthogneiss	724 + 5 Ma (magmatic)	intrudes unit 4, cover sequence
3	341	Crowley, 1997	deformed pegmatite	1852 + 4 Ma (magmatic)	intrudes lower part of unit 4, cover sequence
4	180	Crowley, 1997	metamorphosed leucogranite	1762 + 6 Ma (magmatic)	intrudes ? unit 4 ?, cover sequence
5	WN-474	Parrish & Scammel, 1988; Okulitch et al, 1981	Mt. Copeland syenite gneiss	740 ± 36 Ma (magmatic) 59 + 1 Ma (metamorphic)	intrudes unit 4, cover sequence in Jordan River area
6	locality 9	Parrish, 1995	syenite	670 + 96 Ma (magmatic) - 93 Ma (magmatic)	intrudes top of unit 2, core paragneiss
7	187	Crowley, 1997	Kirbyville granodiorite orthogneiss	1862 + 1 Ma (magmatic)	intrudes unit 2, core paragneiss in Kirbyville anticline
8	R212	Armstrong et al, 1991	dyke	2103 + 16 Ma (magmatic)	Dyke intruding unit 1, core orthogneiss
9	R244	Armstrong et al, 1991	core orthogneiss	2066 + 8 Ma (magmatic)	core orthogneiss of unit 1
10	R245	Armstrong et al, 1991	orthogneiss	2010 + 7 Ma (magmatic)	orthogneiss within unit 2, core gneiss
11	PCA-3058-83	Armstrong et al, 1991	post-kinematic granitic intrusion	1951 ± 8 Ma (magmatic ?), or metamorphic ?)	intrudes unit 1 (?), core gneiss
12	257	Crowley, 1997	semipelitic schist	2.95 - 2.94 Ga (n=2) 2.88 Ga (n=1) 1.85 - 1.81 Ga (n=4) 1.75 Ga (n=1) 1.21 Ga (n=1)	derital zircons in unit 6, cover sequence
13	300	Crowley, 1997	pelitic schist	2.86 Ga (n=1) 1.84 - 1.81 Ga (n=4)	detrital zircons in unit 6, cover sequence
14	335	Crowley, 1997	quartzite	2.05 - 2.04 Ga (n=2) 2.02 Ga (n=1) 2.00 - 1.99 Ga (n=5)	detrital zircons in unit 3, cover sequence
15	S85-6	Ross & Parrish, 1991	quartz pebble conglomerate	2.166 Ga (n=1) 2.00 - 1.99 Ga (n=7)	detrital zircons at base of unit 3, cover sequence

syenitic to granitic orthogneisses and intrusive carbonatites. These orthogneisses help constrain the age of this succession (Crowley, 1997).

Description

The stratigraphic succession for the cover sequence along the northwestern margin of Frenchman Cap dome is shown in Figure 3. It comprises approximately 1 km of metamorphosed rocks that are exposed in the core of the Mount Grace syncline (Figure 5). Correlations to the south along the margins of the dome suggest that this represents approximately half the known cover sequence of Frenchman cap dome.

A basal quartzite (Unit 3) overlies core gneisses throughout the margins of the dome. In the Kneb-Cottonbelt area, it thickens from a few metres at its most northern exposures to several hundred meters southeast of Cottonbelt (Figure 5). It comprises a number of generally fining-upward sequences. The basal unit typically consists of coarse-grained feldspathic and micaceous quartzite, overlain by an orthoquartzite that commonly grades upward to a micaceous quartzite, and is capped by a quartz-rich micaceous schist. Thick-bedded, generally massive orthoquartzite grading up into thin-bedded, fine-grained micaceous quartzite and capped by a few metres of micaceous schist, forms the top of Unit 3 east of Cottonbelt (Figure 5).

Unit 4 is a sequence of dominantly calcareous and pelitic schists between Unit 3 and the regionally extensive crystalline marble of Unit 5. Calcareous and pelitic rocks interfinger extensively and grade laterally into each other. The top of Unit 4 is thinner bedded and more heterogeneous, and includes impure marble layers, quartzite, amphibolite, and the Mount Grace carbonatite tuff (described below). Calcsilicate layers within Unit 4 consist largely of granular quartz, plagioclase, microcline and diopside, with variable phlogopite, muscovite, actinolite, calcite and garnet. Coarse quartz-feldspar-mica sweats are common, and late tourmaline-bearing pegmatites locally crosscut foliation.

A grey-weathering calcite marble (Unit 5) is also a prominent marker in the cover sequence. It is commonly underlain by a white orthoquartzite or by the orthoquartzite and a few metres of intervening calcsilicate gneiss.

A succession of calcsilicate gneiss and pelitic schist of Unit 6 overlies Unit 5. The basal part is calcareous and includes the Cottonbelt and Jordan River sulphide layers. The upper part (Unit 6b) is mainly micaceous schist and gneiss with occasional thin amphibolite, quartzite and quartz-pebble conglomerate layers. The conglomerates consist of large flattened and elongated clasts of

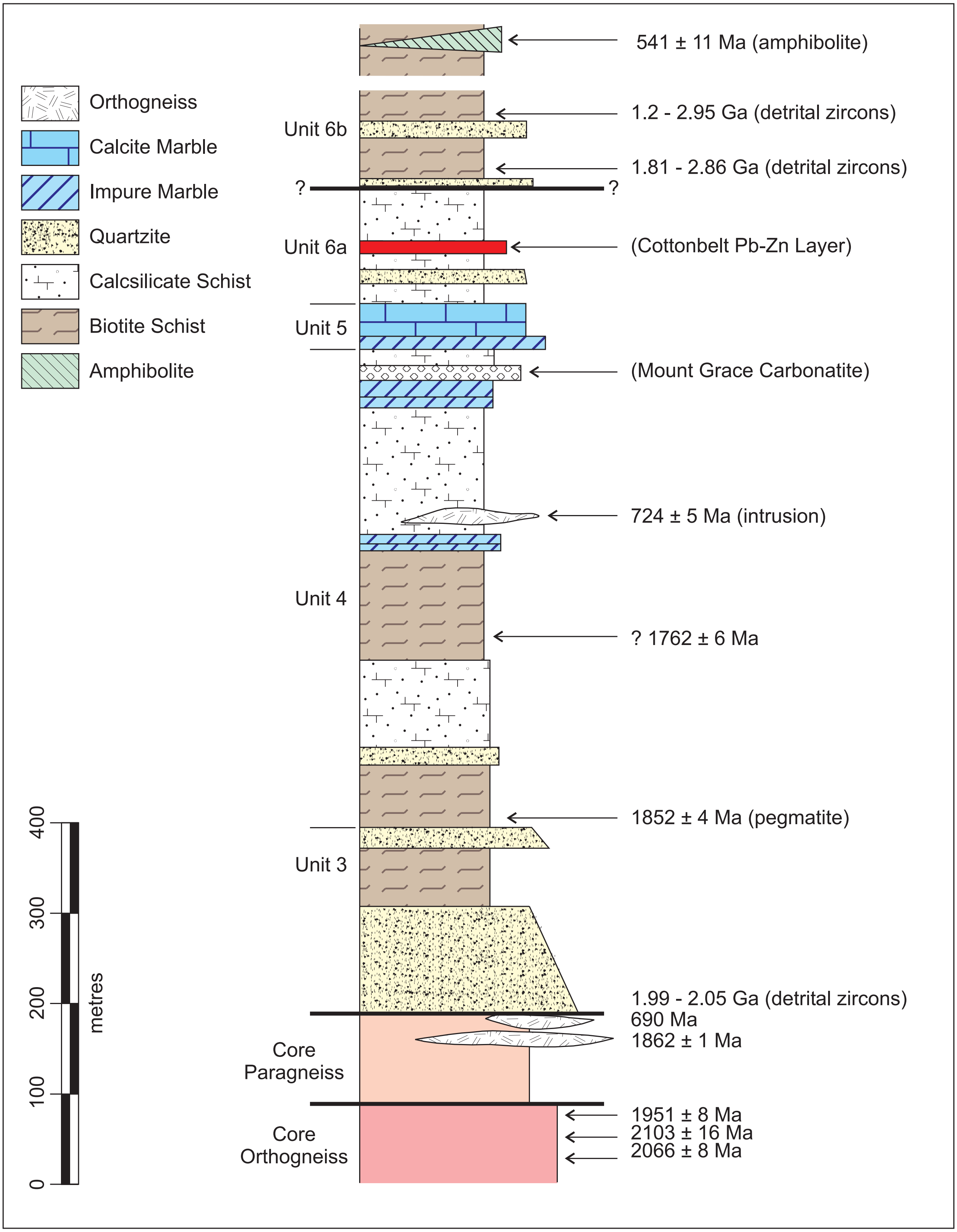

Figure 3. Stratigraphic succession in the Mount Grace - Kirbyville Creek area (from Höy, 1987 and Scammel and Brown, 1990); U-Pb data is from Crowley (1997), Parrish (1995), Armstrong *et al.* (1991) and Ross and Parrish (1991). *See* table 1 for summary of U-Pb data.

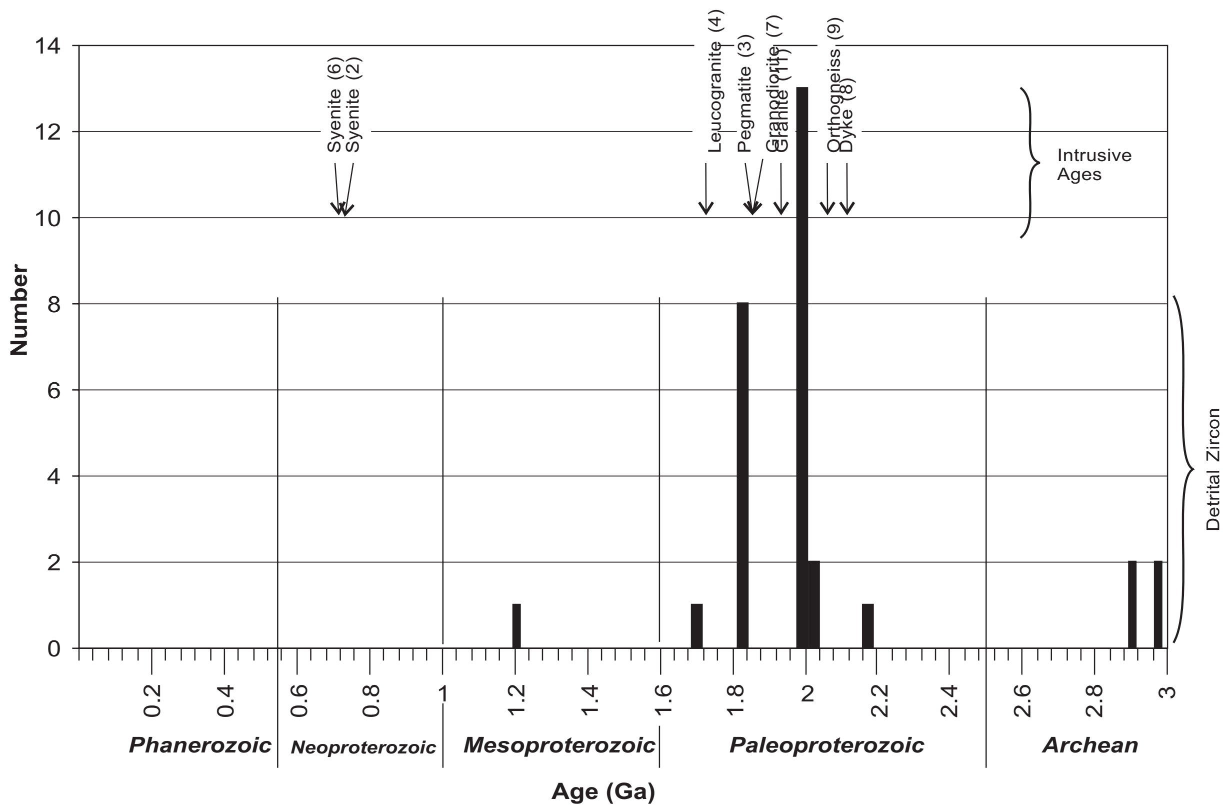

Figure 4. Bar graph showing distribution of U-Pb detrital and intrusive ages, Frenchman Cap dome (*see* Table 1 for data sources).

orthoquartzite in a granular quartz-feldspar-mica matrix. They may be graded with coarse grained feldspathic quartzite (“grit”) at the top.

Farther north in the Kirbyville Creek area, several hundred metres of cover sequence apparently overlie Unit 6 (Scammel and Brown, 1990). This overlying succession includes considerable quartzite and arkosic rocks, amphibolite, schist and gneiss, but considerably fewer calcareous units than in the underlying succession.

Correlations of the Monashee cover sequence in Frenchman Cap dome are shown below (Figure 8). The most distinctive marker units are the basal quartzite (Unit 3), the prominent white marble (Unit 5) and the Mount Grace carbonatite. In particular, the succession including the carbonatite, an impure marble, thin quartzite, amphibolite and white marble, comprises a marker succession that occurs at both the Cottonbelt and Jordan River deposits.

Mount Grace Carbonatite

The Mount Grace carbonatite has been extensively studied (McMillan and Moore, 1974; Höy, 1987; Höy and Kwong, 1986; Höy and Pell, 1986). It is the most prominent marker unit along the western margin of Frenchman cap dome, extending more than 60 kilometres from Jordan River in the south to north of Kneb occurrence (Figure 2).

The carbonatite commonly comprises a blocky tephra layer associated with a number of thin, laterally persistent, finer grained tuff layers. In the field it is recognized and characterized by an unusual pale to medium-brown weathering colour. Grains of dark brown phlogopite, colourless apatite and needles of amphibole weather in relief. Pyrrhotite, pyrochlore and zircon are locally developed accessory minerals. The blocky tephra layers contain three distinctive types of matrix-supported clasts: small granular albite clasts up to 3 cm in diameter, “syenite” clasts to approximately 10 cm in diameter, and large rounded to subrounded heterolithic clasts. The albitite and “syenite” clasts are interpreted to be pieces of fenite, whereas the lithic clasts were derived primarily from underlying core gneisses (Höy, 1987).

Analyses of the Mount Grace carbonatite, presented in Höy (op. cit.) indicate that it is mainly a sövite or calcite carbonatite. It is highly enriched in strontium (ave. 4460 ppm), barium (2300 ppm) and manganese (3100 ppm). Total rare earth element concentrations range from approximately 600 ppm to greater than 8000 ppm, with average values of 1000 to 2000 ppm.

Age Constraints: Cover Sequence

Estimates of the depositional ages for the cover sequence have ranged from Mesoproterozoic to Paleozoic. These ages were based initially on lithological correlations with Kootenay terrane and North American rocks to

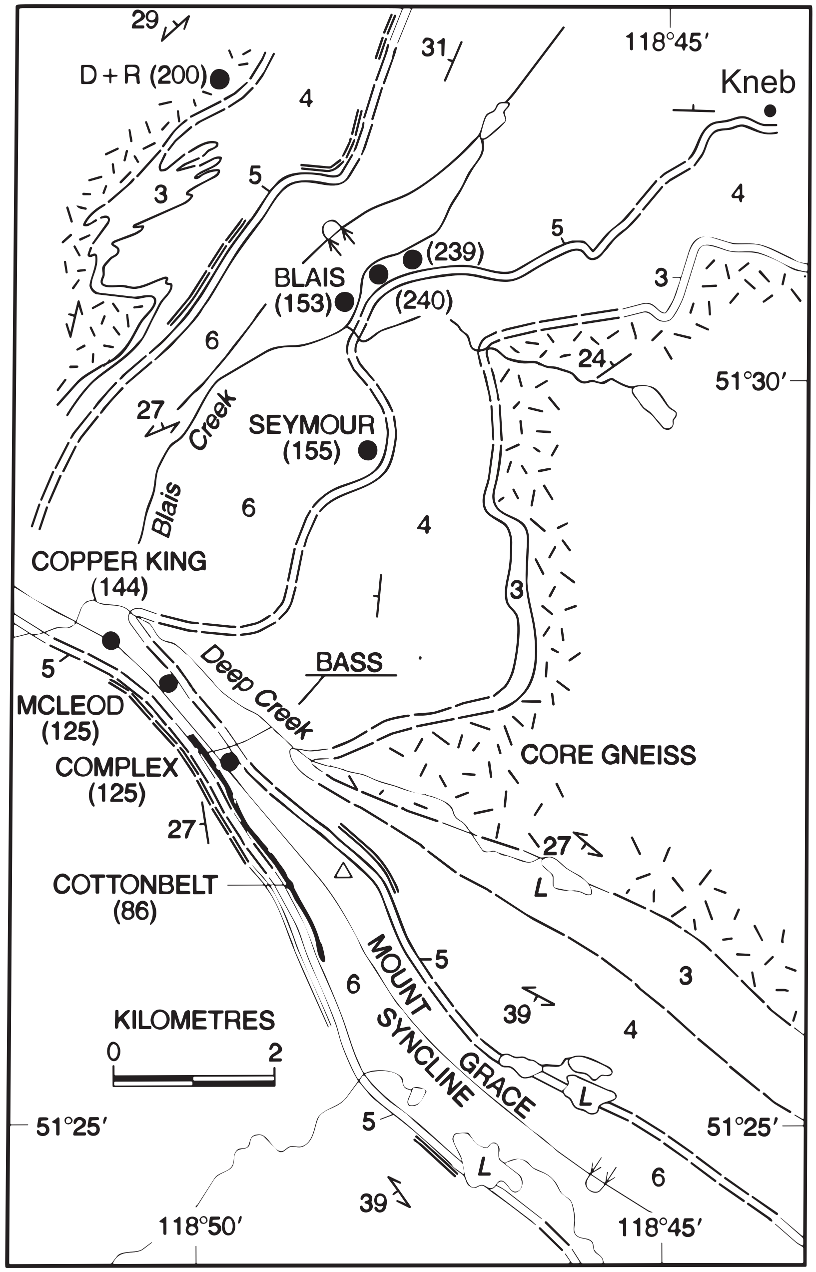

Figure 5. Geology and mineral occurrences of the Mount Grace area, northern Frenchman Cap dome (after Höy, 1987). Numbers in brackets are BC Minfile numbers.

the east. The platformal nature of the Monashee cover succession, and the 740 Ma intrusive age for the Mount Copeland syenite in the lower part of the sequence (Okulitch *et al.*, 1981; Parrish and Scammel, 1988), supported a Neoproterozoic to Paleozoic age. A Pb-Pb Cambrian model age for the Cottonbelt deposit (Höy and Godwin, 1988) supported these regional correlations.

Better constraints on the age of the cover sequence, based on dates of detrital zircons and intrusions, have been determined by Crowley (1997); detrital zircons provide a maximum age for the host unit, and intrusive dates, a minimum age. The youngest detrital zircons in Unit 3 at the base of the cover sequence (Ross and Parrish, 1991; Crowley, op. cit.) indicate that the depositional age is less than 1.99 Ga (Table 1, Figure 3). A pegmatite that intrudes overlying rocks of Unit 4 is dated at 1852±4 Ma, thereby restricting deposition of the basal succession to between 1.99 Ga and 1.85 Ga. As suggested above (Age constraints: core gneisses) this depositional age range is probably further restricted to post 1.95 Ga. A second intrusion, higher in the succession but still below the Cottonbelt sulphide layer, has a 1762±6 Ma date, confirming the Paleoproterozoic age for this part of the succession (Crowley, 1997).

Attempts to date the Mount Grace carbonatite have not been successful. Zircons collected from a carbonatite sample from near the headwaters of Kirbyville Creek were mainly composite, "being composed of mainly 55-60 Ma metamorphic crystals surrounding rare and very small Precambrian zircons of mainly detrital origin" (sample RS-3, Parrish, 1995, p. 1641).

Maximum age constraints on the overlying part of the cover sequence are restricted by 1.2 Ga detrital zircons in Unit 6b (Crowley, 1995; Table 1). These are from a semipelitic schist in the core of the Mount Grace syncline, several hundred metres stratigraphically above Cottonbelt (Figure 3). An amphibolite from the Kirbyville Creek area north of Cottonbelt has also been dated (Parrish, 1995) at 541±11 Ma. The amphibolite is interpreted to be stratigraphically above the section exposed in the core of the Mount Grace syncline (Scammel and Brown, 1990). As it is not known whether this amphibolite is intrusive or extrusive, this date only provides a minimum age for the host succession. However, it is within a package that includes mafic pyroclastics and it is therefore likely that even if it is intrusive, it is a subvolcanic sill or dyke and therefore provides a depositional age.

In summary, the basal part of the cover sequence, below the Cottonbelt sulphide layer, is between 1.95 and 1.85 Ga. The top of the sequence, at the stratigraphic level of the amphibolite complex, is probably 540 Ma or Early Cambrian in age. This tremendous age span suggests that there are one or more unconformities in the cover sequence. Along the western and southern margin of the dome, the succession below the Cottonbelt and Jordan River sulphide layers appears to be continuous with no recognized unconformity. It is therefore probable that the sulphide layers are within a Paleoproterozoic stratigraphic succession. However, conglomerates in the succession overlying the sulphide layers may record an unconformity as is shown on Figure 3.

COTTONBELT (082M 086)

Introduction

The geology of the Cottonbelt deposit is described in considerable detail in Höy (1987) and is only reviewed briefly here. Cottonbelt is an unusual lead-zinc-magnetite layer in calcsilicate gneisses near the base of Unit 6. It has been traced or projected on surface for approximately 2.5 kilometres strike length. Geological reserves are estimated at approximately 750,000 tonnes containing 6 percent lead, 5 percent zinc and 50 g/tonne silver. Other mineral showings in the Mount Grace area include widely scattered occurrences of galena, chalcopyrite, pyrrhotite and magnetite in calcsilicate gneisses, marbles and quartzites north of Cottonbelt; perhaps the most important of these is Kneb, described below.

Cottonbelt was first staked in 1905 by Cotton Belt Mines Ltd. Surface stripping and trenching, bulk sampling and driving of a number of shafts and tunnels was done on Cottonbelt and immediately adjacent properties up until 1911. By 1922, shafts of 12 metres had been sunk on the Bass showing, 45 metres on Copper King and 75 metres on Cottonbelt (Figure 5). By 1927, 15 buildings had been constructed in the Cottonbelt area and approximately 500 metres of underground development completed. Sixteen short diamond-drill holes in 1926 intersected almost continuous mineralization along a strike length of approximately 2 kilometres, at depths of 82 to 112 metres. Underground work continued through 1927-1928, but was eventually suspended due to the remoteness of the area, difficult access and narrow widths of the mineralized layer.

Work resumed in the 1970s with surface mapping, trenching and geophysical surveys by Great Northern Petroleum and Mines Ltd. Between 1976 and 1978, Metallgesellschaft Canada Ltd. in a joint venture with United Minerals Ltd. carried out considerable mapping, sampling and geophysical surveys, and drilled two holes totaling 517 metres in an attempt to intersect possibly structurally thickened mineralization in the core of the Mount Grace syncline.

In 1995, with Explore B.C. Program support, CanQuest Resources Corporation completed geological and geophysical surveys and 1937 metres of diamond drilling in 27 holes, confirming the great lateral extent but limited and variable thickness of the deposit (Gibson, 1996). Resources were estimated at 725,000 tonnes containing 11 percent combined lead and zinc and 58.3 grams per tonne silver (Information Circular 1996-1, p. 23-25).

The Mount Grace area, and north to the headwaters of Ratchford Creek, were mapped by the author in 1978 (Höy, 1979; Höy and McMillan, 1979) and by M. Journeay as part of a Ph.D. thesis (Journeay, 1986). The area was revisited in 1986 as part of a regional study of alkaline rocks of the Canadian Cordillera (Höy and Pell, 1986; Höy and Kwong, 1986) and then again this past summer. The latest work focused on regional correlations and evaluation of Cottonbelt as a Broken Hill-type deposit.

Host Succession

Cottonbelt is within a highly metamorphosed, calcareous succession near the base of Unit 6 in the cover sequence of Frenchman Cap dome (Figure 2) As described above, the cover sequence comprises a thick basal quartzite (Unit 3), a sequence of calcareous and pelitic schists (Unit 4) that includes the Mount Grace carbonatite, and a grey-weathering crystalline marble (Unit 5).

The structure of the Cottonbelt area is dominated by the Mount Grace syncline, an isoclinal, recumbent fold that is draped around the northwestern margin of Frenchman Cap dome (Figure 5). Core gneisses are exposed in both its limbs and the youngest rocks in the area, Unit 6, in its core. Since Cottonbelt occurs on the western overturned limb of the Mount Grace syncline, it and its host stratigraphy are inverted, with older rocks occurring in the hangingwall and younger in the footwall.

A detailed, right-way-up section through Cottonbelt is illustrated in Figure 6. The Mount Grace carbonatite is generally underlain by an impure, siliceous marble up to a few metres thick, and stratigraphically overlain by 5 to 10 metres of calcsilicate gneiss that may contain one or two thin quartzite layers and minor amphibolite near the top. Elsewhere, such as in the Kneb deposit area, the quartzites and amphibolites are up to several metres in thickness. The calcsilicate unit is overlain by marble of Unit 5 followed by dominantly calcsilicates at the base of Unit 6a. Unit 6a includes scapolite-bearing calcsilicate gneiss, sillimanite and kyanite schist layers and a crumbly, grey to light brown-weathering impure dolomitic marble referred to as the “camp marble”.

The Cottonbelt layer has sharp contacts with host rocks. The stratigraphic footwall varies from calcsilicate schist to well-layered garnet-sillimanite-muscovite schist or garnet-biotite schist. Garnet content in these layers is commonly up to 50 percent. The immediate base of the sulphide layer is typically a calcsilicate with locally minor dispersed galena. Garnet-sillimanite-muscovite schist interlayered with garnet-biotite schist also occurs just above the sulphide layer. However, analyses of these garnet-rich schist layers in the immediate footwall (CB2000-1a) and hangingwall (CB2000-1b) do not show manganese enrichment (Table 2).

The top of Unit 6a is mainly a calcsilicate schist with thin garnet-sillimanite or garnet-kyanite layers, quartzites and metavolcanic amphibolites. The quartzites locally contain minor dispersed garnet or muscovite. Interlayered sillimanite schist, quartz-feldspar gneiss, biotite schist and thin quartzites of Unit 6b overlie Unit 6a.

Mineralization

Cottonbelt is a sulphide-oxide layer comprising variable amounts of sphalerite, galena and magnetite, minor pyrrhotite and traces of chalcopyrite, pyrite, tetrahedrite and molybdenite. Gangue mineralogy is dominated by a massive to crudely banded manganiferous calcsilicate olivine-pyroxene-amphibole assemblage. Sulphides are only occasionally finely laminated. In general, massive sulphides are restricted to a single layer; however, thin layers can occur in the immediate footwall or hangingwall, and disseminated galena is locally noted in stratigraphic footwall calcsilicates or marbles. Some of these different styles of mineralization are shown in Photo 1 (a-c).

A common and distinguishing feature of the sulphide layer is the high MnO content. Analyses of 14 mineralized samples showed that MnO content ranged from 1.4 to 13.28 percent, with an average of greater than 8 percent (Höy, 1987).

Gangue minerals are unusual as they reflect the high manganese content and the overprint of regional metamorphism to upper amphibolite facies. Silicate minerals include varying proportions of knebelite (a manganiferous olivine), actinolite and manganiferous cummingtonite, pyroxenes, spessartine, biotite and minor accessory chlorite. Pyroxenes include diopside, hedenbergite, kanoite (a manganese-rich magnesium pyroxene) and less commonly eulite (a manganiferous orthopyroxene). Ankerite is the dominant carbonate, but minor calcite and kutnahorite (a calcium-manganese carbonate) have been identified (Höy and Kwong, 1986). Accessory minerals include epidote, plagioclase, graphite, gahnite and hematite.

Discussion

Cottonbelt is assumed to be a metamorphosed sulphide layer, initially deposited in a shallow marine platformal environment (Höy, 1987). The abundance of scapolite in some layers has been attributed to metamorphism of sedimentary layers containing evaporitic minerals, and thin quartzites are inferred to represent chert layers (Höy, 1987). Mafic volcanics in the succession, and a change from platformal carbonate deposition to possibly deeper water shales (now preserved as micaceous schists) suggest regional extension in a possible rift environment.

Evidence of a synsedimentary origin for the sulphide layer includes its layer-like form, crude to locally well-developed layering, premetamorphic formation, association with layers of probable exhalite origin and, perhaps most important, the occurrence of widespread mineralization at this discrete horizon. Mineralization at this level occurs on the east limb of the Mount Grace syncline at the McCleod and Complex showings, widely dispersed over several metres strike length approximately 6 kilometres farther north, and at Kneb, 11 kilometres northeast of Cottonbelt (Figure 5). As well, detailed stratigraphic correlations with the Jordan River deposit indicates that it also is at the same stratigraphic level (*see* Figure 8).

A number of layers within the stratigraphic succession are believed to have exhalite origin. These include some of the thin, fine-grained quartzite and rare garnet quartzite layers that occur immediately overlying the sulphide layer. A thin quartzite layer containing minor gahnite (a zinc spinel) discovered approximately 6 kilometres northeast of Cottonbelt, is also assumed to be a metamorphosed distal exhalite.

Alteration assemblages around the margins of Cottonbelt are not well developed or preserved probably due, at least in part, to extreme attenuation on the limb of the recumbent Mount Grace syncline. Sulphide gangue is enriched in manganese, with up to 13 percent MnO in some samples. It is also possible that the high calcium and magnesium content in the gangue, with development of calcsilicates during regional metamorphism, may reflect an original exhalite or alteration chemistry, rather than exclusively a sedimentary protolith. Silica content is typically low, with generally little free quartz. Locally, high sillimanite content in some adjacent layers may reflect local aluminum enrichment. The virtual total lack of iron sulphides in adjacent layers is noteworthy. There is no rusty-weathering envelope or footwall to the Cottonbelt layer.

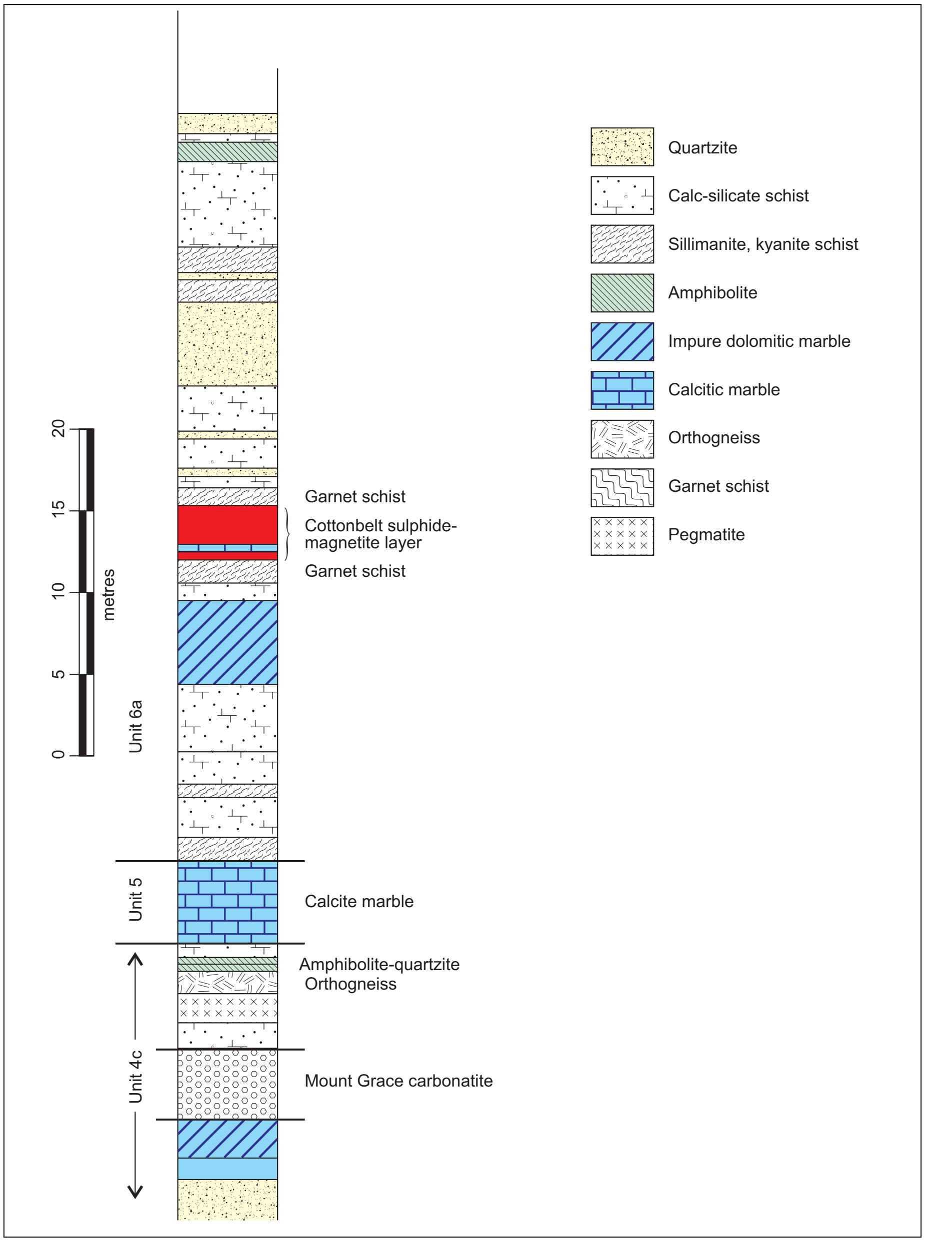

Figure 6. Detailed section through the mineralized interval, Cottonbelt deposit.

Metavolcanic rocks occur in the Cottonbelt stratigraphic succession. The Mount Grace carbonatite tuff occurs stratigraphically below the Cottonbelt sulphide layer and massive amphibolites occur above and below the layer. The Mount Grace carbonatite records extreme alkalic volcanism prior to formation of the Cottonbelt sulphide layer. Felsic volcanic protoliths have not been recognized, possibly because they do not exist in the immediate stratigraphic succession or perhaps because subsequent high grade metamorphism and intense deformation have made it difficult to identify them.

Deposit Classification

The Cottonbelt deposit is a massive lead-zinc layer in an original sedimentary succession, a feature common to both sedex and Broken Hill-type deposits. It probably occurs in a rift setting as it is associated with both alkalic and tholeiitic volcanism and occurs near a transition from shallow water platformal to deeper water?, more pelagic environments.

However, a number of features of the deposit and host succession are more typical of Broken Hill-type deposits. These include the unusual skarn-like mineralogy, a result of a calcareous gangue, an unusually high Mn content, and the abundance of magnetite rather than the more com-

TABLE 2
WHOLE ROCK ANALYSES OF SELECTED LITHOLOGICAL HAND SAMPLES FROM THE COTTONBELT, KNEB, JORDAN RIVER AND RUDDOCK CREEK DEPOSIT AREAS

Lab No.	Field no.	Note	UTM east	UTM north	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	Ba*	LOI	SUM	Rb	Sr	Zr	Nb	Y	V
					%	%	%	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm
Ruddock Creek area																							
55570	RC-1	amphibolite	368866	5737800	49.11	0.93	17.39	9.05	0.2	7.98	10.93	1.1	1.29	0.03	0.03	1.17	99.21	75	279	62	11	24	184
55571	RC-5	bi amphibolite	368951	5738370	48.11	2.8	14.97	14.38	0.2	6.13	8.05	2.05	1.89	0.31	0.03	0.75	99.67	144	316	160	23	27	337
55572	RC-9	calcsilicate	369392	5788193	40.88	1.13	26.95	6.05	0.1	0.46	22.28	0.25	0.05	0.07	0.01	1	99.23	7	755	236	53	57	121
55573	RC-26A	marble, M zone	368212	5738744	36.06	0.5	9.48	2.41	0.02	0.64	27.29	0.67	2.41	0.12	0.18	16.77	96.55	81	1340	95	13	24	48
55574	RC-37	serpentinite	368301	5737704	40.68	0.01	0.46	8.43	0.1	40.81	0.03	0.01	0.17	0.01	0.01	7.46	98.18	24	<3	7	4	<3	20
55575	RC-39	amphibolite	368234	5737720	48.33	1.3	13.43	14.18	0.2	7.23	11.6	1.96	0.4	0.11	0.01	0.8	99.55	16	148	72	3	32	342
55576	RC-41	amphibolite	368157	5737993	49.72	1.58	14.07	13.76	0.23	6.86	10.43	1.7	0.6	0.1	0.01	0.77	99.83	13	214	87	11	34	374
55577	RC-52	impure quartzite	368798	5737741	65.52	0.01	14.02	4.34	1.14	0.68	1.88	4.53	2.85	0.01	0.22	4.23	99.43	94	227	41	7	31	11
55578	RC-57a	gn quartzite	369274	5737086	69.19	0.1	14.05	3.82	0.07	0.01	11.46	0.17	0.01	0.01	0.01	0.67	99.57	4	414	35	6	19	33
55579	RC-61a	marble	368505	5737940	24.25	0.37	8.22	3.56	0.05	1.23	35.02	0.7	1.72	0.09	0.02	23.06	98.29	56	2844	52	12	20	32
55580	RC-61b	marble	368505	5737940	29.4	0.43	10.1	3.84	0.03	1.42	31.48	0.77	1.83	0.1	0.02	18.85	98.27	59	2562	66	15	17	34
55581	RC-63	hb gneiss	368567	5737620	42.95	0.87	6.32	13.84	0.18	25.45	6.69	0.66	0.2	0.15	0.01	1.96	99.28	13	96	55	17	18	131
Kneb area																							
55582	Kneb-30a	footwall calcsilicate	379532	5710319	71.33	0.01	0.55	5.32	0.36	6.44	12.43	0.01	0.1	0.01	0.01	2.57	99.14	8	109	12	<3	6	16
55583	Kneb-30b	gangue	379532	5710319	68.16	0.01	0.28	6.21	0.38	6.96	14.05	0.01	0.02	0.01	0.01	3.05	99.15	7	134	3	<3	12	18
Jordan River area																							
55586	JR-1	carbonatite	401149	5665434	21.09	0.25	5.8	4.57	0.41	6.13	31.14	2.29	1.02	0.58	0.29	24.35	97.92	33	5796	6	146	34	32
55587	JR-5	carbonatite	401592	5665022	25.53	0.33	8.14	5.17	0.33	5.28	27.73	2.89	0.99	0.36	0.21	21.59	98.55	40	2956	7	119	37	30
55588	JR-8	impure marble	401758	5664821	3.65	0.01	0.28	1.13	0.09	1.95	51.25	0.11	0.07	0.03	0.05	41.06	99.68	11	345	10	<3	20	9
55589	JR-10	impure marble	401675	5664907	1.98	0.01	0.23	1.37	0.14	2.27	51.16	0.69	0.02	0.01	0.01	41.84	99.73	6	295	11	6	13	4
55590	JR-11a	carbonatite	401461	5665168	21.17	0.3	8.52	3.65	0.1	4.13	30.2	3.66	1.78	0.21	0.19	25.23	99.14	75	2078	40	62	22	42
55591	JR-11b	carbonatite (?)	401461	5665168	17.45	0.21	7.01	2.75	0.07	2.69	36.22	2.07	0.87	0.05	0.1	29.88	99.37	43	761	35	10	19	37
55592	JR-12a	carbonatite (?)	401366	5665310	23.53	0.3	9.93	2.71	0.01	3.29	30.3	2.79	1.41	0.05	0.12	24.71	99.15	55	646	37	7	14	53
55593	JR-12b	carbonatite (?)	401366	5665310	10.39	0.05	1.14	1.13	0.05	3.44	47.58	0.15	0.07	0.03	0.01	35.49	99.53	12	331	32	6	8	4
55594	JR-13a	bi amphibolite	401366	5665310	66.94	0.89	13.38	5.88	0.14	3.92	3.34	0.56	3.09	0.11	0.03	1.02	99.3	157	116	269	37	38	108
55595	JR-13b	bi amphibolite	401366	5665310	64.13	0.87	13.82	6.59	0.2	4.8	3.46	0.46	3.59	0.12	0.03	1.19	99.26	195	93	237	26	28	126
Cottonbelt area																							
55597	CB2000-1a	gn-si schist, hangingwall	373588	5700806	60.06	0.82	20.64	7.88	0.11	1.55	1.27	0.37	4.42	0.12	0.13	1.9	99.27	164	115	182	20	29	99
55598	CB2000-1b	gn-si schist, footwall	373588	5700806	50.49	0.75	21.57	16.26	0.28	3.18	0.37	0.2	5.28	0.11	0.14	1.15	99.78	195	59	110	19	26	101
55599	CB2000-2	amphibolite	373644	5700821	43.93	1.98	14.27	12.4	0.23	9.65	12.21	2.14	0.62	0.56	0.03	1.36	99.38	16	608	135	46	24	264
55600	CB2000-3	ky schist	373709	5700825	41.5	1.04	22.95	15.19	0.07	10.23	0.4	1.73	2.29	0.12	0.03	4.34	99.89	105	38	228	17	20	136
55601	CB2000-4a	gn-si schist, hangingwall	373743	5700547	51.65	0.79	22.47	13.89	0.3	2.61	0.57	0.28	5.55	0.09	0.15	1.37	99.72	200	73	114	20	23	95
55602	CB2000-5b	gn schist	373760	5700411	58.15	0.87	22.19	8.98	0.15	1.99	0.61	0.27	4.63	0.09	0.1	1.78	99.81	179	81	195	20	20	83
55603	CB2000-7	amphibolite	373475	5701034	45	3.45	14.88	13.93	0.2	6.48	9.35	3.35	1.25	1.07	0.13	0.73	99.82	43	388	165	44	28	313
55604	CB2000-9	amphibolite	373455	5701051	44.9	2.98	15.77	14.06	0.23	5.71	11.06	3.27	0.31	0.52	0.01	0.72	99.54	9	520	158	46	24	386

Notes

Steel mill grinding @ Cominco; Lab: Cominco Research Lab

Method: oxides - fused disc, X-ray fluorescence

Method - trace elements: Pressed pellet X-ray fluorescence

Ba* = Fused disc analysis for XRF calibration. Values should be used with CAUTION.

Photo 1. (1a). Exposure of the Cottonbelt sulphide-magnetite layer enclosed in light-coloured garnet-sillimanite schist and calcsilicate gneiss.

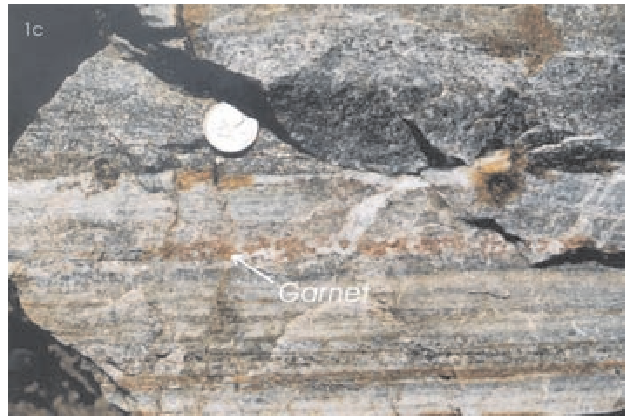

Photo 1c. Semi-massive sulphide-magnetite mineralization (top) in quartz-rich gangue, enclosed in spessartine garnet-calcareous quartzite host.

Photo 1b. Massive to semi-massive magnetite, sphalerite and galena mineralization in manganiferous calcsilicate gangue, in contact with siliceous marble with minor dispersed sulphide and magnetite (top).

mon iron sulphide phases. Immediate host rocks have abundant garnet and sillimanite, similar to Broken Hill host rocks. Thin quartzite and garnet quartzite layers that occur stratigraphically above Cottonbelt are similar to some of the exhalite facies that characterize Broken Hill stratigraphy as is an occurrence of gahnite with quartz located 6 kilometres northeast of Cottonbelt.

KNEB (082M 241)

Introduction

The Kneb occurrence was discovered during regional mapping by the author in 1980 and described briefly in a bulletin released in 1987 (Höy, 1987). It is located at an elevation of approximately 2150 metres at the headwaters of Ratchford Creek, 11 kilometres north-northwest of Cottonbelt (Figure 5). It is within the cover sequence of the Monashee Complex, at approximately the same stratigraphic level as Cottonbelt. A number of other unnamed showings of both Pb-Zn and Cu occur at this level southwest of Kneb.

Cominco Ltd. staked Kneb in 1998, and in 1999 conducted a geophysical program that comprised 24.7 km of electromagnetic and 19.2 km of magnetic surveys (Holyroyd, 1999). This survey concentrated on the showing and its projected extension beneath the glacier to the east. As the showing is not conductive and only weakly magnetic, it was difficult to trace. However, a small magnetic high located beneath glacier ice is a possible source of newly-discovered, high grade lead-zinc boulders (Holyroyd, 1999).

Host Succession

The Kneb occurrence is in Unit 6a, a dominantly calcsilicate assemblage above the white marble of Unit 5. Footwall rocks to Kneb were only poorly exposed, due to snow and moraine cover. However, several hundred metres of hangingwall rocks are exposed just north of Kneb in the east limb of the Mount Grace syncline (Figure 7).

Kneb occurs at the top of a tan weathering, massive to layered dolomitic marble approximately 15 metres thick. The marble contains minor knebelite, pyroxene and amphibole and trace chalcopyrite and pyrrhotite. Immediate

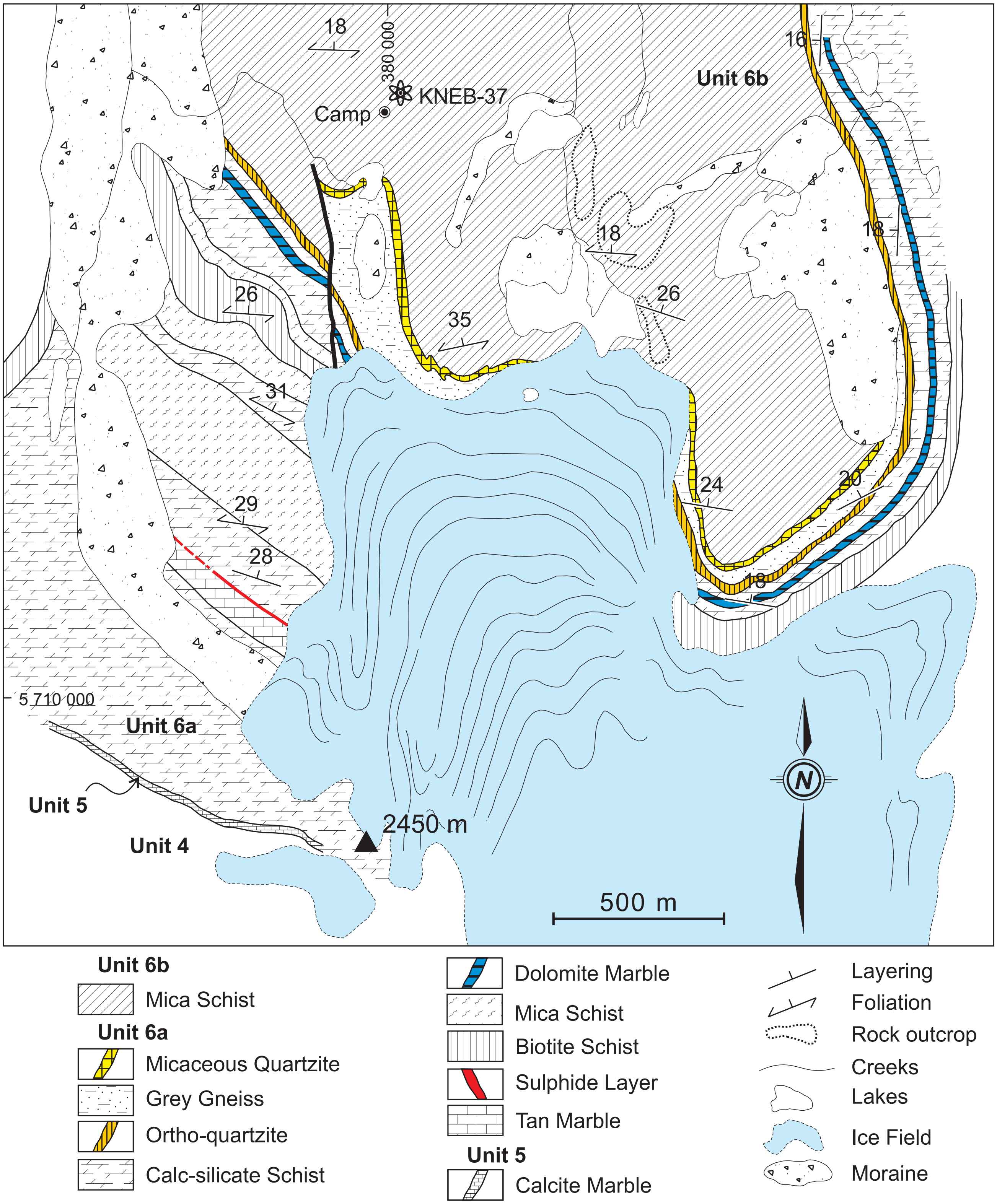

Figure 7. Geology of the Kneb deposit area.

hangingwall rocks comprise diopside rich calcsilicate schists interlayered with minor garnet-muscovite schist. Approximately 100 metres of mixed micaceous schists, calcsilicate schists and granular quartz-feldspar mica schists overlie these hangingwall rocks. This is overlain by a prominent, rusty-weathering coarse-grained biotite schist, with minor dispersed pyrrhotite, and thin interlayers of calcite marble and calcsilicate schist. The top of Unit 6a (Figure 7) comprises silver-coloured garnet-muscovite schist, calcsilicate gneisses, a thin well-bedded dolomitic marble and massive to layered quartzite (Photo 2). Thin amphibolite layers that occur just above the quartzite may correlate with amphibolite layers that occur above Cottonbelt, or with amphibolites farther north in the Kirbyville Creek area.

Unit 6b comprises mainly grey quartz-feldspar orthogneisses (?) and micaceous schist. The grey gneisses are commonly massive to foliated, swirled, and contain numerous coarser quartz-feldspar augens. One of these (located on Figure 7) has been submitted for zircon extraction and U-Pb dating in an attempt to provide a minimum age for the underlying Kneb and Cottonbelt deposits. Within the orthogneisses are well-layered and foliated micaceous schists and gneisses. These paragneisses are commonly rusty-weathering muscovite-biotite-garnet schists that are locally associated with impure quartzite layers or with thin hornblende schist layers.

Mineralization

Kneb is a thin, semi-massive to massive sulphide layer in marble and calcsilicate schist. It comprises mainly chalcopyrite with variable amounts of sphalerite, galena and pyrrhotite. To the northeast, massive sulphide boulders that appear to originate beneath glacier ice are mainly galena and sphalerite.

Mineralization occurs at the top of a tan dolomitic marble and is overlain by diopside-rich calcsilicate schist (Photo 3). It is within a thin siliceous zone comprising mainly quartz with minor dispersed garnet and sulphides. This siliceous zone grades out to an envelope of diopside "skarn-like" rock that contains minor dispersed pyrrhotite, chalcopyrite, dolomite, amphibole, quartz, knebelite and garnet. These alteration assemblages are better developed in the footwall, with widths up to several metres. Although the silica and skarn zoning are crudely developed as described above, in detail they interfinger considerably. The hangingwall alteration is thinner, comprising mainly quartz with minor dispersed sulphides and silicates that grade outward to calcsilicate schists.

The sulphide-silica layer is up to several metres thick and comprises mainly quartz with variable chalcopyrite, galena, sphalerite and pyrrhotite. A thin chalcopyrite-rich layer occurs near the top of the sulphide zone. Gangue minerals include diopside and an amphibole, and generally minor carbonate, knebelite and garnet. The sulphides, quartz and a thin dolomite are crudely layered.

Analyses of the Kneb sulphide layer (Table 3) show the high copper content, generally low zinc and only very minor lead. Manganese is high, with two samples containing 6536 and 4736 ppm Mn. Gold and silver contents are low, but cobalt and nickel range up to several hundred ppm.

Photo 2. Well-bedded sequence of micaceous schist, quartzite, marble, and calcsilicate gneiss near the top of Unit 6a, Kneb prop-

Photo 3. Kneb sulphide layer (top) enclosed within calcareous quartzite and underlain by tan-coloured dolomitic marble.

Discussion

Kneb has many similarities to a Besshi deposit. It is a semi-massive copper-zinc deposit within a metasedimentary succession that contains minor mafic metavolocanics. However, as only a limited extent of the sulphide layer is exposed, and as massive sulphide boulders that may be sourced along strike are lead-zinc rich, it is possible that Kneb is a zoned sedex or BHT deposit with only the more proximal, copper-rich portion exposed.

JORDAN RIVER (082M 001)

Introduction

The Jordan River property, also know as the King Fissure, is located on the steep north slopes of a ridge between Copeland and Hiren creeks (Photo 4). Access is by helicopter from Revelstoke, 20 kilometres to the southeast. A number of other showings and deposit types are

TABLE 3
ANALYSES OF SELECTED MINERALIZED HAND SAMPLES OF THE KNEB, JORDAN RIVER AND RUDDOCK CREEK DEPOSITS

Lab No.	Field No.	Deposit	UTM East	UTM North	Mo ppm	Cu ppm	Pb ppm	Zn ppm	Ag ppm	Ni ppm	Co ppm	Mn ppm	Fe %	As ppm	U ppm	Au ppm	Th ppm	Sr ppm	Cd ppm	Sb ppm	Bi ppm	V ppm
Ruddock Creek																						
52265	H96RC-1	E zone	368900	573700	1	459	31116	99999	4	119	34	668	14.83	8	< 5	< 2	< 2	74	312.1	2	21	27
52266	H96RC-2	E zone	368900	573700	< 1	13	29239	99999	5.7	3	14	336	5.14	< 2	< 5	< 2	< 2	81	379.2	< 2	28	9
52267	H96RC-3a	E zone	368900	573700	15	88	16623	46858	1.3	16	4	232	1.02	2	9	< 2	< 2	723	58.6	12	< 2	9
52268	H96RC-4	E zone	368900	573700	1	17	32060	7494	8.6	2	< 1	17	0.09	< 2	< 5	< 2	< 2	170	33.5	71	2	< 1
52269	H96RC-8	M zone	368207	5738758	< 1	215	34011	99999	3.2	71	36	877	10.73	8	< 5	< 2	< 2	134	251.5	5	27	23
52270	H96RC-9	M zone	368207	5738758	142	228	9718	43515	2	52	11	130	4.41	< 2	< 5	< 2	< 2	107	59.5	16	6	12
55605	RC-11b	F zone	368532	5737545	10	25	38931	99999	10.6	51	24	443	5.38	5	< 10	< 4	< 2	97	237.2	< 5	41	40
55606	12b	F zone	368537	5737520	9	190	37463	99999	7.7	105	26	454	14.49	< 5	< 10	< 4	2	144	292.7	14	15	35
55607	13	F zone	368508	5737526	18	532	7745	21826	6.9	381	42	114	23.64	< 5	< 10	< 4	9	99	28.5	< 5	110	87
55608	14a	F zone	368379	5737418	6	9	853	5161	< .5	19	4	188	1.13	< 5	< 10	< 4	10	202	4.9	< 5	< 5	79
55609	14b	F zone	368379	5737418	12	616	35216	99999	5.4	185	49	500	16.96	< 5	< 10	< 4	4	78	179.1	12	10	50
55610	14c	F zone	368379	5737418	22	128	493	2100	< .5	58	9	314	4.23	< 5	< 10	< 4	8	107	0.4	< 5	< 5	175
55611	17	lower G	368335	2737675	8	19	41058	99999	9.9	< 2	38	454	6.88	5	< 10	< 4	< 2	52	413.6	11	22	12
55612	18	lower G	368320	5737730	12	55	35502	99999	6.5	7	26	93	5.93	5	< 10	< 4	< 2	44	340.1	15	< 5	49
55613	23	upper G	368350	5738000	22	46	42666	99999	3.8	17	28	313	6.78	< 5	< 10	< 4	2	60	302.9	10	< 5	45
55614	26b	M zone	368207	5738758	26	206	38198	99999	4.6	75	25	1400	9.12	< 5	< 10	< 4	< 2	96	256.2	19	6	118
55615	26c	M zone	368207	5738758	10	242	3990	54475	0.9	90	15	428	7.19	< 5	< 10	< 4	5	153	66	< 5	6	149
55616	26d	M zone	368207	5738758	5	30	3834	40371	3	9	2	168	1.13	< 5	20	< 4	< 2	796	48.8	14	20	7
55617	26e	M zone	368178	5738764	22	20	21503	99999	3.8	6	10	626	3.83	5	< 10	< 4	< 2	420	255.1	23	8	8
55618	43a	upper G	368234	5738087	19	553	25157	99999	9.3	235	55	649	14.98	< 5	< 10	< 4	< 2	57	313.7	5	66	198
55619	43b	upper G	368234	5738087	28	8	8303	2227	5.9	17	2	1485	5.31	< 5	12	< 4	6	123	4.8	7	72	162
55620	43c	upper G	368234	5738087	20	283	170	20319	< .5	151	27	235	4.68	< 5	24	< 4	2	16	44.9	< 5	< 5	10
55621	47a	F zone	368200	5738485	31	651	10961	58146	2.1	402	54	282	23.48	5	< 10	< 4	5	61	71.5	7	8	332
55622	47b	F zone	368200	5738485	35	53	34697	99999	18.5	12	8	441	3.2	< 5	< 10	< 4	< 2	301	377.3	49	20	4
55623	56		369239	5738022	8	49	235	876	< .5	27	8	797	2.61	< 5	< 10	< 4	10	175	< .4	< 5	< 5	92
55624	36	upper G	368384	5738063	15	150	30883	99999	4.3	110	33	389	10.09	< 5	< 10	< 4	2	77	191.9	9	16	89
Jordan River																						
55626	JR-3a		401084	5665420	3	935	32364	62411	164.3	85	19	10653	8.87	< 5	< 10	< 4	12	109	243.3	167	< 5	63
55627	3b		401084	5665420	7	211	30083	79625	151.1	15	9	8174	5.93	< 5	< 10	< 4	9	152	325	148	< 5	49
55628	4		401038	5665433	5	58	29792	78508	115.5	20	8	5755	3.76	6	< 10	< 4	9	191	336.7	139	< 5	47
55629	6		401889	5664688	< 2	378	31465	668	65.9	8	2	140	0.97	10	< 10	< 4	< 2	2218	7.8	228	< 5	< 2
55630	7		401767	5664784	18	128	1675	36061	1.5	75	15	519	27.43	< 5	< 10	< 4	3	9	18.3	19	< 5	15
55631	9		401680	5664864	34	244	21855	99999	38.5	27	16	4451	17.27	5	< 10	< 4	9	65	555.8	46	6	140
Kneb																						
55633	Kneb-30c		379532	5710319	4	9325	371	1000	10.3	48	23	2719	12.27	< 5	< 10	< 4	2	130	3	< 5	< 5	9
55634	Kneb-30d		379532	5710319	< 2	6182	2752	865	15.7	10	7	4968	7.52	< 5	< 10	< 4	< 2	111	3.8	16	38	27
54962	KNEB 5		379532	5710319	< 2	2624	37	139	1.7	106	46	6536	30.44	11	15	< 4	< 2	144	5.6	< 5	< 5	2
54963	KNEB 6		379532	5710319	< 2	14294	42	806	12.4	32	20	4736	13.78	< 5	< 10	< 4	< 2	108	2.1	< 5	< 5	11
54964	KNEB 7		379532	5710319	3	1483	16	66	1.4	188	103	807	39.62	< 5	< 10	< 4	3	5	< .4	< 5	< 5	2
54965	KNEB 8		379532	5710319	6	1477	8	19	1.3	216	111	493	49.56	< 5	< 10	< 4	3	2	< .4	8	< 5	< 2

TABLE 3 CONTINUED
ANALYSES OF SELECTED MINERALIZED HAND SAMPLES OF THE KNEB, JORDAN RIVER AND RUDDOCK CREEK DEPOSITS

Lab No.	Field no.	Deposit	UTM East	UTM North	Ca %	P %	La ppm	Cr ppm	Mg %	Ba ppm	Ti %	Al %	Na %	K %	W ppm	Zr ppm	Sn ppm	Y ppm	Nb ppm	Be ppm	Sc ppm	Au** ppb	Pt** ppb	Pd** ppb
Ruddock Creek																								
52265	H96RC-1	E zone	368900	573700	5.3	0.024	1	35	< .01	11	0.05	0.64	0.06	0.15	< 2									
52266	H96RC-2	E zone	368900	573700	6.5	0.013	1	45	< .01	21	0.02	0.46	0.14	0.11	< 2									
52267	H96RC-3a	E zone	368900	573700	26	0.124	3	52	0.02	76	0.01	0.63	0.01	0.02	< 2									
52268	H96RC-4	E zone	368900	573700	14	0.007	2	46	0.01	56	< .01	0.33	0.43	0.2	< 2									
52269	H96RC-8	M zone	368207	5738758	8.1	0.068	3	36	0.06	19	0.07	1.12	0.07	0.11	< 2									
52270	H96RC-9	M zone	368207	5738758	6.8	0.044	< 1	107	< .01	19	0.01	0.48	0.13	0.1	< 2									
55605	RC-11b	F zone	368532	5737545	4.4	0.07	3	118	0.05	144	0.04	0.93	0.08	0.18	< 4	4	5	6	7	2	1	< 2	< 2	< 2
55606	12b	F zone	368537	5737520	3.3	0.024	< 2	113	0.07	161	0.08	1.04	0.06	0.22	< 4	2	7	6	4	1	2	< 2	5	8
55607	13	F zone	368508	5737526	2	0.139	14	75	0.05	157	0.24	1.98	0.05	0.52	< 4	10	35	13	18	< 1	5	< 2	2	22
55608	14a	F zone	368379	5737418	3.7	0.033	27	61	0.37	424	0.22	3.79	0.51	0.14	< 4	5	2	10	11	5	7	< 2	< 2	2
55609	14b	F zone	368379	5737418	5.1	0.068	5	99	0.12	184	0.11	1.55	0.1	0.24	< 4	2	7	8	5	2	3	4	< 2	< 2
55610	14c	F zone	368379	5737418	3.6	0.213	25	75	0.24	60	0.36	3.24	0.43	0.07	< 4	5	2	15	19	1	7	< 2	5	3
55611	17	lower G	368335	2737675	8.6	0.01	< 2	145	0.01	156	0.01	0.37	0.02	0.01	< 4	2	10	5	< 2	< 1	1	2	2	3
55612	18	lower G	368320	5737730	6.3	0.053	< 2	135	< .01	113	0.01	0.24	0.03	0.14	< 4	< 2	2	3	< 2	< 1	1	< 2	< 2	< 2
55613	23	upper G	368350	5738000	3.4	0.051	< 2	137	0.05	182	0.03	0.39	0.05	0.14	< 4	< 2	4	4	< 2	< 1	1	< 2	2	< 2
55614	26b	M zone	368207	5738758	3.5	0.076	4	145	0.08	173	0.06	0.73	0.05	0.31	< 4	< 2	4	9	2	1	2	< 2	7	5
55615	26c	M zone	368207	5738758	2.9	0.215	16	112	0.17	124	0.12	1.85	0.26	0.93	< 4	3	< 2	11	4	3	4	< 2	8	7
55616	26d	M zone	368207	5738758	27	0.058	< 2	32	0.02	345	0.01	0.12	0.02	0.02	< 4	2	< 2	7	< 2	< 1	1	< 2	4	3
55617	26e	M zone	368178	5738764	18	0.033	5	85	0.08	240	0.01	0.4	0.02	0.07	< 4	< 2	3	10	< 2	< 1	1	< 2	3	< 2
55618	43a	upper G	368234	5738087	1.3	0.207	5	144	0.11	224	0.09	1.25	0.15	0.43	< 4	2	7	13	4	2	3	< 2	3	24
55619	43b	upper G	368234	5738087	16	0.054	23	71	0.45	135	0.33	6.52	0.06	0.02	< 4	11	9	19	24	11	8	3	< 2	< 2
55620	43c	upper G	368234	5738087	0.8	0.2	2	54	0.03	303	0.01	0.12	0.02	0.02	< 4	< 2	< 2	4	< 2	< 1	1	< 2	3	6
55621	47a	F zone	368200	5738485	1.4	0.195	8	127	0.18	115	0.11	1.99	0.18	1.05	< 4	2	2	16	4	2	5	< 2	3	5
55622	47b	F zone	368200	5738485	11	0.028	2	105	0.06	162	< .01	0.45	0.04	0.14	< 4	< 2	7	5	< 2	1	1	2	< 2	< 2
55623	56		369239	5738022	3.7	0.15	29	57	1.14	292	0.2	4.31	0.61	1.16	8	4	2	19	11	1	7	< 2	4	4
55624	36	upper G	368384	5738063	3.4	0.093	4	106	0.08	159	0.07	1.07	0.06	0.31	< 4	< 2	4	7	3	1	2	3	< 2	< 2
Jordan River																								
55626	JR-3a		401084	5665420	2	0.035	38	92	2.25	197	0.28	6.23	0.07	2.13	9	2	2	15	8	1	10	94	< 2	< 2
55627	3b		401084	5665420	3.2	0.025	22	104	1.27	111	0.22	4.51	0.11	1.64	< 4	2	3	10	6	1	7	73	< 2	< 2
55628	4		401038	5665433	3.8	0.03	22	97	1.38	110	0.22	4.65	0.1	1.89	< 4	2	3	11	7	2	7	53	< 2	< 2
55629	6		401889	5664688	0.1	< .002	< 2	3	0.02	144	< .01	0.07	0.01	0.02	< 4	< 2	< 2	< 2	< 2	< 1	< 1	33	3	< 2
55630	7		401767	5664784	0.1	< .002	2	46	0.05	128	0.01	0.34	0.03	0.09	5	< 2	2	< 2	< 2	< 1	< 1	26	3	2
55631	9		401680	5664864	1.6	0.023	14	128	1.26	219	0.14	2.94	0.06	1.22	< 4	3	3	8	5	1	5	813	< 2	< 2
Kneb																								
55633	Kneb-30c		379532	5710319	7.2	0.005	< 2	18	2.79	46	< .01	0.05	0.03	0.01	< 4	< 2	< 2	< 2	< 2	< 1	1	76	< 2	< 2
55634	Kneb-30d		379532	5710319	13	0.027	5	12	6.01	109	0.04	0.63	0.07	0.2	< 4	< 2	2	4	< 2	< 1	3	130	< 2	< 2
54962	KNEB 5		379532	5710319	8.4	0.005	< 2	6	2.23	11	< .01	0.03	0.01	0.01	< 4	3	< 2	2	< 2	< 1	< 1	13		
54963	KNEB 6		379532	5710319	11	0.008	< 2	25	5.42	4	< .01	0.12	0.04	< .01	< 4	2	< 2	< 2	< 2	< 1	1	45		
54964	KNEB 7		379532	5710319	0.8	< .002	< 2	57	0.37	15	< .01	0.05	0.01	0.01	< 4	< 2	< 2	< 2	< 2	< 1	< 1	3		
54965	KNEB 8		379532	5710319	0.2	< .002	< 2	57	0.1	9	< .01	0.05	0.01	0.01	< 4	< 2	< 2	< 2	< 2	1	< 1	2		

Notes

Samples milled by ACME in a Cr-Steel mill. Possible Fe & Cr contamination from grinding

Method: HCLO4-HNO3-HCl-HF digestion - inductively coupled plasma emission spectroscopy

Lab: ACME Analytical

**FAA = Fire assay-ICP finish

99999: greater than 9.9 per cent

Photo 4. Steep slopes on the north side of Copeland ridge, showing the location of the Jordan River sulphide layer in the northeast limb of the Copeland syncline. The core of the syncline is located just south (right) of the sulphide layer, and underlying rocks of Units 4 and 5 are exposed to the north.

known in the immediate area, probably the most important being the Mount Copeland molybdenite deposit located along the margins of a syenite gneiss complex approximately 300 metres west of the Jordan River deposit. Mount Copeland (082M 002) was mined from 1970 to 1974 by King Resources Ltd., producing 1,191 tonnes of molybdenum from 169,729 tonnes of ore. Its geology is described in considerable detail by Fyles (1970) and summarized in BC Minfile.

The Jordan River deposit was reportedly discovered in the late 1800s by prospectors following up on the discovery of placer gold in Jordan River (Riley, 1961). Systematic exploration began on the property in the 1950s after it was optioned by Consolidated Standard Mines Ltd. Work included mapping, sampling and drilling by this company and Bunker Hill Exploration Ltd., and continued in the 1960s under Bralorne Pioneer Mines Ltd.

Exploration in the Jordan River area continued in the 1990s for Equinox Resources on the behalf of the owner, First Standard Mines Ltd. (MacGillivray and Laird, 1990). This work resulted in the recognition that a buff-weathering marble mapped by Fyles (1970) was the Mount Grace carbonatite of the Cottonbelt area, supporting a regional structural reinterpretation of the Jordan River area proposed by Höy and McMillan (1979) and Höy and Brown (1981). Subsequent work led to the discovery of several occurrences of gem-quality crystals, including emerald-green gahnite, almandine garnet and black tourmaline (Laird, 1997).

The current project concentrated on confirming the correlation of the Jordan River stratigraphy with that at Cottonbelt and evaluating Jordan River as a Broken Hill-type deposit. This report relies considerably on the regional and property-scale mapping by Fyles (1970) and more detailed work, including considerable sampling, by MacGillivray and Laird (1990) and Laird (1997).

Regional Geology

Fyles (1970) established a stratigraphic succession in the Jordan River area but conceded that above the Bews Creek fault, in the Jordan River deposit area, stratigraphic tops were not known. Höy and McMillan (1979) correlated Unit 10 of Fyles (op. cit.) with the core gneisses, thereby extending these gneisses well to the south as well as inverting the stratigraphy in the embayment of cover rocks of the deposit area. This revision of facing directions allowed correlation with similar successions to the south (Read, 1980) and to the north in the Perry River, Cottonbelt and Kirbyville Creek areas (Höy and Brown, 1981; Höy, 1987; Scammel and Brown, 1990). Detailed work corroborated these structural and stratigraphic revisions with the recognition of the marker Mount Grace carbonatite in the footwall of the Jordan River deposit (MacGillivray and Laird, 1990).

The revised stratigraphic succession of the Jordan River area is shown in Figure 8. The nomenclature follows that established at Cottonbelt. Unit 3 comprises mainly white quartzite with rare interlayers of micaceous schist and calcsilicate gneiss. Unit 4 includes a thick succession of calcsilicate gneisses, marbles, micaceous schists and a relatively thick quartzite (Unit 7 of Fyles, 1990). The top of Unit 4, the “grey-green gneiss” of Fyles, comprises mainly quartz-biotite-hornblende gneiss with lesser amounts of calcsilicate gneiss, fine-grained mica schist, a few thin, well-defined quartzite layers and the carbonatite tuff. Unit 5 is a distinctive white calcite marble that is recognized throughout the margins of Frenchman Cap dome. It is overlain by a calcsilicate-quartzite succession and the sulphide layer and, in the core of the Copeland syncline, sillimanite-biotite schists of Unit 6a (Figure 9).

The carbonatite on the northeast limb of the Copeland syncline is a tan to brown-coloured calcite marble layer that is interlayered with white to buff-coloured marble, and commonly underlain by a 30 cm thick, layered white marble. It is overlain by a mixed calcsilicate-im-

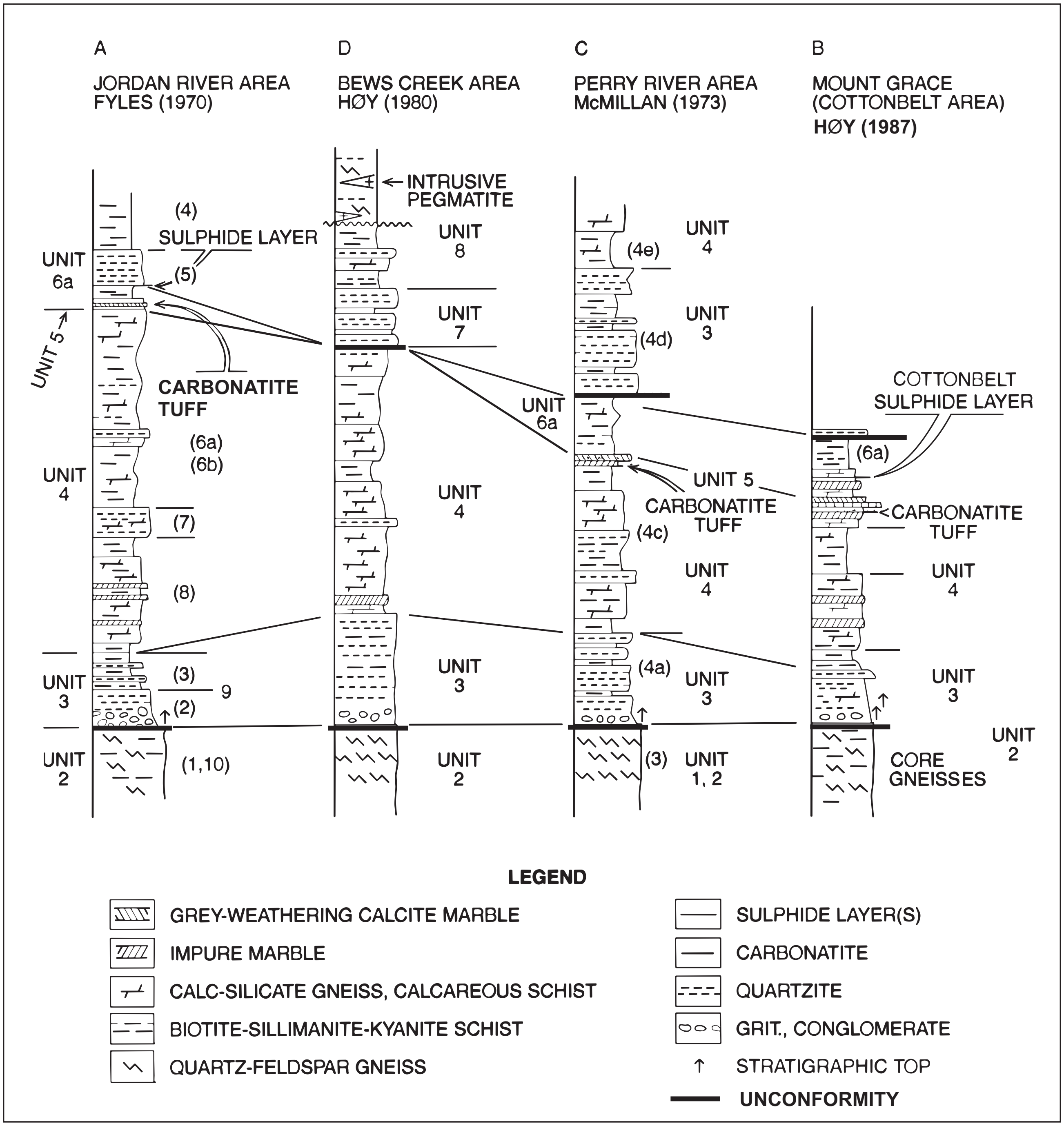

Figure 8. Composite cover sequence section, Jordan River deposit area, and correlation with sections along the west and north margin of Frenchman Cap dome; note numbers in brackets in the Jordan River section refer to unit designations of Fyles (1970); after Fyles (1970), Höy (1980), McMillan (1973) and Höy (1987).

pure marble succession, several metres thick, and the grey-weathering calcite marble of Unit 5. It is recognized in the field by its distinctive colour, numerous dispersed grains of brown mica and, less commonly, amphibole and abundant small clasts of granular, white albite. Analyses of the carbonatite (JR-1, JR-5, JR-11a; Table 2) shows that it contains up to 5800 ppm Sr, 146 ppm Nb, 0.58 percent P2O5, 0.29 percent Ba and 0.41 percent Mn. Rare earth element concentrations in two samples reported by Laird (1990) are also highly anomalous, with up to 608 ppm La, 1108 ppm Nd and 731 ppm Ce. Analyses of samples of buff to white marbles immediately adjacent to the carbonatite (Table 2) have trace and rare earth element concentrations that are comparable to marbles with sedimentary protoliths, as summarized in Höy (1997).

An orthogneiss, the Mount Copeland syenite, is exposed south of the Jordan River deposit area (Figure 9). It is a medium-grained, grey nepheline-feldspar-biotite gneiss that appears to have been involved in all deformation phases (Fyles, 1970). Lenses of coarse-grained K-feldspar pegmatites are common within it. The Mount Copeland syenite has been dated 740 ± 36 Ma (Parrish and Scammel, 1988), a similar age as the Mount Grace syenitic orthogneiss in the Cottonbelt area (Table 1; Crowley, 1997).

The structure of the deposit area is dominated by the Phase 2 Copeland syncline (Fyles, 1970). Its hinge and limbs are clearly outlined by Unit 5 and the sulphide layer. In the western part of the deposit area (Figure 9), the syncline plunges 30 degrees towards 150 degrees with an axial plane that dips south 45 degrees (Fyles, op. cit.). To the east, the fold becomes very tight and the plunge decreases through the horizontal to a low westerly plunge, resulting in the banana-shaped outcrop pattern. In the west, a syncline-anticline pair, folds E and F, warp the south limb of the Copeland syncline, and extend beyond the area mapped by Fyles, a distance of over 8 kilometres. The hinges of these Phase 2 folds are generally open and concentric with little appreciable thickening of the sulphide sequence (Photo 5).

Phase 1 folds are small recumbent isoclines with axial planes essentially parallel to layering. Fold axes are outlined by a penetrative mineral lineation which, throughout the deposit area, generally plunge to the southwest.

Mineralization

The Jordan River deposit comprises a sequence of one or more sulphide layers, with lenses of quartz and locally barite, in a calcsilicate gneiss succession that totals up to 10 metres in thickness (Fyles, 1970). Measured reserves reported by Riley (1961) total 2.6 million tonnes containing 5.6 percent Zn, 5.1 percent Pb and 37.7 g/tonne silver.

The sulphide layers are massive to crudely banded. They comprise mainly fine-grained pyrrhotite, sphalerite and galena with scattered grains of pyrite in a gangue of quartz, barite, calcite, plagioclase, garnet and some calcsilicate minerals. Barite content ranges from isolated grains within the sulphides to massive layers that contain variable amounts of sulphides.

Analyses of a number of hand samples of the sulphide layer in the northeast limb (Figure 9) are given in Table 3. A number of the samples contain considerable manganese, ranging up to 10653 ppm Mn, and relatively high cadmium and antimony. Silver content is higher than in other stratiform sulphide layers in the Northern Monashees, with three of the six samples containing more than 115 ppm Ag. These values are comparable to or somewhat lower than those reported by MacGillivray and Laird (1990) but much higher than in the measured reserves of Riley (1961). Gold content is also relatively high with one zinc-rich sample assaying 813 ppb Au (Table 3).

Discussion

The only age constraints on the Jordan River succession is the 740 Ma Copeland syenite that intrudes Unit 4 below the Jordan River deposit. However, the recognition of the carbonatite tuff and white calcite marble just below the Jordan River sulphide layer allows direct correlation with the Cottonbelt succession. Both sulphide deposits are stratabound layers at approximately the same stratigraphic level and, based on arguments from the Cottonbelt area, the Jordan River host succession may therefore be as old as 1.85 billion years. As in the Cottonbelt area, no unconformities have been recognized in the cover sequence below the Jordan River deposit.

Jordan River has many features that are typical of metamorphosed sedex deposits. Diagnostic features of Broken Hill-type deposits, such as siliceous or manganese rich envelopes, unusual chemistry, abundance of recognized exhalite facies in surrounding stratigraphy, or magnetite within ore lenses are not apparent. However, slightly elevated manganese, copper and antimony, and high gold and silver content, are typical of BHT deposits. It is probable that Jordan River represents a metamorphosed stratiform sulphide deposit that is closer to the sedex end of a BHT-sedex spectrum.

RUDDOCK CREEK

Introduction

The Ruddock Creek deposit was discovered in 1960 by prospectors under the supervision of Earl Dodson of Falconbridge Nickel Mines Ltd. The property was mapped in detail by H.R. Morris of Falconbridge in the summers of 1961 to 1963 and by J. T. Fyles in 1968 (Fyles, 1970). The writer spent one week on the property in late August of this year, mapping in detail the eastern part of the Ruddock Creek property. Exploration on Ruddock Creek included considerable drilling by Falconbridge from 1961 to 1963. Cominco Ltd. optioned the property in 1976, and during the late 1970s conducted extensive exploration that included considerable drilling,

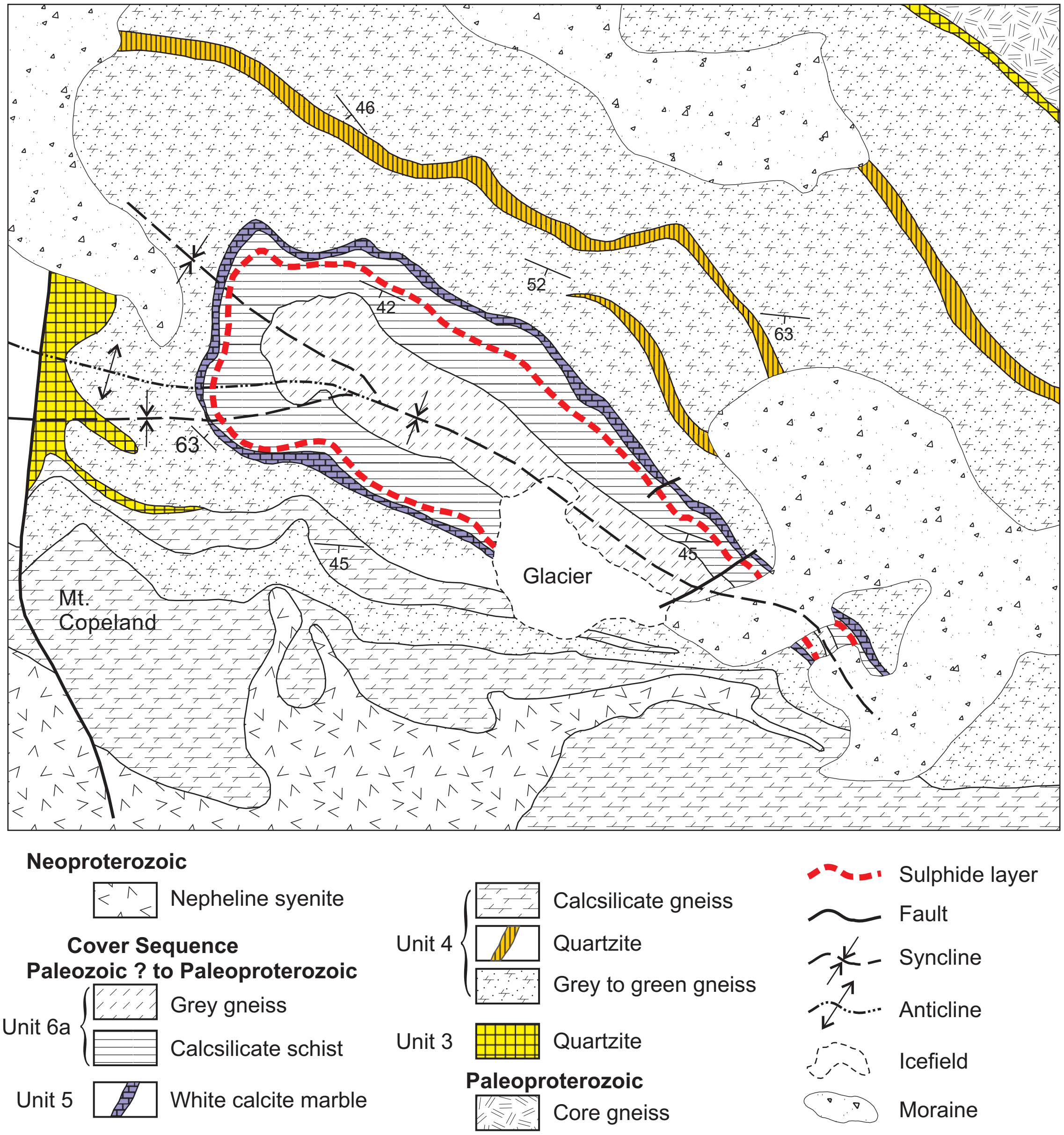

Figure 9. Geology of the Jordan River deposit area (after Fyles, 1970).

more detailed mapping, sampling and geophysical surveys. A considerable part of this work was directed towards defining the closure of the tight fold that forms the E zone. Double Star Resources Inc. obtained the Ruddock Creek claims in 1999 and this past summer began a program that consisted mainly of structural mapping and sampling. This report draws extensively on previous work; it describes main geological features, presents some new geochemical data and attempts correlations with units at other Monashee massive sulphide deposits to the south.

Ruddock Creek is located in the Script Ranges, nearly 100 kilometres north of Revelstoke (Figure 1). It is accessible by helicopter from both Revelstoke or Blue River, 50 km to the northwest. Ruddock Creek is a thin massive sulphide layer that can be traced or extrapolated through a distance of nearly 13 kilometres on south facing slopes near the headwaters of Ruddock Creek and a small tributary of Oliver Creek (Figure 10). Although most showings are above treeline and exposure is excellent, the steep topography on north facing slopes, together with glacier and snow cover, and very extensive “pegmatite” and “granite” tend to obscure this horizon.

Host Succession

As noted by previous workers, it is difficult to develop a composite section due to the pervasive “granite” and “pegmatite”, and structural complexity. Much of this granitic material contains remnant metasedimentary lay-

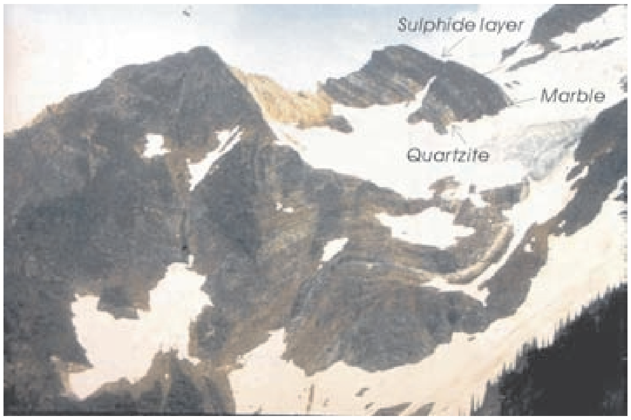

Photo 5. The Copeland syncline, viewed to the east, outlined by marble of Unit 5 and quartzites of Unit 6.

ers, only a few of which are shown on Figure 11. In some places, only the sulphide layer remains, entirely enclosed in granitic rock. However, a general succession, as noted by Fyles (1970), comprises a structurally lower calcareous section with the sulphide layer near the top, and an upper non-calcareous section. More detailed descriptions (below) are mainly from exposures on the slopes above the E zone and just west of the camp and E zone fault. As both of these exposure areas are on the upper limb of a tight, overturned syncline, they are interpreted to be inverted (Fyles, 1970).

The lower calcareous section comprises a mixture of calcsilicate gneisses, micaceous schist, pure to impure marble and minor amphibolites and thin quartzites. Calcsilicates are typically pale green with abundant diopside and variable garnet, quartz, feldspar and amphibole. They range in composition into impure quartzites with dispersed diopside and other calcareous minerals. At least two grey-weathering, white calcite marbles are recognized, separated by several hundred metres of mixed calcsilicates and schists. The lower grey marble, exposed northwest of camp (Figure 11) is structurally underlain by a tan to buff-coloured impure diopsidic marble and overlain by calcsilicate gneisses. Rusty-weathering biotite ± sillimanite schist layers are common within the calcareous section, particularly directly below the sulphide layer. Quartzites are not common, although a number of thin layers with minor diopside or garnet occur within a few hundred metres above and below the sulphide layer. Other thin quartzite layers that contain dispersed pyrrhotite and less commonly sphalerite occur in the section below the sulphide layer east of the E showing. They are interpreted to be recrystallized siliceous exhalite units. Some that contain only dispersed garnet may also be exhalative in origin, similar to those described at Broken Hill. Analyses of two of these quartzites (RC-52 and RC-57a, Table 2) show values fairly typical of impure sedimentary quartzites; however, slightly elevated Mn in one sample may reflect an exhalative origin.

The tan weathering marble described above was analyzed with the possibility that it is a carbonatite, even though it did not contain lithic clasts nor dispersed biotite characteristic of carbonatites at Jordan River and Cottonbelt. Analyses (RC-61a and RC-61b, Table 2) indi-

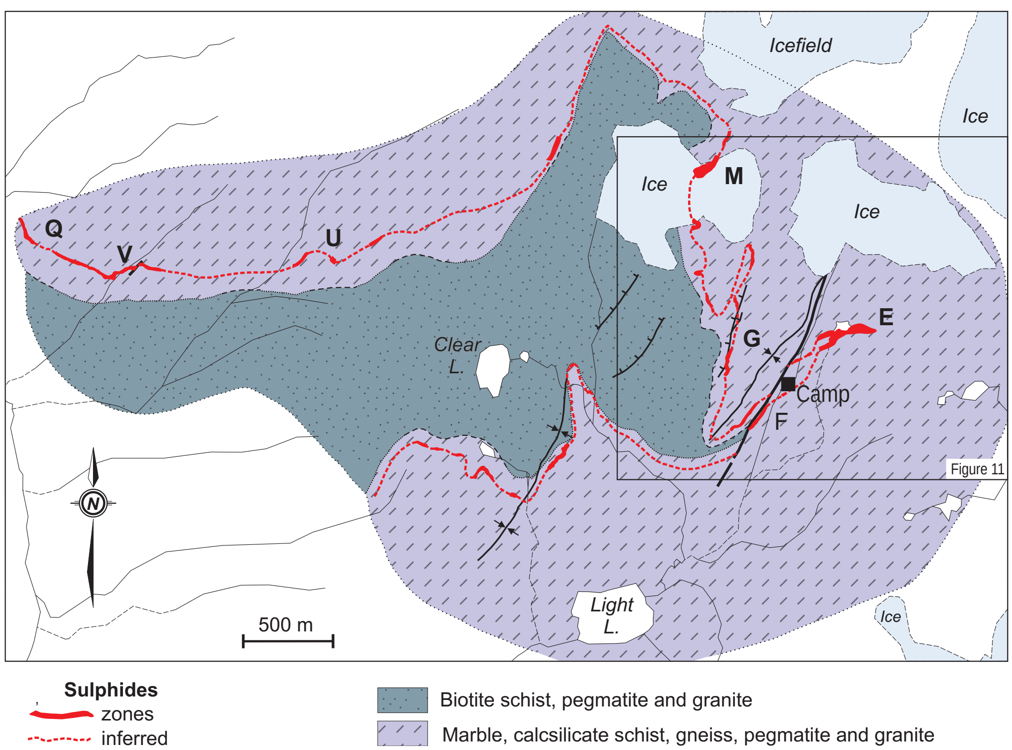

Figure 10. Geology of the Ruddock Creek deposit area (after Fyles, 1970).

cate it is mainly a calcitic marble with Ba and Mn contents typical of sedimentary limestones. Only Sr is anomalously high, but is still within the upper range of marble with a sedimentary protolith.

The upper non-calcareous section is only exposed as remnant brown-weathering biotite schist layers enclosed in pegmatite and granite in the western part of the map area (Figure 11). Fyles (1970) estimated that it may have a total stratigraphic thickness of 300 to 400 metres.

"PEGMATITE" AND "GRANITE"

These rocks include a wide variety of textures and grain sizes, ranging from coarse-grained unfoliated pegmatite, through medium-grained, massive to foliated quartz-feldspar "granite", to aplite and aplitic gneiss. They occur throughout the map area, typically covering more than 50 percent of the outcrop area (Figure 11). As described by Fyles (1970), they can form thick, essentially continuous sheets with only minor remnant metasedimentary layers to thin cross-cutting dykes. Contacts with metasediments are typically sharp whereas contacts between the granitic phases range from sharp to gradational. Most granitic bodies are foliated, although many appear to be massive and discordant. They were emplaced prior to, during and after penetrative deformation.

Structure

The structure of the Ruddock Creek area has been described in considerable detail by Fyles (1970) and Marshall (1978) and is reviewed only briefly here. It is dominated by the E fold, a tight Phase 1(?) synform with a hinge zone exposed at the E showing. The fold plunges 27 degrees towards 285 degrees, with an axial plane that dips 45 degrees to the north (Fyles op. cit.).

Phase 2 folds are recumbent with west-dipping axial surfaces. Their hinge zones range from tight to relatively open. On the slopes just west of the E fault, a Phase 2 synform (the FG synform of Fyles, op. cit.) plunges west and trends to the north-northeast (Figure 11). Layering in its eastern limb, including the F zone, strikes northeast and dips to the northwest, while layering in the west limb strikes more northerly, with a steep west dip. The apparent thickening of the Lower G zone is probably due to structural repetition by minor folds on the west limb of the FG synform.

Faults include north-trending mylonite zones and late northeast-trending faults that commonly form prominent air-photo lineaments. One of these, the E zone fault, has been studied in considerable detail as it offsets the mineralized hinge zone of the E fold. The mylonites are most conspicuous in sulphides in the Lower G zone and the M zone.

Mineralization

The distribution of the Ruddock Creek sulphide layer is shown in Figures 10 and 11. Zones of thickened mineralization, due either to structural complexity or possibly original sedimentary thickening, are also labeled. Between these zones, the sulphide layer is typically not recognized due to extensive granite, or may be marked by slight rusting in granite or a very thin sulphide layers in calcsilicates.

E ZONE

The E zone is well exposed at an elevation of 2230 metres, adjacent to a small lake (Photo 6). It is a thickened and structurally repeated sulphide zone in the hinge of the Phase 1 syncline. Mineralization in both limbs trends westward to the E fault where they are offset approximately 250 metres down to the west, measured in the plane of the fault (Fyles, 1970). The total exposed length of mineralization in the E zone is nearly 300 metres, with a width of 18 metres across strike in the east and 70 metres across the limbs in the west (Mawer, 1976). Drilling has extended the known plunge length of the hinge zone to approximately 200 metres, for a geological reserve of 1.4 million tonnes containing 10 percent Zn + Pb with a Zn to Pb ratio of 5:1 (Mawer, op. cit.).

The zone comprises a number of individual sulphide layers, comprising mainly sphalerite and galena with pyrrhotite. They are separated by rusty-weathering quartzite with disseminated pyrrhotite and sphalerite, thin calcsilicate schist, and thin marble that contains sulphides and thin discontinuous laminations of fluorite (Photo 7). Fyles noted that the zone comprises two structurally repeated and thickened sulphide layers. However, a number of thin sulphide layers, as well as disseminated sulphides, occur throughout the rusty-weathering zone below the main sulphide layers. Marshall (1978) also recognized two additional layers and suggested that the E zone represents an original thicker portion of the Ruddock Creek horizon. He further argued that there appears to be little thickening of individual layers as they are traced around the hinge of the E fold. The conclusion that this zone represents an originally thicker mineralized interval seems to be reasonable in light of the thickness and extent of the alteration here, the number of sulphide layers, and the number of thin mineralized quartzite layers in the immediate underlying stratigraphy.

Mineralization comprises dark sphalerite and less galena, pyrrhotite, minor pyrite and trace chalcopyrite, in a rusty-weathering calcareous quartzite gangue. Gangue minerals include quartz, calcite, fluorite, feldspar, muscovite, brown mica, and minor amphiboles, pyroxene (diopside?) and barite.

Analyses of selected hand sample of the E zone are given in Table 3. Analyses of the mineralized quartzite layers in the section below the sulphide zone are also given in Tables 2 and 3. As described above, one of these layers has slightly elevated manganese content (compared to sedimentary quartzites) and sample RC-56 (Table 3) has elevated Pb, Zn, Mn, Ba and W suggesting that these may be exhalite horizons.

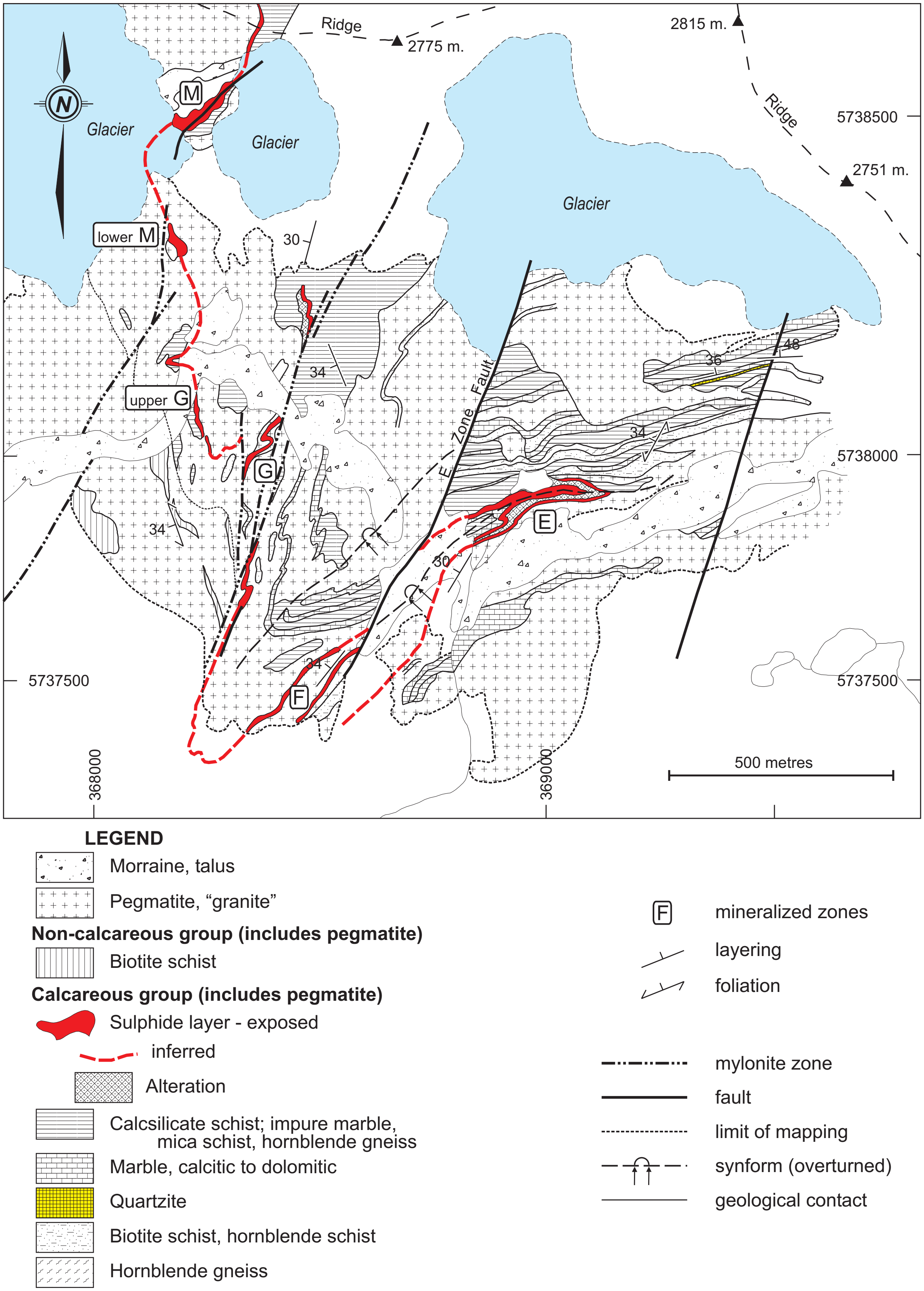

Figure 11. Detailed geology of the eastern part of the Ruddock Creek deposit area. UTM Nad 83 grid.

Photo 6. View to the southeast of the E zone in the core of the E zone syncline. The syncline closes to the east (left). Note abundant pegmatite in foreground.

F ZONE

The F zone is exposed as a number of sulphide lenses located southwest of the camp (Figure 11). One of these lenses (RC-11) is enclosed by pegmatite and has a pegmatite lens within it. The sulphide lens is exposed for 20 metres along a cliff face and is up to 2 metres thick. It comprises massive, fine-grained sphalerite, pyrrhotite and galena with minor to abundant clear quartz, feldspar and pyroxene? grains. Towards the margins of the lens, quartz content increases until it comprises a mineralized quartzite with dispersed sulphides.

RC-12 is a sulphide pod approximately 10 metres in length and 3 metres thick. It varies from massive pyrrhotite, sphalerite and galena with a quartz gangue to quartzite with disseminated sulphides.

RC-13 is a thin sulphide exposure, comprising mainly massive pyrrhotite with sphalerite and galena, on strike southwest of RC-11. It is immediately underlain by streaked, fine-grained quartzite with disseminated sulphides. The sulphide and siliceous envelope are within diopside-plagioclase calcsilicates. The analyzed sample (Table 3) is a quartz-diopside rock containing pyrrhotite, sphalerite and galena.

RC-14 is exposed at the top of a high steep cliff farther to the southwest. The massive sulphide layer (RC-14b; Table 3) is approximately one metre thick, and contains numerous small rounded quartz grains. Quartzite in its immediate footwall (RC-14a) and hangingwall (RC-14c) contains disseminated pyrrhotite, sphalerite and galena, pyroxene? and rare garnet and calcsilicate minerals. The sulphide zone is underlain by a thin impure marble layer that grades upward to calcsilicate just beneath the footwall quartzite, then granular biotite-quartz-feldspar gneiss, and finally calcsilicate gneiss.

G ZONE

The G zone includes a number of discrete sulphide zones on the inverted western limb of the FG synform.

Photo 7. Fluorite layers in calcite marble in footwall rocks at the E zone.

Shearing, probably related to east-directed thrusting, has both attenuated sulphide layers of the G zone and repeated them farther northwest as the upper G zone. The mineralized layers are exposed discontinuously along a strike length of approximately 400 metres. Although relatively thin or poorly exposed at surface, drilling (DDH ED-4) intersected a true thickness of 16 metres at the upper G zone containing 6.12 percent Zn and 0.79 percent Pb (Mawer, 1976). This interval included barren pegmatite as well as a number of higher grade sulphide layers. Eight X-ray holes drilled in 1977 also intersected mineralization, with the one 2-metre interval in DDH UG 77-4 containing 1.79 % Pb and 11.08 % Zn within a zone 28 metres thick that contained 0.32 % Pb and 2.28 % Zn (Nichols, 1978). The lower G was also tested by six X-ray drill holes with one intersection of 5 metres grading 2.59 % Pb and 11.91 % Zn (Nichols, op. cit.).

The lower G zone (Figure 11) comprises a contorted massive sulphide layer that is intermixed with remnants of impure marble and calcsilicate gneiss layers. It is stratigraphically underlain by impure tan to white calcite (with minor fluorite) marble and calcsilicate and overlain by quartzite with disseminated sulphides and rare emerald green gahnite? grains. Open to relatively tight macroscopic folds, with similar vergence as the FG synform, repeat the sulphide layer. North-striking mylonites cut both sulphides and host rocks. Analyses of a number of selected hand samples of the lower G zone (RC-17, RC-18 and RC-23) are given in Table 3. They are similar to those of the E and F zones, with high Zn and Pb values and low silver content.

The upper G zone is exposed on both sides of a moraine northwest of the lower G zone. A small exposure (partially snow covered) just south of the moraine comprises a 1-metre thick, medium-grained black, sphalerite-pyrrhotite-galena layer with quartz and minor calcite and garnet gangue. It is underlain by dark quartz that contains disseminated sulphides and garnet, and locally overlain by massive coarse-grained garnet-pyroxene skarn that contains variable quartz and sulphides. Analyses of a sample of the sulphide layer (RC-43a) is shown in Table 3. High manganese content of the garnet-rich skarn (RC-43b) indicates that the garnet is mainly spessartine. The high zinc content of the quartzite in the footwall (RC-43c) suggests that it is an alteration assemblage.

M ZONE

The M zone comprises a number of exposures, largely enclosed by glacier ice, at elevations ranging from 2450 metres to 2675 metres. The largest of these (RC-26; Figure 11) includes several sulphide layers that are structurally repeated by tight, west-plunging recumbent folds. The lower exposure of the M zone is 260 metres downslope to the south from the main showing, and the highest exposure is located on the ridge to the north of the main showing.

Sulphide layers at the main M showing comprise mainly sphalerite, pyrrhotite and galena with quartz and minor calcite and fluorite gangue. Sulphides (sample RC-26b, Table 3) are generally massive with clear quartz eyes, but also are locally layered or mylonitized. They are within a siliceous, tan-weathering calcite marble that contains streaks of fluorite, minor barite and occasional to relatively abundant sulphides (RC-26a, 26d). In some places, a siliceous, quartz-sulphide envelope (RC-26e) surrounds the sulphide layers, or occurs below them. The sulphide layers and host rocks are stacked due to a series of recumbent Phase 2? folds with rounded hinge zones that plunge at variable angles to the west and northwest. These folds are broadly warped by south plunging Phase 3 folds.

The lower M zone was only partially exposed within glacier ice and snow. The exposed sulphide layer has a thickness of 2 metres; it comprises mainly pyrrhotite and sphalerite and minor galena with a quartz-rich gangue (sample RC-47a). It is structurally underlain by “pegmatite” and overlain by a very silicified zone comprising mixed quartzites, calcsilicates and marbles.

The quartzite, commonly in contact with the sulphide layer, ranges from pure to containing variable amounts of garnet and diopside and randomly dispersed grains of gahnite(?) or sulphides. It is overlain by a pale green to tan siliceous calcsilicate or skarn assemblage, comprising mainly diopside, quartz, minor garnet and some dispersed sulphides. Lenses of swirled sphalerite, galena, quartz and calcite, but virtually no iron sulphide, occur within the calcsilicate zone. One of these lenses (RC-47b) contains the highest silver content (18.5 g/tonne) of any sample analyzed from the Ruddock Creek area. Other lenses in the calcsilicate unit include quartz-garnet, quartz-garnet + diopside and quartz - pyrrhotite units. Farther removed from the massive sulphides, the calcsilicate zone is less quartz rich, comprising mainly diopside or garnet, or a diopside - garnet ± quartz assemblage. This alteration zonation appears to reflect decreasing silica and increasing manganese with distance above the sulphide layer.

DISCUSSION

Ruddock Creek comprises a number of sulphide layers within a thin (less than 20 metre thick) stratigraphic package. These can be traced or extrapolated through a strike length of approximately 13 kilometres. Locally, they are structurally repeated or thickened by folding and possibly thrust faulting. The E zone may be structurally thickened, but it is also possible that it comprises an originally thicker sedimentary succession that localized the tight E syncline.

The sulphide layers are commonly enclosed, overlain or underlain by a zone of intense silicification, now occurring as a quartzite with variable garnet, sulphide and calcsilicate mineral content. This zone typically grades outward to a magnesium-rich calcsilicate zone or manganiferous garnet “skarn” assemblage. Dispersed sulphides, commonly with higher lead/zinc ratios occur in the alteration envelope.

A number of thin quartzite layers in the underlying succession are interpreted to be exhalite units. They may contain disseminated sulphides, mainly pyrrhotite and minor sphalerite, garnet, and rarely gahnite.

It is difficult to correlate the Ruddock Creek stratigraphy with that at Cottonbelt and Jordan River as there are no distinctive marker units other than the sulphide layer itself; carbonatites were not clearly identified at Ruddock Creek, although a tan-weathering marble in the underlying stratigraphy superficially resembles the Mount Grace carbonatite. Despite this, it is possible that Ruddock Creek is in the same package as other stratabound sulphide occurrences as most appear to be at a similar stratigraphic level. As well, the broad subdivision between a lower calcareous and an upper noncalcareous section is common to all occurrences. This, however, may simply reflect a similar change in depositional environment at all occurrences, from more shallow to deeper water environments that reflects extensional tectonics and basin deepening.

Ruddock Creek has some features diagnostic of Broken Hill-type deposits. The relatively high base metal/iron sulphide ratio, high fluorine and the calcareous host typify BHT deposits. As well, the pronounced quartz and spessartine alteration envelope around sulphide layers is characteristic of these deposits. Finally, the numerous sulphide-quartzite layers in the footwall stratigraphy, and occasional gahnite-quartzite and garnet-quartzite layers, are similar to the exhalite horizons around BHT deposits.

SUMMARY

A number of stratabound zinc-lead-silver deposits occur in highly metamorphosed and deformed metasedimentary rocks in the Monashee Mountains in southeastern British Columbia. Some of these, including Big Ledge and Kingfisher south of Revelstoke and Jordan River, Cottonbelt and Ruddock Creek to the north, have been fairly extensively explored, but none have had any production. The deposits are thin layers of massive to semi-massive sulphides that have strike lengths of several kilometers and widths of generally less than a few meters. They are intensively deformed and metamorphosed and locally invaded by extensive zones of pegmatite and granite.

The deposits are within the Monashee Complex, a succession of mainly platformal rocks, referred to as the cover sequence, that unconformably overlies crystalline basement of the core complex. The core complexes are exposed in two structural culminations, the Frenchman Cap dome in the north and Thor-Odin in the south. The age of the core complex is reasonably well constrained by Paleoproterozoic granitic orthogneisses that range in age from ca. 1.87 to 2.27 Ga.

The age of the cover sequence, particularly that part of the succession hosting the sulphide layers, is not as well known. Estimates based mainly on lithologic correlations with Kootenay terrane and North American rocks to the east have ranged from Mesoproterozoic to Paleozoic. Recent dating of detrital zircons and intrusions, however, indicate that deposition of the basal part of the cover sequence occurred between ca. 1.95 and 1.85 Ga (Crowley, 1997). The sulphide layers occur only a few hundred meters above this basal part of the sequence. A maximum age for rocks considerably higher in the succession, above the sulfide layers, is provided by 1.2 Ga detrital zircons, and a minimum age by a 541 Ma magmatic amphibolite. These ages are compatible with a Cambrian Pb-Pb galena date on Cottonbelt. However, if the sulphide layers are Cambrian, then the thin interval separating them from the basal part of the sequence requires a major unconformity, recording a hiatus of ca. 1.3 billion years. As this unconformity is not recognized in the field, either by omission of units or distinctive lithologies, the suggestion that the sulphide layers themselves are Paleoproterozoic must be considered. This requires reevaluation of the lead isotopic systematics of Cottonbelt.

A number of features of some of the deposits, and of the host successions, are typical of a class of deposits referred to as the Broken Hill-type. These include skarn-like mineralogy, a result of a calcareous gangue, locally high Mn content, and the abundance of magnetite (at Cottonbelt) rather than iron sulphide phases more common in typical sedex deposits. Immediate host rocks may contain fluorite and have abundant garnet and sillimanite, similar to Broken Hill host rocks. As well, thin quartzite, garnet-quartzite and sulphide-quartzite layers are similar to some of the exhalite facies that characterize Broken Hill stratigraphy, as is the local occurrence of gahnite in some of these layers.

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