CHAPTER 4

INTRODUCTION

The Rossland mining camp is the second largest lode gold producing camp in British Columbia, with recovery or more than 85,900 kilograms of gold and 109,500 kilograms of silver between 1894 and 1941. Vein deposits are in three main belts, referred to as the North belt, Main veins and South belt (Figure 4-1). Mineralization in the Rossland camp also includes molybdenite deposits on the western slopes of Red Mountain and a number of high-grade gold-quartz veins in the Sheep Creek valley and on the eastern slopes of O.K. Mountain just west of Rossland. These latter veins have been described in Chapter 3.

Gold-copper vein deposits of the Rossland camp have been described by a number of authors; the most comprehensive reports are by Drysdale (1915), Gilbert (1948) and Thorpe (1967). Stevenson (1936) described in some detail the workings of the gold-quartz veins west of Rossland, and Fyles (1984), the setting of the camp and the molybdenite deposits on Red Mountain. The regional geology in the vicinity of the camp is presented in Höy and Dunne (1997).

The origin and age of gold-copper veins in the Rossland camp and the relationship, if any, between these veins and other styles of mineralization in the immediate camp vicinity, have been the focus of considerable discussion and debate. The purpose of this chapter is to summarize the regional geology around Rossland, to describe the main deposit types, and to present a model for intrusive-related gold-sulphide veins. The importance of this deposit type, referred to as “intrusion-related Au-pyrrhotite veins” by Alldrick (1993) and initially believed to be restricted to a deposit in Western Australia (Rowins, 2000). Furthermore, the Rossland model has been applied to exploration on a number of similar style veins in the Greenwood camp west of Rossland (L. Caron, personal communication, 1998).

GEOLOGICAL SETTING

The geology of the Rossland area is illustrated on Figure 4-1. The southern part of the area is underlain mainly by volcanic rocks of the Early Jurassic Elise Formation. These rest unconformably on meta-sedimentary rocks of the late Paleozoic Mount Roberts Formation and are in apparent fault contact with underlying rocks of Unit Cs, interpreted to be mainly a siliciclastic assemblage of the Slide Mountain terrane. Locally, the Elise Formation is unconformably overlain by coarse conglomerates of the Late Cretaceous Mount Sophie Formation.

A number of igneous suites intrude these rocks. The Rossland sill, a subvolcanic monzogabbro intrusion and the Rossland monzonite both host a considerable number of the productive veins of the Rossland camp. The intrusions are cut by the Middle Jurassic Trail pluton and by alkaline Coryell intrusions of Middle Eocene age. The Eocene Sheppard intrusions occur as stocks in the southeastern part of the area or form north-trending felsic dikes; they are also cut by the Coryell intrusions.

UNIT CS (CHARBONNEAU CREEK ASSEMBLAGE)

Rocks assigned to Unit Cs are restricted to the southeastern part of the Rossland area. The more western of the two exposed areas was mapped in detail (Höy and Andrew, 1991a). It includes tan to black-coloured argillite, silty argillite and minor siltstone, a massive pale grey limestone, some massive dolomite and dolomitic siltstone. These rocks are locally silicified, sheared, brecciated and veined. To the east, north of the Pend O’Reille River, these rocks include mafic volcanic rocks with MORB signatures (Einersen, 1994). Tight, minor folds occur locally, and crenulated phyllites indicate at least two periods of deformation.

The intense shearing and brecciation, particularly along the margins of Unit Cs, and the truncation of adjacent units in the Elise Formation, suggest a faulted contact between Cs and the Elise. It is probable that this fault contact is the western extension of the Waneta fault, a thrust fault that is interpreted to mark the boundary of Quesnellia with Slide Mountain and North American rocks.

Unit Cs is late Paleozoic in age; in correlative exposures farther east, Little (1982b) described brachiopods of probable Late Mississippian age and Einersen (1994) identified abundant holothurian sclerites of probable Mississippian to Pennsylvanian age (C.M. Henderson, written communication to J. Einersen). Einersen (op. cit.) divides Unit Cs into two assemblages, the Charbonneau Creek and Harcourt Creek assemblages. The western exposures of Cs south of Rossland are included in the Charbonneau Creek assemblage that Einersen (op. cit.) correlates with the Upper Mississippian McHardy assemblage of the Milford Group; the more easterly Harcourt Creek assemblage is correlated with the Davis assemblage of the Kootenay terrane.

The McHardy assemblage is considered by Klepacki and Wheeler (1985) to be part of a siliciclastic succession beneath mafic volcanic rocks in the Slide Mountain terrane. Hence, the Charbonneau Creek assemblage may represent the most southern exposures of Slide Mountain in British Columbia. Alternatively, W. Howard (personal communication, 2000) favours correlation of the Charbonneau Creek assemblage with Kootenay terrane rocks, specifically the Davis assemblage of the Milford Group. The assemblage is...
Figure 4-1. Geological map of the Rossland area, Rossland-Trail map sheet (082F/04); after Höy and Andrew (1991b), Fyles (1984), Little (1982b) and Drysdale (1915). See Figure 4-2, in pocket for detail.
within a thrust panel, separated from overlying Quesnel rocks by the Waneta fault and from underlying Kootenay terrane rocks by the Tillicum Creek fault.

The Charbonneau Creek assemblage appears to record mainly shallow-water deposition in a lagoonal and shosh environment (Einersen, 1994). Possible correlation with the McHardy assemblage, and inferred stratigraphic ties with the Davis assemblage, which unconformably overlies the Lardeau Group of the Kootenay terrane (Roback, 1993; Roback et al., 1994; Klepacki and Wheeler, 1985; Klepacki, 1985), suggested deposition as a “marginal basin assemblage” along the western ancestral North American margin (Einersen, op. cit).

MOUNT ROBERTS FORMATION

The Mount Roberts Formation consists of a succession of dominantly fine-grained siliceous rocks, argillite, carbonate and minor greenstone and conglomerate of Pennsylvanian and possibly Permian age (Little, 1982b; Höy and Dunne, 1997). In the Rossland area, the formation is exposed near Patterson at the United States border, and on the eastern slopes of Mount Roberts and Granite and OK mountains northwest of Rossland (Figure 4-1). These localities are described by Little (1982b) and Höy and Andrew (1991a) and the exposures on Mount Roberts, by Fyles (1984).

The Patterson exposures comprise dominantly fine-grained silstone, dark grey to black argillite or pale grey-green silty chert. Numerous fine, irregular hairline fractures typically cut the more siliceous units; quartz veining is less common. These units are either massive or thinly laminated. Locally, graded and scoured sandstone lenses occur within the siltstone and provide rare stratigraphic-top indicators. Carbonate units, including grey brecciated limestone and rusty weathering, well-bedded fossiliferous dolomite, are conspicuous near the uppermost exposures of the Mount Roberts Formation.

Outcroppings on the eastern slopes of Mount Roberts and Granite Mountain are similar, comprising mainly black to grey siliceous argillite and siltstone. Rare silt scours, graded beds and a number of bedding-cleavage intersections indicate that the Mount Roberts Formation at this location faces west. Thicker bedded, graded siltstone and sandstone beds are locally interbedded with thin, impure dolomite and limestone lenses. These units also face west and are unconformably overlain by volcanic breccias of the Elise Formation.

The Mount Roberts Formation is locally ‘basement’ to arc rocks of Quesnellia, with the Rossland Group unconformably overlying it at Patterson and elsewhere. It unconformably overlies the Trail gneiss, a succession of grey-green siliceous siltstone, argillaceous siltstone, limestone, and minor chert, quartzite and a variety of plagioclase porphyries in an argillaceous or granular sandy matrix. Locally, a coarse limestone breccia derived from the underlying Mount Roberts Formation is at the base of the

The Archibald Formation is typically a heterolithic pebble conglomerate with subrounded to subangular clasts of grey-green siliceous siltstone, argillaceous siltstone, limestone, and minor chert, quartzite and a variety of plagioclase porphyries in an argillaceous or granular sandy matrix. Locally, a coarse limestone breccia derived from the underlying Mount Roberts Formation is at the base of the

ROSSLAND GROUP

The Rossland Group in the Rossland area includes a coarse basal conglomerate, correlated with the Archibald Formation, and an overlying thick accumulation of mafic flows, pyroclastic rocks and interlayered metasedimentary rocks of the Elise Formation (Höy and Andrew, 1991a; Höy and Dunne, 1997). The Hall Formation is missing, due to nondeposition or to erosion prior to deposition of the unconformably overlying Mount Sophie Formation. The age of the Elise Formation is constrained by late Sinemurian fossils in the upper part of the Archibald Formation, a 197 Ma U-Pb zircon age from tuffs within the formation, and Toarcian fossils in the Hall Formation (see summary and references, Chapter 2).

The Archibald Formation at Patterson consists of a veneer of conglomerates, up to several hundred metres thick, that lies unconformably on the Mount Roberts Formation. The Mount Roberts paleosurface is irregular, resulting in isolated patches of Archibald in depressions in the surface and small outcrops of Mount Roberts on paleohighs (Figure 3-4, in Höy and Dunne, 1997). Most commonly, a limestone unit in Mount Roberts lies along the paleosurface.

The Archibald Formation is typically a heterolithic pebble conglomerate with subrounded to subangular clasts of grey-green siliceous siltstone, argillaceous siltstone, limestone, and minor chert, quartzite and a variety of plagioclase porphyries in an argillaceous or granular sandy matrix. Locally, a coarse limestone breccia derived from the underlying Mount Roberts Formation is at the base of the
TABLE 4-1
ANALYSES OF INTRUSIVE CLASTS WITHIN THE ARCHIBALD FORMATION
IN THE FRUITVALE AND MONTROSE AREAS

<table>
<thead>
<tr>
<th>Lab No.</th>
<th>Field No.</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>SUM</th>
<th>Zr</th>
<th>Nb</th>
<th>Sr</th>
<th>Y</th>
<th>V</th>
<th>Nd</th>
<th>Rb</th>
</tr>
</thead>
<tbody>
<tr>
<td>54483</td>
<td>Montrose</td>
<td>65.7</td>
<td>0.43</td>
<td>15.21</td>
<td>1.25</td>
<td>0.05</td>
<td>1.95</td>
<td>5.8</td>
<td>4.38</td>
<td>1.95</td>
<td>0.1</td>
<td>99.2</td>
<td>102</td>
<td>11</td>
<td>578</td>
<td>22</td>
<td>100</td>
<td>&lt;5</td>
<td>38</td>
</tr>
<tr>
<td>54484</td>
<td>Montrose</td>
<td>60.2</td>
<td>0.37</td>
<td>17.26</td>
<td>4.86</td>
<td>0.11</td>
<td>1.8</td>
<td>7.07</td>
<td>5.05</td>
<td>0.58</td>
<td>0.14</td>
<td>99.4</td>
<td>71</td>
<td>11</td>
<td>646</td>
<td>18</td>
<td>75</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>54485</td>
<td>Archibald</td>
<td>53.7</td>
<td>0.6</td>
<td>14.6</td>
<td>4.65</td>
<td>0.18</td>
<td>1.58</td>
<td>10.21</td>
<td>3.75</td>
<td>2.11</td>
<td>0.17</td>
<td>99.2</td>
<td>106</td>
<td>10</td>
<td>543</td>
<td>22</td>
<td>144</td>
<td>&lt;5</td>
<td>40</td>
</tr>
</tbody>
</table>

NOTES
Oxide analyses: Fused disc - X-ray fluorescence; trace elements: pressed pellet XRF
SUM = Sum of oxides
Laboratory = Cominco Research Labs.

Figure 4-3. Trace element diagrams of analyses of intrusive clasts in the Archibald Formation, Fruitvale and Montrose areas, showing their subvolcanic arc provenance.
Archibald. The argillaceous matrix is commonly tinged purple, suggestive of subaerial exposure. Bedding, clast-sorting or winnowing, grading or other features indicative of fluvial environments are lacking. These sedimentary conglomerates are distinct from tuffaceous conglomerates in the Elise as they contain virtually no volcanic clasts or a tuffaceous matrix.

The origin of the porphyritic clasts within the basal part of the Archibald Formation is not known. A number of these clasts in the Fruitvale and Montrose areas have been analyzed (Table 4-1). Low Nb, Y and Rb values (Figure 4-3) indicate a volcanic arc provenance, suggesting derivation from subvolcanic arc plutons that were exposed in Early Jurassic time. It is most likely that these clasts record plutonism in the underlying Mount Roberts Formation, but also possible that they record Triassic plutonism, related to Nicola arc volcanism, or older Devonian plutonism associated with arc volcanics of the Kootenay terrane.

The Elise Formation in the Rossland area is described in considerable detail by Höy and Dunne (1997). It comprises a north to northwest-dipping homoclinal succession that extends north from Patterson to Rossland. A composite section is illustrated on Figure 4-4.
The base of the Elise is a gradational contact with the Archibald, placed where either volcanic clasts are first noticed or the matrix becomes tuffaceous. Plagioclase-porphryy lapilli tuffs of Unit Je8l locally overlie the tuffaceous conglomerate. Argillaceous turbidite siltstones (Unit Je10a) and mafic flows and flow breccias (Unit Je4) overlie the tuffaceous conglomerates and lapilli tuffs. The mafic flows comprise massive augite porphyry, flow breccias and possible minor lapilli tuff; it is the only significant mafic flow succession in the Rossland area.

Unit Je7x is a succession of dominantly fine mafic tuff beds that generally coarsen upward into crystal tuffs that contain small, widely scattered augite porphyry lapilli and numerous plagioclase and augite crystals. Layers of lapilli tuff and, less commonly, pyroclastic breccias become more prominent near the top of the succession. These are interpreted to be mainly surge and pyroclastic flow deposits recording subaerial to possibly very shallow water conditions.

South of the Rossland monzonite, interbedded argillaceous siltstone and tuffaceous sandstones of units Je10 and 10a host a number of vein deposits of the South belt (Höy and Andrew, 1991a,b). They may correlate with rust-weathering argillites and siltstones on the west slope of Red Mountain, host to the Red Mountain molybdenite deposits. Mafic lapilli tuffs of Je8l overlie these metasediments.

In summary, the Elise Formation in the Rossland area comprises dominantly mafic to intermediate lapilli tuffs interlayered with prominent sections of tuffaceous siltstone and argillaceous siltstone. Mafic flows are subordinate and tuffaceous conglomerates are essentially restricted to the basal part of the succession. The Elise Formation in the Rossland area was deposited on a structural high that is exposed in the Patterson area and on the eastern slopes of Mount Roberts. Virtually the entire basal succession of the Rossland Group, the Archibald Formation, and a considerable part of the lower Elise is missing. Despite this, the Elise in the Rossland area represents one of the thickest successions recognized, in excess of 5000 metres.

**SOPHIE MOUNTAIN FORMATION**

The Sophie Mountain Formation (Bruce, 1917; Little, 1960) is exposed on Mount Sophie, on the ridge a few kilometres southeast of Baldy Mountain, and on the ridge north of Lake Mountain (Höy and Andrew, 1991b). The formation comprises poorly sorted, heterolithic conglomerate with thin interbeds of argillite and argillaceous siltstone. The conglomerate consists dominantly of rounded clasts of quartzite and other sedimentary rocks. Clasts derived from the underlying Elise Formation are rare or absent. The Sophie Mountain Formation represents deposition in small, structurally controlled basins in Late Cretaceous time.

**MARRON FORMATION**

The Middle Eocene Marron Formation (Bostock, 1940; Church, 1973; Little, 1982b; Fyles, 1984) is exposed on the eastern slopes of OK Mountain and Mount Roberts just west of Rossland and to the east of Goodeve Creek. The formation comprises dark grey, green and, locally, mauve andesitic flows and minor lapilli tuff, tuffaceous sandstone and tuffaceous conglomerate. It is in fault contact with the Elise Formation near Rossland (Fyles, 1984) but unconformably overlies the Elise in the southwest part of the map area; it is intruded by Middle Eocene Coryell intrusions.

**INTRUSIVE ROCKS**

Numerous intrusive rocks, ranging from batholithic bodies to small stocks and dikes, occur throughout the Rossland area. They are described in considerable detail by Fyles (1984), Little (1982b) and Höy and Dunne (1997) and hence will be only briefly described here.

**EARLY? JURASSIC MONZOGABBRO INTRUSIONS**

The Rossland sill (Fyles, 1984), exposed on the east slopes of Red Mountain and just south of the Rossland monzonite, hosts many of the western extensions of the Main Rossland veins and virtually all of the North belt veins. It is an inequigranular to porphyritic augite porphyry intrusion (Photo 4-1). It is interpreted to be an Early Jurassic subvolcanic intrusion, similar to many other, small Elise Formation-age, monzogabbro intrusions throughout the Rossland Group.

Elsewhere in the Rossland area, monzogabbro or gabbro stocks are also found in the Elise Formation on the ridge southwest of Deer Park Hill and on the southern slopes of Malde Mountain. As well, a similar small intrusion occurs in the Mount Roberts Formation west of Patterson. These intrusions are fine to medium grained and generally porphyritic with 30-40% plagioclase phenocrysts in dark green-grey matrix. Farther east in the Nelson area, they host copper-gold porphyry mineralization (see Chapter 3). They are petrographically distinct from the Eagle Creek plutonic complex, Rossland monzonite and Silver King intrusions.

Based on their chemistry and mineralogy, these monzogabbro intrusions are interpreted to be Elise-age subvolcanic intrusions. Although they have not been dated,
they may be similar in age to a number of known Early Jurassic mafic plutons recognized elsewhere in the southern Cordillera, and interpreted to record more extensive arc magmatism. The Lexington porphyry in the Greenwood camp is dated at \textit{ca.} 200 Ma (Church, 1992) and a diorite near Christina Lake has a 197 ± 5 Ma age (Acton \textit{et al.}, 1999); a similar massive to foliated diorite on the southwest side of the Valhalla complex is dated at 193 ± 1 Ma (Parrish, 1992). As well, a leucocratic sill that intrudes the McHardy assemblage in the Slide Mountain terrane is dated at 196 Ma (Roback, 1993). The recognition of inheritance in zircons from some of these plutons, in particular the Lexington porphyry, and the occurrence of at least one within Slide Mountain terrane that can be tied to Kootenay terrane stratigraphy (Klepacki, 1985; Roback, \textit{op. cit.}) support a model for deposition of the Rossland Group close to marginal North America.

These plutons record arc magmatism and are part of a suite of subvolcanic intrusions related to the Early Jurassic arc volcanics of the Elise Formation.

**ROSSLAND MONZONITE**

The Rossland monzonite, centered on the town of Rossland, hosts many of the Main veins of the Rossland camp. It has been described by numerous workers, including Drysdale (1915), Bruce (1917), Gilbert (1948), Little (1960, 1963, 1982b), Fyles (1984), Höy and Andrew (1991a,b) and Höy and Dunne (1997). The following description is summarized largely from Höy and Dunne (\textit{op. cit.}).

The Rossland monzonite is a composite stock with coarse to fine-grained phases, and mafic-rich to intermediate (feldspar-dominated) phases (Photo 4-2). Fe₂O₃/FeO ratios of a number of hand samples (Table 4-2) indicate that the more mafic phases tend to be more oxidized, in contrast to reduced, intermediate phases. Contacts between these phases range from gradational to intrusive with, more commonly, coarse grained or more feldspathic phases being younger (Drysdale, 1915). More mafic monzodiorite rocks comprise 40-60% andesine, up to 25% orthoclase, and augite variably replaced by hornblende and biotite. Magnetite and apatite are ubiquitous accessory minerals, sphene is rare, and a small amount of quartz occurs as late, resorbed crystals. It can grade to a dark greenish black rock comprised dominantly of pyroxene and hornblende with abun-

**TABLE 4-2**

**FE₂O₃ (TOTAL), FeO AND Fe₂O₃ VALUES OF SELECTED HAND SAMPLES OF THE ROSSLAND MONZONITE SHOWING OXIDATION STATE RATIOS**

[Samples with Fe₂O₃/Fe₂O₃+FeO ratios greater than ~0.4 are considered oxidized, those below, more reduced]

<table>
<thead>
<tr>
<th>Lab No.</th>
<th>Field No.</th>
<th>Fe₂O₃(t) (%)</th>
<th>FeO (%)</th>
<th>Fe₂O₃</th>
<th>Fe₂O₃/Fe₂O₃+FeO</th>
<th>Fe₂O₃/FeO</th>
</tr>
</thead>
<tbody>
<tr>
<td>36429</td>
<td>R91-14</td>
<td>10.99</td>
<td>5.84</td>
<td>4.50</td>
<td>0.435203532</td>
<td>0.770549315</td>
</tr>
<tr>
<td>36432</td>
<td>R93-5</td>
<td>10.72</td>
<td>6.64</td>
<td>3.34</td>
<td>0.334733865</td>
<td>0.503157831</td>
</tr>
<tr>
<td>36966</td>
<td>R99-8</td>
<td>4.16</td>
<td>2.72</td>
<td>1.14</td>
<td>0.294836962</td>
<td>0.418111765</td>
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<tr>
<td>42005</td>
<td>286-9</td>
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</tr>
<tr>
<td>42007</td>
<td>287-7</td>
<td>8.41</td>
<td>4.35</td>
<td>3.58</td>
<td>0.451162621</td>
<td>0.822033333</td>
</tr>
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<td>287-14</td>
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<td>3.26</td>
<td>0.493805789</td>
<td>0.975526347</td>
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<td>313-4</td>
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<td>5.69</td>
<td>3.21</td>
<td>0.360437232</td>
<td>0.56356819</td>
</tr>
<tr>
<td>41684</td>
<td>318-3</td>
<td>7.03</td>
<td>4.12</td>
<td>2.45</td>
<td>0.37304495</td>
<td>0.59501068</td>
</tr>
<tr>
<td>41685</td>
<td>320-14</td>
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<td>6.07</td>
<td>5.94</td>
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<td>0.979309555</td>
</tr>
<tr>
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<td>323-3</td>
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<td>5.23</td>
<td>2.75</td>
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<td>0.525411281</td>
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<tr>
<td>41688</td>
<td>324-22</td>
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<td>3.48</td>
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<td>3.99</td>
<td>1.80</td>
<td>0.310394055</td>
<td>0.450103509</td>
</tr>
</tbody>
</table>

Analytical methods:
FeO: Acid decomposition / acid soluble / volumetric
Fe₂O₃(t): X-ray fluorescence (see Bulletin 102)
Fe₂O₃ = % Fe₂O₃(t) - (% FeO)x(1.1113)

Photo 4-2. Coarse-grained Rossland monzonite, consisting of mainly large augite, partially replaced by hornblende, orthoclase and plagioclase, from the Iron Colt deposit (2.5 cm coin scale).
dant biotite. Other phases include monzonite and, at the Centre Star deposit, an exposure of biotite clinopyroxenite several metres across.

There has been considerable debate regarding the age of the Rossland monzonite and its relationship to the Elise volcanics. Höy and Dunne (1997), based on petrographic evidence, the locally intense alteration of the pluton, contact relationships with the Elise rocks, and chemistry suggested that it was a subvolcanic intrusion, comagmatic with the Elise Formation. Furthermore, U-Pb zircon data seemed to support an Early Jurassic age (Höy and Dunne, op. cit.), although J. Gabites and J. Mortenson (personal communication, 1996) suggested that these data indicated a Middle Jurassic age for the Rossland monzonite.

Uranium-lead zircon data from another Rossland monzonite sample are presented in Appendix 4 and plotted in Figure 4-5. Concordant data from two fractions indicate a 167.5 ± 0.5 Ma age for the Rossland monzonite. These data support a Middle Jurassic age for the Rossland monzonite, a similar age as the Nelson, Trail and Bonnington plutonic rocks.

**DIORITE PORPHYRY DIKES**

Diorite porphyry dikes, referred to as diorite porphyrite by Drysdale (1915) and Gilbert (1948), are common in underground workings in the area of the Main veins. The similar orientation and their close proximity to the veins suggest a genetic link (Drysdale, op. cit.). Drysdale suggested that these were phases of the Middle Jurassic Trail pluton, whereas Gilbert (op. cit.) concluded that they grade into the Rossland monzonite, and may be a dike or marginal contact phase. This interpretation is supported by Fyles (1984) who noted similar hornblende porphyries in the margins of the Rossland monzonite and intense alteration of these dikes, in contrast to less altered dikes that appear to be related to the Trail pluton.

**RAINY DAY PLUTON**

The Rainy Day pluton is a small quartz diorite stock exposed along Highway 22 just west of the town of Rossland.

It is considered important in the metallogeny of the Rossland camp as it, and possibly associated dikes on Red Mountain (Eastwood, 1966; Fyles, 1984), are interpreted to have been the source of molybdenite mineralization in the camp. The following description of the stock is taken mainly from Fyles (1984).

The pluton varies from a central, more massive quartz diorite to a marginal porphyritic zone. It comprises approximately 50% plagioclase, 15-20% quartz, 5-15% orthoclase microperthite, 10-15% biotite, 5% hornblende and 5% augite.

Contacts with Elise Formation country rocks are generally sharp and irregular. The pluton is truncated to the west by the Coryell intrusion and is in sharp contact with the Rossland monzonite in the south. Fyles (op. cit., p. 21) suggested that “the relationships between the two stocks are not entirely conclusive” but that “dike-like masses of quartz diorite appear to extend from the Rainy Day pluton into the Rossland monzonite indicating that the monzonite is older”.

“The Rainy Day pluton is highly fractured with a network of intersecting veinlets containing very fine-grained pyroxene, quartz, hornblende, biotite, chlorite, carbonates and sulphides (pyrite and molybdenite)” (Fyles op. cit., p. 22).

U-Pb analyses of a composite sample of the Rainy Day pluton, collected along the roadcut west of Rossland, are tabulated in Appendix 4, and shown on Figure 4-6. A York regression through these fractions gives an upper intercept age of 174.6 ± 3.6 Ma, which is probably the upper limit on its age. A weighted mean of the $^{206}Pb/^{238}U$ of the most concordant fractions, A and B, gives the best estimate of the lower limit on the age of the pluton, at 166.3 ± 1.4 Ma. The large uncertainty in this date does not resolve the question of the relative ages of the Rainy Day and Rossland plutons.

**RED MOUNTAIN QUARTZ DIORITE DIKES**

Three dikes, described by both Eastwood (1966) and Fyles (1984), occur in the vicinity of the molybdenite mine on the western slopes of Red mountain. The similarity in alteration and composition to the Rainy Day pluton suggests that they are part of a common magmatic suite. One of these dikes, the A zone dike, is intensely altered, brecciated and veined or replaced by molybdenite. It is described in more detail below (see Red Mountain Mo deposits).

A smaller dike within the A pit, also brecciated and cut by veins of molybdenite (Photo 4-3), has yielded a lower intercept U-Pb zircon age of 162.3 ±1.2/–2.5 Ma (Figure 4-7; Appendix 4).

The dikess generally strike east with steep dips. The largest (Figure 4-2, in pocket) is up to 100 metres in thickness and 600 metres in length. Others are smaller and discontinuous, but several extend several hundred metres in length.

**ULTRAMAFIC ROCKS**

Ultramafic rocks in the vicinity of the Rossland camp are described by Fyles (1984) and Ash (2001). Fyles (op.
cit.)) suggested that these bodies of “serpentinite” are probably within faults and Höy et al. (1992) interpreted that they were tectonically emplaced during a period of regional compression in Middle Jurassic time.

Detailed studies of one of these, the O.K ultramafic body located in the Little Sheep Creek valley just west of Rossland (Fyles, op. cit.; Figure 4-1) have been undertaken by Ash et al. (1992) and Ash (2001). They described it as mainly an olivine wehrlite with erratically distributed areas of dunite and pyroxene-bearing dunite.

The O.K ultramafic body is in fault contact with surrounding host rocks. Fine-grained mafic volcanic rocks exposed along its northern contact may be of oceanic crustal affinity, related to the ultramafics (Ash et al., op. cit.) rather than part of the oceanic arc Elise Formation (Höy and Andrew, 1991b). These volcanic rocks host a number of very high-grade quartz veins, including the IXL, O.K and Mid-night deposits.

Early interpretations of the origin and age of the O.K. ultramafic body, and others in the Rossland area such as the larger Record Ridge body farther south, have varied considerably. Drysdale (1915) suggested that they are altered augite porphyry stocks, and Fyles (1984) inferred that they are plutonic, possibly Late Cretaceous rocks. Little (1982b) suggested that they were part of an ophiolitic assemblage, related to the Late Paleozoic Mount Roberts Formation.

Ash (2001) confirmed that these are plutonic cumulate bodies. Furthermore, based on detailed petrographic studies and analyses of platinum group elements in massive chromite from the Record Ridge ultramafic, Ash further concluded that these bodies have an ophiolitic rather than an Alaskan-type affinity. Ash (2001) suggested that, based on the close spatial and structural association with the Mount Roberts Formation, this formation, the ultramafic bodies, and possibly related mafic volcanic rocks, be referred to as the Mount Roberts Assemblage. However, it is not resolved if this assemblage is therefore part of the oceanic Slide Mountain terrane; the Mount Roberts Formation has also been interpreted to be part of the Kootenay (Wheeler and McFeely, 1991) or Quesnel (Roback, 1993; Roback and Walker, 1995) terranes.

**MINERALIZATION**

Two occurrences of chromite mineralization in ultramafic rocks in the Rossland area are documented in B.C. MINFILE.

The Vandot occurrence (082F/SW130) is in the Record Ridge ultramafic body between the two main forks of Sophie Creek, seven kilometres southwest of Rossland. Massive pods, lenses and veins of chromite and magnetite are exposed in a number of pits within serpentinite. As well, millerite, linnaeite and pyrite are reported (BC MINFILE). One of these lenses is up to 30 cm in width and strikes 330 degrees. Analyses of a number of samples of this mineralization are reported in Assessment Report 4927. These samples contain trace silver and gold, 1.0 to 1.4 g/t platinum, and up to 160 ppm cobalt, 0.23% nickel and 16.5% chromium.
A second chromite occurrence, referred to as Little Sheep Creek ultramafics (082F/SW214) is located in the Little Sheep Creek valley approximately 3 km southwest of Rossland. This occurrence is associated with minor asbestos.

Fyles (1984, p. 23) describes exploration for nickel near the northern contact of a mass of serpentinite on the Midnight property along the west side of Little Sheep Creek: “exploration companies sampled underground workings and reported several thousand tonnes of serpentinite averaging 0.25% nickel. Selected samples assayed as high as 0.45% nickel. In samples submitted to R.V. Kirkham of the Geological Survey of Canada, pyrite, millerite (NiS) and a mineral of the linnaeite group were identified. Ten samples taken by (Fyles) at various places throughout the two masses of serpentinite exposed in the area gave nickel assays of less than 0.24 per cent.”

STRUCTURE AND TECTONICS

The structure of the Rossland area has been well described by Fyles (1984) and Little (1982b). Fyles divided the area into two domains separated by the “Rossland break”, an east-trending zone marked by a number of faults and intrusions, including the Rossland monzonite, Rainy Day pluton and serpentinites. Fyles suggested that the Rossland break is a zone of “structural weakness that may have originated when the Rossland Group was laid down...” (Fyles, 1984, p.29). South of the break, structures trend northeasterly whereas to the north, they trend northerly.

Detailed mapping, concentrated largely south of Rossland (Höy and Andrew, 1991a; 1991b) has, in large part, confirmed the structures outlined by Fyles. However, correlation of both map units and structural patterns to those farther east has allowed a better understanding of the stratigraphic position of the Rossland mining camp and of the tectonic evolution of the area. Three phases of deformation affecting Rossland-age rocks are recognized:

- extensional tectonism during deposition of lower Rossland Group rocks in Early Jurassic time;
- east-directed thrust faulting and associated minor folding before intrusion of Middle and Late Jurassic plutons;
- normal faulting in Eocene time.

EARLY JURASSIC

The Rossland area is underlain by a tectonic high, bounded by growth faults, that is first evident in early Rossland time (Höy and Dunne, 1997). The basal sedimentary succession of the Rossland Group, the Archibald Formation, records deposition in a fault-bounded structural basin located east of the Rossland map area, in the Beaver Creek valley (Andrew et al., 1990a,b). The source area, based on facies analyses, was inferred to lie immediately to the west. In the Rossland area, the Archibald Formation is missing or represented by a thin basal conglomerate and the entire lower part of the Elise Formation is generally missing (Figures 4-1, 4-4) confirming the presence of a tectonic high and source area here. The orientation and exact position of the bounding growth faults are not known; however, the rapid facies changes in Elise rocks just east of Waneta suggest that the late north-trending faults located there might be the loci of some of the syndepositional Rossland growth faults. The location of other north-trending faults, including the Eocene Champion Lake fault, may also be controlled or modified by either fault-controlled facies changes in Rossland Group rocks or Rossland-age growth faults. Finally, the east-trending Rossland break also appears to record a zone of structural weakness in Rossland time (Fyles, 1984) suggesting that the uplifted tectonic high in the Rossland area may have been controlled by an orthogonal pattern of block faults. Block-faulted regions, with fault-bounded basins and tectonic highs, generally record extensional tectonics. These areas tend to localize later structures and intrusions and hence are favourable sites for structurally controlled mineral deposits.

MIDDLE JURASSIC

A period of compressive tectonism, evident throughout the Rossland Group in Middle Jurassic time, produced tight folds, a penetrative cleavage and intense shearing in eastern exposures, and more open, upright folds and thrust faults farther west. Southeast of the Rossland area, the Waneta and Tillicum Creek faults record further reworking of the Quesnellia - Slide Mountain - Kootenay terrane boundary. The Waneta fault, initially recognized by Fyles and Hewlett (1959) in the Salmo area, separates rocks of the ?Slide Mountain Charbonneau Creek assemblage from those of Quesnellia (Einersen, 1994). The Tillicum Creek fault separates the Charbonneau Creek assemblage from the Harcourt Creek assemblage, correlated by Einersen (op. cit.) with the Milford Group Davis Creek assemblage of the Kootenay terrane. Both faults contain slivers of ultramafic rocks along them and, hence, both are interpreted to be thrusts that place Quesnel rocks and oceanic rocks onto Kootenay terrane and North American rocks.

The Waneta fault has been traced westward into the Rossland area (Little, 1982b; Höy and Andrew, 1991a; 1991b) where it is covered by the Late Cretaceous Sophie Mountain Formation or the Eocene volcanic rocks of the Marron Formation (Figure 4-1).

The Snowdrop fault west of Rossland is a west-dipping structure, marked by intense shearing and brecciation, that places a west-facing panel of Mount Roberts Formation and basal Elise on younger Elise Formation (Sections A-A’, B-B’, Figure 4-2, in pocket). Related folds are concentrated in only a few areas; the Rossland area is essentially a west to northwest-dipping homoclinal succession of Rossland Group rocks (Fyles, 1984; Höy and Andrew, 1991a,b).

The age of this compressive deformation is constrained in the Nelson area to be post-Toarcian (ca. 187 Ma), the youngest age of Rossland Group rocks, and pre-intrusion of middle Jurassic Nelson plutons (ca. 167 Ma). Furthermore, Höy and Andrew (1997, p. 84) have argued that the ca. 174-178 Ma ‘Silver King intrusions’ (south of Nelson) are a syncollisional intrusive suite that records the earliest onlap
of the eastern margin of Quesnellia with North American crustal rocks. Farther north in the Kootenay arc, Colpron et al. (1996) constrain “juxtaposition of the Intermontane superterrane over the North American margin” between 187-173 Ma and post-emplacement, southwest-verging deformation between 173-168 Ma. High temperature shear zones within the ‘tail’ of the Nelson pluton south of Nelson, suggest strain may have continued along the Waneta fault during emplacement of the batholith (Vogl and Simony, 1992).

**EOCENE**

Steeply dipping, generally north-trending normal(?) faults occur throughout the Rossland area. A number of these on the slopes of Mount Roberts just west of Rossland have been described in considerable detail by Fyles (1984). As described above, they appear to be along a major structural break that was the locus for earlier thrust emplacement of ultramafic rocks.

The OK fault appears to be a listric normal fault that is overturned to the east at higher structural levels (Fyles, 1984; Stinson, 1995). Marron Formation rocks in the western block have been down-dropped in excess of 600 metres (Fyles, op. cit.). Similarly, the Jumbo fault is inferred to be overturned at higher structural levels, with a steep east-dip near surface exposures. It is interpreted to be downthrown to the west (Fyles, op. cit.). Shattered syenites along the east side of the fault indicate movement after Eocene emplacement of the Coryell intrusion. The Snowdrop fault lies in the panel of Mount Roberts Formation rocks between the OK and Jumbo faults. It is a west-dipping fault that is inferred to be older than, and unrelated to the normal faults. A spectacular breccia with large angular fragments and a quartz-calcite-hornblende-sulphide matrix is exposed along the Cascade highway just northwest of the gold-quartz veins in the Jumbo Creek valley. Höy and Andrew (1991a) suggested that this may be from an earlier thrust fault, related to emplacement of ophiolitic rocks.

North-trending faults southeast of Rossland, of inferred Eocene age, include the Violin Lake, Tiger Creek and Malde Creek faults (Figure 4-1). The Violin Lake fault is a vertical structure with an unknown amount of displacements (Little, 1985). It appears to truncate the Waneta fault and possibly the Eocene Marron Formation in the south, but produces little, if any offset of the Rossland monzonite; hence, it may die out to the north. The Tiger Creek fault is inferred from truncation and displacements of units in the Elise Formation (Figure 4-1). However, it also dies out northward as it displaces the Rossland monzonite only minimally. A number of north-trending faults with minor right-lateral displacement in the Malde Creek area, southwest of the Tiger Creek fault, may follow the loci of Rossland-age growth faults. They are associated with pronounced facies changes in the Rossland Group, and appear to die out up-section.

These late faults are younger than the Eocene intrusive and extrusive events. The Jumbo fault brecciates Middle Eocene Coryell intrusive rocks; the OK and Violin Lake faults truncate Middle Eocene lavas of the Marron Forma-

**MINERAL DEPOSITS**

The following sections describe the molybdenite breccias on the western slopes of Red Mountain, the copper-gold veins of the North belt and Main veins, the South belt lead-zinc-silver veins and high-grade gold-quartz veins located approximately 4 kilometres southwest of Rossland in the Little Sheep Creek valley (Figure 4-8). These latter veins are in highly altered “greenstones” adjacent to a small unit of serpentinite. The various deposits are classified, constraints are placed on their ages, and a metallogenic model is presented that integrates these somewhat diverse deposit types.

Most of the mines and veins of these camps are not described individually in this report, as access and sampling was largely restricted to dump material; the descriptions of many of the veins by Drysdale (1915) and of the molybdenite mineralization by Fyles (1984) still remain the most comprehensive.

Molybdenum deposits on Red Mountain produced about 1.75 million kilograms of molybdenum from approximately 1 million tonnes of ore between 1966 and 1972 (Appendix 3; B.C. MINFILE data). Molybdenite occurs dominantly in quartz veins and veinlets cutting a coarse breccia complex in a west-dipping and facing, hornfelsed and skarned siltstone succession (Fyles, 1984). The molybdenite and host quartz diorite intrusive breccias have been dated at 162-163 Ma by Re-Os and U-Pb methods respectively (see below and Appendices 4 and 7), which is younger than the Rossland monzonite and associated gold-copper veins.

Drysdale (1915) divided the veins of the Rossland camp into three main belts, termed the North belt, Main veins and South belt. All veins trend east-west, with variable but generally steep northerly dips. The veins cross the western exposures of the Rossland monzonite, the Rossland sill, and metavolcanic and metasedimentary rocks of the structurally higher Elise Formation to the west.

We conclude in this paper that Cu-Au vein mineralization of the Rossland camp is spatially and genetically related
to diorite porphyry dikes, which are late phases of the Rossland monzonite. Furthermore, we suggest that the diverse character, mineralogy, alteration and tenor of these veins are related largely to depth of emplacement and proximity to the Rossland pluton. Skarn alteration and associated higher temperature Au-Cu veins occur in eastern, structurally deeper exposures whereas more brittle Pb-Zn-Ag veins occur at higher structural levels in western exposures in the South belt. This model is compatible with paleomagnetic data that suggests that the Rossland monzonite and host Rossland Group were tilted down to the west in Eocene time, thereby exposing progressively shallower structural levels in the west.

RED MOUNTAIN Mo DEPOSITS

INTRODUCTION

The molybdenite deposits on the western slopes of Red Mountain have been described in considerable detail by Fyles (1984), and this summary is based in part on his work. Recent work by Webster et al. (1992) and Ray and Webster (1997) describes the general characteristics of molybdenite skarns and the mineralogy and chemistry of the Red Mountain deposits.

Exploration for molybdenum on the western and upper slopes of Red Mountain began in 1962 by Torwest Resources Ltd. and subsequently continued on the southern slopes by Cascade Molybdenite Mines Ltd. (Fyles, 1984). Production by Red Mountain Mines Ltd. began in 1966 from a number of shallow pits and, until 1972, produced 1,748,871 kilograms of molybdenum from 939,397 tonnes of ore (Coxey deposit, Appendix 3) (Photos 4-4a and 4b). Geological mapping, geochemical and geophysical surveys, and drilling were carried out by Minefinders Inc. from 1972 to 1974. In 1981, David Minerals drilled nine short holes on the Novelty to test for gold, molybdenum and cobalt mineralization (Richardson, 1982).

Molybdenite occurs within a breccia-skarn complex that contains irregular, generally north-striking intrusive breccia dikes. The breccia complex trends roughly north-south, with a maximum exposed length of 2 700 metres and a width up to 1 200 metres (Figure 4-8). It extends across the Mountain View, Nevada, Coxey, Novelty and Giant claims. It is developed in fine-grained metasediments near the top of the exposed Elise Formation. A sill complex, referred to as the Rossland sill, intrudes the Elise Formation just east of the molybdenite deposits and is, in turn, intruded by the Rossland monzonite. Numerous north-trending dikes cut the monzonite, the Rossland sill and the Elise Formation rocks in the vicinity of the molybdenite breccia complex.

Figure 4-8. Simplified geological map of the Rossland copper-gold camp (for details, see Figure 4-2, in pocket); modified from Drysdale (1915), Thorpe (1967), Fyles (1984), Cominco Ltd. unpublished data and Héy and Dunne (1997).
HOST ROCKS

The molybdenite breccia complex is exposed on the western slopes of Red Mountain within an assemblage of generally west to southwest-dipping, dark grey to black siltstones and argillites. These metasediments are typically rusty weathering containing disseminated pyrrhotite and minor pyrite. Occasional white quartzite layers and calcsilicates, suggestive of a calcareous protolith, are also noted.

Hornfelsed and skarned argillite and siltstone, within and adjacent to the breccia complex, are pale to medium green, grey, buff or purplish brown, laminated to massive hard “cherty” rocks (Fyles, 1984). They comprise fine-grained quartz and feldspar with variable biotite, pyroxene (diopside?) and hornblende, and locally minor garnet and epidote. Typical alteration paragenesis includes early biotite hornfelsing with a purple-brown colouration, followed by prograde skarn diopside ± quartz and minor molybdenite mineralization, then chlorite-amphibole-molybdenite veining with bleached envelopes, and finally late thin carbonate-epidote veins.

These metasediments have been correlated with either the Elise Formation (Fyles, 1984) or the Mount Roberts Formation that implied a thrust contact with underlying Rossland sill (Höy and Andrew, 1991b). Fyles (op. cit.) recognized sills and dikes of the Rossland sill complex cutting overlying metasediments, evidence of an intrusive contact. We support the correlation with the Elise Formation and hence, the interpretation of an intrusive contact between the metasediments and the Rossland sill; detailed mapping (Figure 4-2) illustrates the irregular, intrusive character of the contact. The contact, which is intersected by drilling on the Gertrude property, shows no sign of shearing or brecciation, and thin pyrrhotite veins, similar to veins of the Rossland gold camp, cut the contact and overlying metasediments.

The Rossland sill has been interpreted to be an Elise-age subvolcanic intrusion, similar to other monzogabbro intrusions within the Rossland Group. However, Fyles (1984, p. 19) describes fragmental textures with “subrounded blocks a few centimetres to as much as a metre across that are somewhat lighter in colour than the main mass of porphyry but essentially the same composition.” These fragmental textures are also noted in Gertrude drill core, as are thin layers of green, fine-grained, bedded and occasionally graded tuffs. Hence, it is probable that the Rossland sill is a composite volcanic-intrusive complex that includes sill and dike material as well as Elise augite-phyric flows with flow breccia textures and ash and crystal tuffs.

A number of dikes, described by Fyles (1984), cut the metasediments and the molybdenite breccia complex. Diorite porphyry dikes or ‘diorite porphyrites’ of Drysdale (1915) are closely related to gold-copper vein mineralization in the Rossland camp. In contrast to Tertiary dikes, these dikes trend westerly, parallel to the veins, and are clearly altered and mineralized. On the western slopes of Red Mountain, similar porphyry dikes and sills form “irregular masses several metres across or lenticular sill-like sheets up to a few metres thick lying parallel to bedding in the hornfelsed siltstone” (Fyles, 1984, p.26). This diorite porphyry is “thermally metamorphosed, fractured, bleached, and mineralized with pyrrhotite and molybdenite, (and) is older than the dikes related to the Trail granodiorite”. If these dikes are the same age as those that are related to copper-gold vein mineralization, then the copper-gold mineralization must be older than the molybdenite mineralization.

Large irregular masses of aphanitic to porphyritic intrusions, referred to as andesite or meta-andesite by Fyles (1984), occur as dikes or lenses in the vicinity of the molybdenite pits. They are early, cut by the north trending Eocene dikes and, as shown by Fyles (op. cit.), are also cut by the quartz diorite breccias which host the molybdenite mineralization. Their relationship to other intrusive rocks is not known; it is possible that they are Elise-age intrusions, phases of the Rossland sill, or perhaps related to the Rossland monzonite. Gilbert (1948) correlated them with the diorite porphyrites, but Fyles (op. cit.) concluded that “although this correlation is plausible, it is by no means certain”.

Photo 4-4b. View of Red Mountain mill site on the north side of Red Mountain; note ski runs on slopes of the mountain.
Lamprophyre dikes of Tertiary age generally trend northerly with steep to vertical dips. They are typically dark and fine grained with biotite crystals and abundant potassic feldspar. “Diorite” dikes form a north 20° west swarm that cuts the breccia complex in the D and E pits. They are also dark and fine grained, with small hornblende needles. Their northerly trend and post-molybdenite mineralization emplacement suggest that they are also of Tertiary age.

**MOLYBDENITE BRECCIA COMPLEX**

Fyles (1984, p. 47) described the breccia complex, shown on Figure 4-8, in considerable detail. “Much of the hornfels and hornfelsic siltstone on Red Mountain comprises a breccia with angular blocks ranging up to 30 metres. The attitude of bedding and colour laminations which reflects bedding show that smaller blocks, from a few centimetres to a few metres across, have random orientation (Photo 4-5). Larger blocks, however, are only slightly disoriented from the normal low westerly dip of the siltstone….the margins of the Breccia complex dip steeply and are very irregular. The base appears to be controlled by bedding…. Most of the molybdenite mineralization is within the Breccia complex.”

The matrix of the breccia consists of mainly fine-grained silicate minerals and rock fragments, with rare coarse-grained silicates, quartz, calcite, garnet, scheelite or molybdenite.

Within the breccia complex are irregular, generally east-trending intrusive breccia dikes, referred to above and by Fyles (1984) as ‘Red Mountain diorite dikes’. They comprise subrounded fragments of generally medium-grained, equigranular quartz diorite with clasts up to 0.5 metres in diameter. Locally, concentrations of molybdenite occur within the endoskarn in the quartz diorite breccia. Along the margins of the intrusive breccia, hornfels also occurs as breccia fragments, and in their central portions, non-brecciated quartz diorite may occur. Chloritic alteration is locally intense, producing a pale green colour, and many fragments have pronounced bleached reaction rims along their margins (Photo 4-6).

As noted above, U-Pb analyses of zircons from one of these brecciated dikes yielded a 162.3 +1.2/-2.5 Ma age.

**MINERALIZATION**

Extensive molybdenite mineralization is largely confined to the breccia complex. It is restricted to a depth of less than 200 metres; deeper drill holes discovered only minor disseminated molybdenite and scheelite.

Molybdenite is generally associated with the intense skarn alteration. Mineralization is present as coarse molybdenite, with variable but generally minor pyrrhotite, arsenopyrite, pyrite, and locally minor chalcopyrite, bismuth, bismuthinite and variable amounts of scheelite. The molybdenite occurs in the skarn matrix or in sulphide veins cutting skarn.

**Coxey (082FSWE110)**

Most production from Red Mountain came from the Upper A, A, Upper B and B pits on the Coxey claim near the center of the breccia complex. Skarn alteration increases towards the upper, more eastern exposures (Webster et al., 1992). Brecciation, biotite hornfelsing and prograde, mainly diopside ± garnet skarn alteration are intense (Photos 4-7a and 7b). The garnets are grossularite-andradite solid solutions and ‘diopside’, hedenbergite-diopside solid solutions (Ray and Webster, 1997). Late veins with coarse-grained dark chlorite, calcite and epidote cut the breccia-skarn. Molybdenite, pyrrhotite, arsenopyrite and pyrite, with minor scheelite and magnetite, occur in the skarn as well as in the later veins, commonly with chalcopyrite.

**Mountain View (082FSW140)**

The Mountain View claim is located upslope and northeast of the Coxey. Production was limited to two pits on the property, the E and the F pits (Photo 4-8). Recovered grades of 0.10% tungsten from these pits was the highest mined on Red Mountain.

Detailed petrographic studies show that the skarn in the Mountain View E pit (sample R96-12c, Appendix 5) com-
prises mainly granular quartz, K-feldspar, clinopyroxene (diopside) and garnet, cut by diopside-molybdenite veins. Molybdenite also occurs in veins with calcite, wollastonite(?) and minor ilmenite, locally altered to a sphene, rutile and pyrite assemblage. A second sample (R96-12a) is dominantly massive garnet intergrown with diopside that is partially replaced by tremolite. Late veinlets contain quartz, calcite, pyrrhotite and chalcopyrite. In the F pit, a thin pyrrhotite-pyrite-chalcopyrite vein cuts the “diopside” skarn. Wallrock to the vein (R96-19b) contains biotite, replaced by amphibole and epidote, and pyrite ± chalcopyrite locally rimmed by pyrrhotite and magnetite. Other gangue minerals include quartz and carbonate (ankerite or siderite).

Analyses of a number of samples from the pits on the Mountain View claim indicate unusually high concentrations of a number of elements (Appendix 6). One sample (R96-12a) contains 3800 ppm uranium, and a second sample (R96-12c) high lanthanum (1800 ppm), cerium (1100 ppm) and neodymium (150 ppm). Tungsten and copper values are also high, but gold is generally less than a few hundred ppb.

Nevada

The Nevada claim is the most western of the molybdenite-producing claims on Red Mountain. In the D pit, a number of late, north-trending dark, fine-grained Tertiary dikes cut pale green diopside skarn. Skarn alteration is less intense than in the Coxey pits to the east, and includes abundant biotite hornfels and diopside, but only minor garnet. Molybdenite, with only minor pyrrhotite, occurs in the skarn and in thin fractures cutting the skarn. One sample of mineralized skarn (R96-15, Appendix 6) contained 2.5% Mo and 3300 ppm barium, but low copper and gold values. A second sample from the B pit contained 4600 ppm Ba (Appendix 6, sample R96-7a).

Novelty (082FSW107)

The Novelty claim is located due south of the Coxey. It has a small exploration pit, and most recently was explored by nine diamond drill holes (Richardson, 1982). The best mineralized intersections are listed in Table 4-3.

Mineralization and chemistry of the Novelty are unusual. It is mainly a molybdenite-arsenopyrite-pyrrhotite skarn with low copper content. The skarn comprises mainly plagioclase (andesine?) and diopside with sulphides, and minor sphene, calcite, sercite, biotite and apatite. Nickel content is high (Appendix 6), as is cobalt which produces cobalt bloom (erythrite) on fracture surfaces. Bismuth and bismuthinite are also abundant; Thorpe (1967, p. 26) reported that “an isolated area of bismuth was observed to include a number of small crystals of molybdenite”.

Gold content, generally low throughout the molybdenite breccia complex, is high in the Novelty pit. One analysis of a skarn sample contained 114 ppm gold and a second, 43.3 ppm (samples R96-7a, R96-7b; Appendix 6). Thorpe (1967) described blebs of gold disseminated in siliceous skarn adjacent to veins and patches of arsenopyrite and molybdenite.

Giant (082FSW109)

The Giant is the most southern of the claims within the breccia complex. Production from the Giant property is included in that of the California claim (Appendix 3); 3 900 tonnes are reported to have been shipped from the Giant prior to operations being suspended in 1903 (Drysdale, 1915). In 1966, 17 drill holes indicated an open pit reserve of 50 000 tonnes containing 0.282% MoS2 and 1.16 g/t gold. In 1971, indicated reserves for the Novelty and Giant were 706 177 tonnes containing 0.2% MoS2 and 1.9 g/t gold (David Minerals Ltd., Statement of Material Facts, Dec 23, 1980).

Considerable trenching and stripping on the Giant claim have exposed a number of highly altered intrusive and metasedimentary rocks, alteration and sulphides. In general, exposures in the stripped area are silicified, skarned and brecciated, and contain disseminated pyrite or pyrrhotite which results in brown to tan coloured outcrops. Exposed rocks include an irregular mass of a granular,
leucocratic, rusty-weathering pyritic intrusion, as well as north-trending lamprophyre and other mafic dikes. Diopsidic skarn alteration in the metasediments appears to be overprinted by sericitic alteration with associated dispersed pyrite. Hence, the original distribution of the skarn alteration may have been considerably larger.

Several styles of mineralization occur on the property: (1) a narrow north-striking, east-dipping vein with cobalt, nickel, arsenic, bismuth, and molybdenum values, (2) an east-west striking pyrrhotite-chalcopyrite vein that is similar to the gold-copper veins of the Rossland camp, and (3) molybdenite, pyrrhotite, bismuth, bismuthinite and minor chalcopyrite in the breccia-skarn complex. All appear to have elevated gold content.

The north-striking vein has gradational boundaries and parallels a fine-grained syenitic dike. Mineralization comprises mainly pyrrhotite with locally abundant native bismuth, bismuthinite, arsenopyrite, pyrite and some molybdenite and chalcopyrite. Native gold occurs dispersed in the sulphides. Analyses of selected hand samples of the vein and immediate skarn hostrocks returned high gold content (5 to 17 ppm), arsenic, nickel, cobalt (4100 to 6000 ppm) and selenium (R96-62a,b,c; Appendix 6).

An east-west trending pyrrhotite vein with minor chalcopyrite cuts silicified sediments. An analysis (R96-61b) returned 0.1% copper and 10.5 ppm gold.

Hornfelsed metasediments, and locally diopside skarn alteration of a metasedimentary breccia, contain irregular masses and veins of molybdenite and pyrrhotite with concentrations of bismuth and bismuthinite locally. Pyrrhotite, pyrite, arsenopyrite and minor chalcopyrite(?) also occur dispersed throughout the metasediments. Analysis of the skarn (R96-62d, Appendix 6) also shows that it contains, at least locally, high gold and copper values as well as anomalous nickel, cobalt, uranium, selenium, cerium, neodymium and samarium.

### Re-OS DATING

A sample of molybdenite from the B pit on the Coxey claim was analyzed at AIRIE, Colorado State University, to obtain a Re-Os date. An age of 162.9±0.5 Ma was determined (see Appendix 7 for data). A similar age for the host intrusive breccia in the A pit is independent supportive evidence for the age of molybdenite mineralization on Red Mountain.

### SUMMARY

Molybdenite and scheelite occur within a skarn-intrusive breccia complex on the western slopes of Red Mountain west of and structurally above the gold-copper veins of the Rossland camp. The breccia complex is largely developed in fine-grained metasedimentary rocks of the Elise Formation, but is also intimately associated with quartz diorite breccia dikes.

Molybdenite and minor scheelite mineralization in the complex appears to be associated with prograde K-Mg-Ca metasomatism that produced diopside, garnet, K-feldspar, calcic plagioclase, variable but generally minor quartz as well as other skarn minerals. It overprints an earlier biotite hornfels and is cut by late, epidote-amphibole veins that also contain pyrrhotite, pyrite, chalcopyrite and rare molybdenite.

Molybdenite mineralization is associated with a variety of other elements that may have a crude camp zonation. In eastern exposures, garnet is abundant and disseminated sulphides are prominent producing rusted outcrops. The molybdenite occurs with locally high concentrations of scheelite (tungsten) and anomalous rusted uranium, lanthanum, cerium and neodymium. Gold and copper contents are low, except in rare crosscutting pyrrhotite-chalcopyrite veins. In southern exposures on the Novelty and Giant claims, gold content is high, and mineralization comprises molybdenite and arsenopyrite with high nickel, cobalt, bismuth, barium and selenium values. Within the central part of the complex, in the eastern pits of the Coxey claim, molybdenite and ar-
Senopyrite with only minor scheelite and low copper-gold values, predominate. The most western and structurally highest exposures consist of brecciated endoskarns with molybdenite and locally high barium values.

**DISCUSSION**

The age of the molybdenite mineralization is 162.9±0.9 Ma, based on Re-Os dating. However, its relationship to intrusive events or to the gold-copper veins of the Rossland camp is less certain. The close spatial association of molybdenite mineralization with the Red Mountain quartz diorite dikes, incorporation of dike fragments in the breccia complex, and a ca. 162 Ma U-Pb zircon age (Figure 4-7), indicate that the molybdenite is related to the dikes. It has generally been assumed that this mineralization is associated with the ca. 166 Ma Rainy Day quartz diorite (Figure 4-6), an intrusion exposed less than a kilometre to the south that contains minor molybdenite mineralization (Fyles, 1984).

Based on similar chemistry and mineralogy with the Rainy Day pluton, and a slightly younger age than this pluton and the Rossland pluton, we suggest that the Red Mountain dikes are a late phase of these plutons, a phase that was associated with explosive volatiles that brecciated, altered and mineralized host Elise metasediments.

“Andesite” intrusions in the skarn complex are early, as they are overprinted by both skarn alteration and molybdenite mineralization. However, they are not brecciated and it is not known if they are cogenetic with the Red Mountain dikes in the breccia complex. Fyles (1984, Figure 5) shows them cut by these dikes, supporting an older age.

As discussed below, copper-gold veins of the Rossland camp are spatially and genetically related to the ca. 167 Ma Rossland monzonite and associated diorite porphyry dikes. Similar porphyry dikes within the breccia complex (distinct from the Red Mountain dikes) are overprinted by skarn alteration and molybdenite mineralization. This supports a model of early Cu-Au vein mineralization followed by brecciation, skarn alteration and molybdenite mineralization associated with 162-163 Ma quartz diorite dike emplacement.

However, thin pyrrhotite-chalcopyrite veins, the western extension of the veins of the North belt in the Rossland camp, appear to cut skarn alteration (but not breccia) related to molybdenite mineralization in the F pit on the Mountain View claim. This implies that molybdenite mineralization is older than the veins. It is probable, however, that these thin veins formed earlier and were unaffected by later skarn alteration.

In summary, we conclude that there are several periods of intrusive activity, and two main periods of sulphide mineralization and alteration in the Red Mountain camp area:

- **ca. 195-197 Ma**: deposition of Elise Formation, followed by intrusion of Rossland sill.
- **early “andesite” dike emplacement.**

**REGIONAL IMPLICATIONS**

Molybdenum occurrences, such as the Stewart and Mammoth within the Nelson-Trail map-area are generally associated with Middle Jurassic Nelson-age intrusions, occurring as molybdenite skarns or porphyries, and associated with tungsten mineralization and breccia complexes (see Chapter 3). We conclude that molybdenite mineralization, brecciation and skarn alteration on Red Mountain is similar, related to late dike phases of the Middle Jurassic Rainy Day quartz diorite.

**ROSSLAND COPPER-GOLD VEINS**

**INTRODUCTION**

Copper-gold veins in the Rossland camp were divided by Drysdale (1915) into three main belts, referred to as the North belt, Main veins and South belt (see Figure 4-8). Production from the Rossland veins, mainly between 1897 and the early 1940s, are summarized in Appendix 3. In total, 85 904 623 grams of gold (~2.76 million ounces), 109 509 814 grams of silver (~3.52 million ounces) and 71 502 kilograms of copper were recovered from the mines of the Rossland camp. Of that, 98 percent came from the Main veins, and 80 percent of this production came from deposits in a central core zone between two large north-trending Tertiary lamprophyre dikes. Deposits in this central zone include the Le Roi, Centre Star, Nickel Plate, Josie and War Eagle mines (Photo 4-9).

Thorpe (1967) first described a clearly defined mineralogical and chemical zonation, also shown on Figure 4-8. A
‘central’ zone located along the western edge of the Rossland monzonite and into the Rossland sill is dominated by massive pyrrhotite with persistent but minor chalcopyrite; an ‘intermediate’ zone, peripheral to the central zone has veins that contain arsenopyrite, pyrite, cobalt, bismuth minerals and molybdenite in addition to pyrrhotite and chalcopyrite. The ‘outer’ zone south of the Rossland monzonite is marked by veins that contain galena and tetrahedrite.

Veins of the North belt are entirely within the ‘intermediate’ zone whereas Main veins extend westward from the ‘intermediate’ zone into the ‘central’ zone. Most veins of the South belt are within the ‘outer’ zone.

The purpose of the following sections is to describe the intrusive-related gold-sulphide veins, attempt to relate these to the structurally higher molybdenite skarn-breccia complex described above, and to develop a model that integrates these with the lead-zinc-silver veins of the South belt and the structural and magmatic history of the area.

**NORTH BELT**

The North belt comprises a zone of discontinuous veins that extend west from Monte Cristo Mountain to the northern ridge of Red Mountain. The veins trend east and dip north at 60° to 70°. Veins in the North belt are mainly pyrrhotite with chalcopyrite in a gangue of altered rock with minor lenses of quartz and calcite. The largest, on the Cliff and Consolidated St. Elmo claims, are exposed for almost 100 metres along strike. However, more eastern exposures of the vein system (Monte Cristo, Evening Star, Cliff) contain considerable arsenopyrite and, locally, trace molybdenite, scheelite and cobalt minerals whereas farther west (St. Elmo, Consolidated St. Elmo) sphalerite and galena are common.

**EVENING STAR (82FSW102)**

Introduction

The Evening Star vein is mainly within metasediments of the Elise Formation along the north edge of the Rossland monzonite. It was in production intermittently from 1896-1908 and 1932-1939, with recovery of 56.7 kilograms of gold, 21.5 kilograms of silver and 1,276 kilograms of copper from 2,859 tonnes of ore, representing a recovered gold grade of approximately 20 g/tone. This production was mainly from a wide and irregular northeast-striking vein of arsenopyrite, pyrrhotite, pyrite and chalcopyrite (Drysdale, 1915). The veins have a high cobalt content with danaite, a cobaltiferous arsenopyrite, and samples of pyrrhotite containing 1.58% cobalt and 0.67% nickel oxide (Drysdale, op. cit.).

Cominco Ltd. optioned the Evening Star claim in 1980 and explored its potential as a low-grade gold stockwork deposit. However, the option was dropped after discouraging results in seven percussion drill holes. In the early 1980s, Gallant Gold Mines optioned the Georgia property, which included a number of the eastern extensions of veins of both the North belt and Main veins and did considerable prospecting, mapping, rock-chip sampling and some geophysical surveying (Troup et al., 1984), and in 1986, conducted some diamond drilling (Hardy, 1986). Exploration in the late 1980s by Antelope Resources included geological mapping, rock geochemical sampling, electromagnetic geophysical surveys, as well as underground rehabilitation and considerable underground drilling (Fowler and Wehrle, 1990). The drilling intersected both thin, irregular veins and zones of mineralized and altered country rocks. The best intersection, in diamond-drill hole 88-37, contained 35.7 g/t gold over 4.4 metres.

In 1990-1991, Vangold Resources continued exploration, with geophysical surveys and some limited drilling, resulting in reported reserves in the “main zone” of 20,000 tonnes grading 17 g/t gold (Wehrle, 1995). Hole NB-91-11, located approximately 125 metres southwest of the main zone (Figure 4-9), intersected 3.1 metres grading 27 g/t gold. Additional drilling in 1994 concentrated on this extension of the main zone. Hole NB-94-5 intersected 1.5 metres grading 12 g/t gold “in a strongly altered volcanogenic sediment containing a 25% mixture of pyrrhotite, pyrite, arsenopyrite and chalcopyrite” (Wehrle, 1995, p.7), and NB-94-6, approximately 3 metres grading 14 g/t gold. A vertical hole, NB-94-7, drilled to test the down dip extension intersected 4.6 metres grading 5 g/t Au at 72.3 metres depth.

**Description**

The vein system consists of irregular, discontinuous veins within altered Elise metasediments and underlying Rossland monzonite. Veins in the Rossland monzonite are generally not as rich nor have the pronounced alteration envelopes as those in the metasediments (Figure 4-10). The veins are parallel to and within numerous diorite porphyry dikes that extend, at depth, into the main mass of the Rossland monzonite. As with other veins in the Rossland camp, their strong structural control is indicated by the prominent regional as well as local preferred orientations, and the prominent shearing both within and along the margins of some of the vein (Photo 4-10). This structural control is also apparent in the parallel orientation of some Rossland monzonite dikes. Late, north-trending, steeply dipping feldspar porphyry dikes, of probable Eocene age, cut the veins,
Figure 4-9. Diamond drill location plan, and simplified geology map of the Evening Star and Georgia claim area, North Belt, Rossland camp (from Wehrle, 1995).
Figure 4-10. Vertical section through the Evening Star deposit, viewed to the northeast (see figures 4-2 and 4-9 for location); section and data from unpublished data, D. Wehrle, Vangold Resources, Inc.
associated alteration and the Rossland monzonite (Figures 4-9, 4-10).

The mineralogy of the Evening Star veins consists of mainly pyrrhotite and arsenopyrite. Chalcopyrite is intimately intergrown with pyrrhotite or occurs as finely dispersed grains. Pyrite, typically after pyrrhotite, and minor sphalerite, molybdenite and magnetite, and trace danaite, bismuthinite and erythrite (cobalt bloom), have been identified (Thorpe, 1967). Gangue minerals in the veins include calcite, a dark green amphibole (termed hornblende, below), chlorite, quartz, fine-grained biotite and minor epidote.

Alteration assemblages are zoned, with more proximal skarn alteration and distal biotite hornfelsing. The distribution of these assemblages, based mainly on examination of specimens from an ore stockpile, is illustrated schematically in Figure 4-11. Sulphides form massive to semi-massive elongate pods and lenses within a medium to dark green skarn assemblage of mainly hornblende, chlorite, epidote, diopside, garnet and plagioclase. An envelope of siliceous, biotitic hornfels, commonly cut by thin hornblende-sulphide veins, surrounds the skarn assemblage (Photo 4-11). The siliceous zone extends out into biotite ± epidote hornfels; thin sulphide veins as well as some disseminated sulphides and locally, low gold grades persist in this zone (Figure 4-10). The distal, biotite hornfels grades laterally into regional, propylitically altered metasediments. Thin quartz-calcite-pyrite veins cut all other assemblages. This mineralogical zonation is reflected in a local chemical zonation as well, with proximal sulphide-Fe-Mg rich assemblages and distal potassic alteration.

A general gradation of skarn mineral assemblages away from the Rossland monzonite has been noted by Stinson and Patterson (1993, p. 250):

“Pockets of garnetiferous skarn, the highest metamorphic grade observed, occur locally in the ore zone within 10 metres of the igneous contact. These exhibit a coarse-grained skarn assemblage of andraditic garnet, diopside and plagioclase, which in turn is overprinted by hornblende along growth zones in garnet, and by quartz, calcite and zeolites. Minor arsenopyrite and pyrite are disseminated in this rock, and chalcopyrite and pyrrhotite are mainly confined to late quartz-carbonate veins.”

“Farther out from the monzonite contact (20 to 40 m) pockets of lower grade skarn are found within the hydrothermally altered country rock. The skarn consists of diopside and plagioclase, overprinted by actinolite and later epidote and chlorite. Minor minerals present include sphene, apatite, sericite and tourmaline. These assemblages are cut by carbonate and quartz-carbonate veins. In the ore zone, arsenopyrite, pyrrhotite, chalcopyrite and other opaque minerals are disseminated in highly variable amounts.”

“Still farther out from the monzonite (40+ m) the volcanics are dominantly fine grained and strongly silicified. These are cut by veins of diopside, wollastonite and/or actinolitic amphibole, 0.5 to 5 millimeter wide, which are partly replaced by calcite. Some actinolite veins contain ar-

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Photo 4-11. Vein and alteration, Evening Star deposit. Dark biotite hornfels is cut by diopside-hornblende-epidote-chlorite-sulphide vein with bleached envelopes; late calcite-pyrite veins cut skarn (see text and Figure 4-11 for details).
senopyrite along their margins, suggesting it might have been formed at these same time as the actinolite alteration. Pyrrhotite is present in the veins as a replacement of arsenopyrite and actinolite."

"These assemblages are crudely arranged outward from the Rossland monzonite, in a similar fashion to skarn zones in the Hedley district as described by Ray et al. (1987). This marked spatial association with the monzonite provides evidence in favour of it being the source of heat and possibly mineralizing fluids for the Evening Star deposit."

Stinson and Patterson (1993) noted two main stages of sulphide mineralization. Early pyrite, arsenopyrite and gold (± bismuth) are followed by chalcopyrite and pyrrhotite. This correlation of gold with arsenopyrite contrasts with the conclusion by Thorpe (1967) that most of the gold occurs in solid solution with chalcopyrite. Stinson and Patterson (op. cit.) also noted late replacement of sulphides by magnetite, and minor hematite and marcasite alteration.

In summary, a simplistic sulphide-alteration paragenesis includes early siliceous biotite hornfelsing, overprinted by intense prograde skarn alteration, followed by retrograde skarn and massive sulphide veining, and finally late pyrite-calcite veining.

### Fluid Inclusion Data

Detailed fluid inclusion data and discussion are presented in Appendices 9a and 9b. Primary fluid inclusions in growth zones in quartz from a quartz-pyrite-calcite vein include aqueous (H₂O-NaCl) Type I, carbonic (CO₂-trace CH₄/N₂) Type V and mixed aqueous and carbonic (H₂O-CO₂-NaCl) Type IV. Homogenization temperatures from Types I and IV fluid inclusions are moderately high from 307°C to 370°C and salinities low to moderate, from 5.5 to 18.5 eq. wt. % NaCl. Estimated trapping pressures for two Type IV inclusion assemblages are 1529 and 2273 bars, corresponding to trapping depths of between about 5.7 and 8.6 km lithostatic load.

### MONTE CRISTO (082FSW101)

The Monte Cristo claim group is located just west of the Evening Star claims (Figure 4-2, in pocket). Production from Monte Cristo is not tabulated in Appendix 3 as ore from this vein, and from a number of others in the Rossland camp, were included in the production of the Centre Star-War Eagle mines.

In contrast to the Evening Star veins, the Monte Cristo veins strike west-northwesterly and are mainly within the Rossland monzonite. Locally, the host monzonite is altered to an endoskarn with an amphibole-quartz-biotite ± pyroxene(?) assemblage. The margins of the vein are generally sheared, and late calcite veinlets extend into the country rock.

The Monte Cristo vein is mainly massive pyrrhotite with less chalcopyrite and magnetite in a dark green gangue. A “10-inch streak of arsenopyrite” was noted by Drysdale (1915). Chalcopyrite occurs intergrown with pyrrhotite, in calcite (± quartz-chlorite) stringers and disseminated in the gangue. Pyrite occurs in late veinlets with chloride and carbonate.

Analyses of a hand sample of massive sulphide (R96-46A; Appendix 6) returned 844 ppb Au, <5 ppm Ag and approximately 10% Cu. Mo (419 ppm) and Zn (134 ppm) values were low, but Co (982 ppm) was relatively abundant. Drysdale (op. cit.) also reported that the gold content of the massive sulphide vein was low, although one crosscutting (?) vein assayed 27 g/t Au. (p. 109). Drysdale also noted that analyses of pyrrhotite from Monte Cristo returned 0.13% NiO and trace Co.

Vein gangue mineralogy consists of mainly sericitized albitic (?) plagioclase (An 0-5?) and pale green mica (Appendix 5). The plagioclase appears to be secondary, forming small subhedral crystals. These grains are typically pervasively altered to sericite and, closer to their margins, green phengitic (Fe-rich) sericite. This green mica also appears to pseudomorph former amphibole(?) crystals. Amphibole also occurs as needle-like laths adjacent to pyrrhotite, associated with quartz and tourmaline. Clear feldspar grains may be K-feldspar (2-3%).

In general, wall-rock alteration of the Monte Cristo veins is not as pervasive as at Evening Star, probably reflecting the intrusive host.

### CLIFF (082FSW136)

The Cliff vein is mainly within the Rossland sill west of Monte Cristo. Total reported production from the Cliff includes that of the Consolidated St. Elmo to the west: 14 868 grams of gold, 99 530 grams of silver and 24 195 kg of copper from 1 915 tonnes of milled ore (Appendix 3), resulting in a recoverable grade of 7.8 g/t Au. This grade is comparable to the average analysis of 1 236 tonnes shipped in 1904 (Drysdale, 1915), and analysis of a selected hand sample of the vein reported in Appendix 6 (R96-48A: 6.2 ppm Au).

The Cliff-Consolidated St. Elmo vein strikes east-west and dips 60°-70° north. It is well exposed at a portal on the east side of the Cliff claim where it occurs as a massive chalcopyrite-pyrrhotite vein approximately 2 metres thick within biotite hornfelsed Rossland(?) sill. The exposed footwall contact is sheared and sharp; only minor disseminated pyrrhotite occurs in the footwall, with minor late fractures, some bleaching but no obvious skarn alteration. The hangingwall contact is also sheared, and the hangingwall host is rusty weathering and bleached with chlorite, hornblende and pyrrhotite alteration.

A polished section of the massive sulphide from this exposure (R96-48a, Appendix 5) indicates that the host is mainly coarsely crystalline clinopyroxene, partly retrograded to actinolite, and is cut by fine fractures filled with limonite. Fine sulphide fractures cutting the pyroxene also contain amphibole, suggesting sulphide mineralization is related to late retrograde alteration rather than the prograde clinopyroxene (?) diopsidic skarn alteration.

Chalcopyrite in this sample occurs with quartz and minor chlorite in veinlets. It also occurs as massive concentrations intimately intergrown with pyrrhotite. Thorpe (1967) also reported the occurrence of native bismuth veins in ar-
senopyrite and pyrrhotite, as well as minor magnetite and trace scheelite.

In summary, a paragenetic sequence involves early prograde skarn alteration, followed by retrograde alteration to amphibole, accompanied by sulphide-quartz ± chlorite veining. Pyrrhotite and possibly chalcopyrite and arsenopyrite appear to be earlier formed sulphides, followed by native bismuth, then pyrite. This sequence is generally similar to that described at the Evening Star vein.

**CONSOLIDATED ST. ELMO (082FSW135)**

The Consolidated St. Elmo is the western extension of the Cliff vein. It also strikes westerly, dips at steep angles to the north and is mainly within the Rossland sill. Production from the Consolidated St. Elmo is included in the data for the Cliff deposit (Appendix 3).

The Consolidated St. Elmo vein contrasts in many features from the structurally lower Cliff vein. Vein samples on a dump at the Consolidated St. Elmo suggest that this portion of the North vein contains more quartz than the Cliff, and skarn alteration is less prominent and more closely confined to gangue within the vein. Arsenopyrite was not observed, but has been reported by Thorpe (1967). Pyrite and sphalerite are common, and minor scheelite is reflected in high tungsten values (see Appendix 6).

The silver content and silver/gold ratio of the Consolidated St. Elmo is also higher than the more eastern, structurally lower veins, with pyrargyrite, a ruby silver, identified by Thorpe (op. cit.).

A polished section of a semi-massive sulphide sample (R96-51c; Appendix 5) indicates that the skarn gangue is mainly fine-grained calcic plagioclase with coarser clinopyroxene (probably diopside), minor sphene, minor K-feldspar, possible garnet, and sulphides. Quartz veins, with epidote, zoisite and clinozoisite, and along the vein margins, sulphides associated with biotite, Fe-rich chlorite, diopside and garnet, cut the skarn. Pyrrhotite is the dominant sulphide, with intergrown chalcopyrite, and magnetite along the margins.

Late alteration includes rare actinolite after pyroxene, pyrargyrite (after tetrahedrite; Thorpe, 1967) and local replacement of pyrrhotite to pyrite. Other samples, however, show intimate intergrowth of pyrite and sphalerite.

The mineralogy and less developed skarn alteration support a model of the North veins developing at higher structural levels in the west. Paragenesis indicates early prograde diopsidic skarn development, followed by pyrrhotite, chalcopyrite and magnetite-epidote-chlorite-quartz veining. Although minor pyrite appears to form after pyrrhotite, massive pyrite intergrown with sphalerite, may be early.

**Fluid Inclusion Data**

Fluid inclusions were evaluated in two quartz-sulphide veins with ‘milled’ or finely brecciated textures, that cut the skarn (Appendix 9b). The abundance of fluid inclusion-filled fractures and small size of the inclusions resemble a quartz texture termed ‘wispy’. The fluid inclusions are characterized by aqueous (H2O-NaCl) Type I, mixed aqueous and carbonic (H2O-CO2-NaCl) Type IV, carbonic (CO2-tr CH4/N2) Type V, multiphase (H2O-NaCl-unknown phases) Type VI and mixed carbonic and multiphase (H2O-CO2-NaCl-unknown phases) Type VII. There is no evidence of sylvite, halite or other readily soluble phases since dissolution of daughter minerals was not observed on heating to decrepitation temperatures (300°C to 327°C).

Homogenization temperatures from Types I and VI fluid inclusions are unusually low, from 102°C to 194°C (Tables A9-3a and A93e; Appendix 9a), and salinities of Type I and IV inclusions are low to moderate, from 6.4 to 20 eq. wt. %NaCl (Table 5). Sample R96-51a probably formed at depths > 10 km lithostatic load given a 150°C ‘pressure correction’.

**ST. ELMO (082FSW134)**

The St. Elmo vein, within Elise Formation metasediments adjoins the Consolidated St. Elmo to the west. It comprises mainly pyrite, pyrrhotite, sphalerite and minor chalcopyrite. In 1908, 70 tonnes of ore were shipped to the Trail smelter, with recoverable grades of 98 g/t silver, 1.3 g/t gold and 2.06% copper. Drysdale (1915) reported that an adit driven along the vein had some molybdenite, sphalerite and galena in the walls. It is not clear if this mineralization was within the veins or, more likely, within the vein host-rocks. Reported molybdenite reserves on the St. Elmo claim are 59 052 tonnes containing 0.28% MoS2 (see BC MINFILE).

**MOUNTAIN VIEW (082FSW140)**

Although the Mountain View claim is considered to be mainly a molybdenite prospect related to other molybdenite occurrences on Red Mountain, it was originally staked to cover the most western extension of the North belt Consolidated St. Elmo-Cliff vein system. As such, it is important as it provides details regarding possible relationships between the molybdenite mineralization and the copper-gold veins.

Drysdale (1915, p. 135) described an east-west striking, 10 metre thick and 60 metre long vein "which averaged $25 to the ton in gold" (approx. 28g/t). A thin pyrrhotite-pyrite ± chalcopyrite(?) vein, trending 080° and dipping 85°N, is visible on the east wall of the Mountain View E pit. This vein cuts hornfelsing and skarn related to the molybdenite breccia complex, suggesting that they formed later than the molybdenite (Fyles, 1970). However, as noted above, we argue that molybdenite mineralization is younger than the vein and that alteration associated with molybdenite mineralization may selectively replace only reactive host rocks and not the earlier sulphide vein; brecciation does not extend to this area.

**JUMBO (082FSW111)**

The Jumbo mine is located on the west side of Jumbo Creek, 3.2 kilometres northwest of Rossland. It is unusual as
it occurs west of the molybdenite breccia complex, considerably separated from other veins of the North belt.

Drysdale (1915) described the vein as ranging up to 10 metres in width and consisting mainly of pyrrhotite, with minor chalcopyrite and trace pyrite, bismuthinite, sylvanite, molybdenite, arsenopyrite and free gold. Dark green gangue, described by C. Leitch (sample R96-28a; Appendix 5), is mainly granular clinopyroxene (diopside?) and quartz with minor sulphides and trace zoisite. The vein is within tan to pale grey, fine-grained rusted metasediments of the upper part of the Elise Formation. Pervasive skarn alteration, typical of exposures to the east, is not evident in surface exposures.

Drysdale (1915) also noted the “close association” of mineralization, particularly the high gold content, with syenite dikes that cut across the veins. The dikes “of aplite or syenite are intrusive into the vein at low angles and are themselves mineralized …. fine-grained syenite or aplite dykes are closely connected with the rich pay streaks and such dykes are in places impregnated with or have seams of sulphides”.

Figure 4-12. A vertical model showing the distribution, tenor and alteration assemblages of veins in the Rossland Au-Cu camp.
Fluid Inclusion Data

The fluid inclusions in quartz gangue from a massive sulphide vein comprise aqueous (H2O-NaCl) Type I, carbonic (CO2-trace CH4-N2) Type II, mixed aqueous and carbonic (H2O-CO2-NaCl) Type III, multiphase (H2O-NaCl-unknown phases) Type VI and mixed carbonic and multiphase (H2O-CO2-NaCl - unknown phases) Type VII phases (Appendix 9).

Primary fluid inclusion homogenization temperatures for multiphase Type VI inclusions range from 145°C to 267°C. Fluid inclusion assemblage 5-1 exhibited homogenization to the vapour phase at 210°C; all other observed homogenization temperatures were to the liquid phase. Secondary fluid inclusion homogenization temperatures for Type I and VI inclusions are moderate and range from 183°C to 231.5°C (Tables A9-3a, 3e; Appendix 9a). Salinities of aqueous fluid inclusions from the same assemblage low at 5.2 eq. wt. % NaCl.

DISCUSSION: NORTH BELT

A simplistic model for the North belt veins is shown in Figure 4-12. The veins trend westward. The Evening Star veins cut Elise metasediments and the northeastern fringe of the Rossland monzonite. The Monte Cristo veins cut the Rossland monzonite, the Cliff and Consolidated St. Elmo are in the Rossland sill, the St. Elmo is in overlying Elise metasediments, and the most western, Mountain View, cuts the fringes of the alteration halo around the molybdenite breccia complex near the summit of Red Mountain.

A number of features indicate that eastern portions of the North belt veins developed at deeper structural levels. Evening Star veins have more diffuse margins and locally well developed and extensive skarn in the hostrocks. Skarn involves early biotite hornfelsing, followed by prograde diopsidic skarn, then sulphide-quartz-calcite veining associated with retrograde hornblende (? actinolite), chlorite and epidote. To the west, intensity and amount of skarn alteration decrease, due only in part to less reactive host rocks. Diopsidic skarn assemblages are essentially restricted to the immediate vein at the Monte Cristo, Cliff and Consolidated St. Elmo, and in these deposits the vein boundaries are typically sharp and locally sheared, with alteration of the host rocks limited to bleaching, minor biotite hornfelsing and minor disseminated pyrrhotite. Farther west, St. Elmo and Mountain View veins also have discrete, sharp boundaries. However, the Mountain View vein and, to a lesser extent, the St. Elmo vein, is in skarn alteration related to the molybdenite breccia complex.

The mineralogy and tenor of the North belt vein system also changes progressively to the west. Massive pyrrhotite, arsenopyrite and chalcopyrite, dominant in the east (Evening Star and Monte Cristo), give way to the west to mainly pyrrhotite, pyrite, chalcopyrite and sphalerite (Consolidated St. Elmo), pyrite, pyrrhotite and sphalerite with only minor chalcopyrite (St. Elmo) and finally mainly pyrite and pyrrhotite at the Mountain View. As well, the eastern veins contain high cobalt and nickel; these and the intermediate veins contain bismuth, and western veins have increasing silver content and silver/gold ratios. Molybdenite in host rocks of the western veins and possibly scheelite, reported at Cliff, may not be related to Rossland vein mineralization, but rather is probably associated with the molybdenite breccia complex to the west. Gold content is highest in the eastern part of the vein system, and appears to generally decrease to the west. Copper content is highest in the central part where the veins cross the Rossland sill, somewhat less in the structurally deeper Evening Star vein, and least in most western exposures. These values are also reflected in the zonation of Au/Cu ratios, illustrated in Figure 4-14, which show a general decrease towards the northern lobe of the Rossland monzonite.

However, the Jumbo deposit farther west has mineralogy more typical of the more eastern North belt veins and the Main veins. It is possible that this is due to its deeper structural level, in the valley of Jumbo Creek, or that it may be related to a separate body of Rossland monzonite, exposed just over a hundred metres to the north (Figure 4-2).

As discussed below, the Rossland veins were developed prior to westward tilting of the area in Eocene time. Hence, the Rossland veins, including those of the North belt, allow a view through a vein system that illustrates deeper structural levels in eastern exposures and more shallow exposures farther west.

MAIN VEINS

The Main veins extend west-southwest from the eastern slopes of Columbia-Kootenay Mountain to the southern slopes of Red Mountain (Figure 4-8). These veins are described by Drysdale (1915), Gilbert (1948), Thorpe (1967) and Fyles (1984) and this summary is based in part on these previous reports.

The veins are dominantly massive pyrrhotite and chalcopyrite with minor molybdenite in the War Eagle (Thorpe, 1967) and Centre Star (Drysdale, 1915). Gangue content is minor, mainly calcite and quartz.

The veins parallel well-defined fractures that trend 060° to 070° (Centre Star - Le Roi) and 120° (War Eagle) and generally dip steeply (60° to 80°) to the north. Other less pronounced mineralized fractures trend approximately east-west and also dip to the north. The veins are in Rossland monzonite in the east and continue westward into augite porphyry of the Rossland sill. Farther west in Elise metasediments, the veins are more diffuse and less well developed.

Many of the veins follow the margins or are within diorite porphyry dikes that extend westward from the Rossland monzonite into the Rossland sill. The dikes are altered and mineralized, as well as locally sheared. Elsewhere, and commonly along strike or down dip, veins are along the margins of the Rossland monzonite and in shear zones in the monzonite or the Rossland sill.

The veins are commonly truncated by north-trending structures, including two large lamprophyre dikes of Tertiary age, referred to as the Josie and the Nickel Plate dikes. Gilbert (1948, p.193) concluded that the ore was post-emplacement of these dikes because shoots of the
Main veins normally stopped abruptly against the dikes, “ores commonly thicken against the dike contacts and send off minor branches along them, and that there is some mineralization in many places, or a stringer representing the vein, within the dikes themselves”. Alternatively, the dikes may parallel older north-trending structures that controlled vein distribution, and sulphides may have been locally remobilized during Tertiary deformation and magmatism.

**CENTRE STAR (082FSW094) - LE ROI (082FSW093)**

The Centre Star - Le Roi vein is the largest and most productive vein system in the Rossland camp. It extends westward within the Rossland monzonite, then follows the southern edge of a tongue of Rossland monzonite into Rossland sill. The vein was mined almost continuously over this length, a strike distance of nearly a kilometre (Photo 4-12). Although the veins are typically depicted as continuous, they actually “are made up of a series of shoots more or less en echelon in strike and dip…..the veins are a series of ore shoots of no great width or strike length, with their greatest dimension along dip. On dip, they usually die out gradually, either through loss of width or loss of metalliferous content. On the strike the same may occur, but more commonly they end abruptly against a dike or other cross structure.” (Gilbert, 1948, p. 193). Drysdale (1915, Map 146A) showed the veins extending west of the Josie dike, but offset to the south and with reduced width. Shearing of the vein is common, with mineralized zones forming discontinuous lenses within a through-going shear.

The Centre Star - Le Roi vein system has simple mineralogy in contrast to the more complex ores of the South and North belts. The vein comprises massive pyrrhotite, less chalcopyrite and traces of native silver and molybdenite. There is a close correlation between copper content and total silver + gold content, with the total metal values increasing to the west in the Le Roi deposit (Thorpe, 1967). This zonation may, however, simply reflect the tendency for metal content to be higher in the Rossland sill than in the Rossland monzonite.

Drysdale (op. cit.) noted that the ore appears to become more siliceous at depth, and although copper tends to decrease, gold content appears to remain constant. A sample from the Le Roi dump (R96-25b, Appendix 5) is a piece of silicified and hornfelsed Rossland sill cut by narrow stringers of magnetite, chalcopyrite and pyrrhotite. Quartz in this sample occurs as anhedral, irregular-shaped grains with abundant tiny fluid inclusions which give the grains a cloudy appearance. These inclusions were too small for evaluation. The cloudy quartz grains are occasionally overgrown by euhedral clear quartz that contained no fluid inclusions. The cloudy quartz texture resembles ‘wispy’ quartz (Reynolds, 1991) which typically forms in deep environments.

The coarse sulphide stringers from sample R96-24a have trapped a broken fragment of an earlier? generation of quartz vein. Secondary? fluid inclusions within this fragment include aqueous (H_2O-NaCl) Type I, multiphase (H_2O-NaCl-unknown phases) Type VI and mixed carbonic and multiphase (H_2O-CO_2-NaCl-unknown phases) Type VII phases. The only homogenization temperature attained was 206.2°C for a fluid inclusion assemblage containing Type VII inclusions.

**Fluid Inclusion Data**

Fluid inclusions in quartz were evaluated from a Le Roi dump sample of a quartz-sulphide vein in hornblende porphyrite that contained fine-grained to disseminated sulphides (Appendix 9b). The quartz-sulphide vein is brecciated and cut by coarse pyrrhotite-chalcopyrite sulphide stringers.

Quartz from the vein typically occurs as anhedral, irregular-shaped grains with abundant tiny fluid inclusions which give the grains a cloudy appearance. These inclusions were too small for evaluation. The cloudy quartz grains are occasionally overgrown by euhedral clear quartz that contained no fluid inclusions. The cloudy quartz texture resembles ‘wispy’ quartz (Reynolds, 1991) which typically forms in deep environments.

The coarse sulphide stringers from sample R96-24a have trapped a broken fragment of an earlier? generation of quartz vein. Secondary? fluid inclusions within this fragment include aqueous (H_2O-NaCl) Type I, multiphase (H_2O-NaCl-unknown phases) Type VI and mixed carbonic and multiphase (H_2O-CO_2-NaCl-unknown phases) Type VII phases. The only homogenization temperature attained was 206.2°C for a fluid inclusion assemblage containing Type VII inclusions.

**WAR EAGLE (082FSW097) - No. 1**

The War Eagle vein system trends west-northwest. To the east it approaches the Centre Star vein but farther west it diverges to the north from the Le Roi vein. Here, numerous other east-trending veins formed within the wedge between the War Eagle and the Le Roi, including the very productive Josie vein. Farther west, the War Eagle vein appears to be
offset to the south along the Josie dike with its western extension west of the dike referred to as the No. 1 vein.

In contrast with the sheared and irregular Le Roi vein system, the War Eagle - No. 1 vein generally has a well-defined hangingwall and footwall, and is typically fairly uniform in width and gold grades (Photo 4-13). The War Eagle has a surface strike length of at least 600 metres; the main stope is approximately 150 metres in length with a pitch length of 250 metres and an average width of 2.5 metres. It commonly follows the contacts of hornblende porphyrite dikes and the Rossland sill. At intersections with north-trending structures, and in particular the north-west-trending “K” fault, the vein can thicken substantially. Small north-trending veins or “ore shoots” locally occur along the lower contact of cross-cutting biotite lamprophyre dikes (Drysdale, 1915).

The War Eagle vein contains mainly massive pyrrhotite and chalcopyrite with minor quartz-calcite gangue. Locally, the vein has a crude sulphide banding. Sphalerite is uncommon, but has been reported in a vein cutting massive pyrrhotite and chalcopyrite (Drysdale, 1915) or locally within the main vein and partially replaced? by pyrrhotite (Thorpe, 1967). Trace amounts of molybdenite, native silver and native gold have also been reported. Large pyrite cubes can occur in the massive pyrrhotite-chalcopyrite ore.

Adjacent to the vein, the host augite porphyry of the Rossland sill is commonly altered to a texture-destructive assemblage of mainly plagioclase, actinolite, biotite, minor sphe and trace apatite.

**Fluid Inclusion Data**

Details of fluid inclusion studies of three samples from the War Eagle deposit are given in Appendices 9a and 9b. R96-31b is from the footwall of the War Eagle vein system, R96-58, from the northwest extension of the War Eagle vein and R96-71a, from the entrance to the War Eagle portal.

Sample R96-58 is a clinopyroxene-amphibole skarn with (1) minor cloudy quartz and associated fracture-controlled pyrrhotite and chalcopyrite. Inclusions in the quartz produce a ‘wispy’ texture, characteristic of deep environments. Rare fluid inclusions large enough to observe in the quartz are characterized by multiphase (H2O-NaCl-unknown phases) Type VI fluid inclusions. One Type VI assemblage homogenization temperature of 141°C was recorded.

Sample R96-71a consists of highly fractured, cloudy, anhedral quartz (1) cut by fractures filled with chalcopyrite, pyrrhotite, clear quartz (2) and magnetite(?). Fluid inclusions in the early, cloudy quartz are typically less than one micron in size which makes them unusable for fluid inclusion petrography. The ‘wispy’ texture of the quartz is characteristic of deep (> 4 km) environments.

The clear quartz (2) that is associated with sulphides in fractures contains salt-saturated (H2O-NaCl) Type III and carbonic (H2O-CO2-NaCl) Type IV inclusions (Appendix 9). Salt-saturated fluid inclusions have one contained solid phase, commonly cubic, which is approximately the same size as the vapour bubble. The homogenization temperatures from fluid inclusions in assemblages FIA 1-1 and 2-3 are low (156°C and 170°C) whereas the two salt phases, presumably halite, melted at 285°C and 331°C respectively. Calculated salinities for these samples are 37 and 41 eq. wt. % NaCl. Homogenization temperatures from Type IV fluid inclusions range from 243°C to 342°C and salinities, from 4 to 10 eq. wt. % NaCl.

Estimates of minimum fluid pressures from Type III inclusions in sample R96-71a are 2443 and 2872 bars, using dissolution of halite, and in Type IV inclusions, 1692 bars, using volume ratios of liquid-to-vapour and homogenization temperatures for CO2 and H2O (see Appendix 9). These trapping pressures correspond to trapping depths of about 9.2 km, 10.8 km and 6.4 km lithostatic load respectively.

Sample R96-31b consists of mainly semi-massive pyrrhotite and pyrite, minor chalcopyrite, traces of magnetite(?), and (2) 5% clear quartz gangue. These sulphides are cut by (3) a one centimetre wide quartz vein. Note that secondary quartz is associated with sulphides in sample R96-31c, collected at the same location (Appendix 5).

Fluid inclusions in the vein quartz (3) are secondary occurring typically along healed fractures. They are characterized by aqueous (H2O-NaCl) Type I, mixed aqueous and carbonic (H2O-CO2-NaCl) Type IV, multiphase (H2O-NaCl-unknown phases) Type VI and mixed carbonic and multiphase (H2O-CO2-NaCl-unknown phases) Type VII. Multiphase fluid inclusion assemblage 2-4 (Appendix 9) exhibits evidence of sylvite, halite or another readily soluble phase since dissolution of one of five daughter minerals occurs at 329°C, after homogenization at 298°C.

The homogenization temperature from a secondary Type I was 208°C and corresponding salinity moderate at 15 eq. wt. % NaCl. Homogenization temperatures from secondary Type VI fluid inclusions to a liquid phase are low to moderate, from 160°C to 300°C.

Types IV and VII inclusions contain trace concentrations of CH4 or N2. Homogenization temperatures range from 295°C to 316°C.
In summary, the paragenetic sequence of quartz deposition in the War Eagle vein is as follows: (1) anhedral quartz with wispy texture that appears to be associated with early skarn alteration, (2) euhedral to subhedral quartz veinlets, sometimes embayed, associated with massive pyrrhotite and chalcopyrite deposition, and (3) late anhedral quartz veinlets (with minor sulphides?) cutting earlier massive sulphides.

‘Wispy’ textures in the (1) early anhedral quartz suggest a deep environment (> 4 km, probably > 8 km) (Reynolds, 1991). The clear quartz in the massive sulphide veins (2) contains Type IV CO2 fluid inclusions and NaCl-saturated inclusions with liquid-vapour homogenization temperatures <220°C and salinity of <41 eq. wt. % NaCl. Estimates of depth of emplacement of these sulphide-quartz veins range from 6.4 to 10.8 km. Fluid inclusions in the late anhedral quartz veinlets (3) are characterized by CO2 (Type IV) and multiphase (Type VI) inclusions which are also indicative of formation in deep environments.

COLUMBIA-KOOTENAY (082FSW151)

The Columbia-Kootenay is the eastern extension of the Main vein system. It is located 1.6 km northeast of Rossland on the east slope of Columbia Kootenay Mountain. The mineralized vein system trends northeast and dips from 45°-75° northwest. Surface exposures at the portals are mixed metasediments and volcaniclastics of the Elise Formation. Drysdale (1915) described the vein at a contact between “biotite-bearing monzonite” in the hangingwall, presumably the Rossland monzonite, and augite porphyrite of the Elise Formation. No diorite porphyrite dikes, typical of vein contacts farther west, were noted.

The vein consists of mainly massive pyrrhotite with minor arsenopyrite and trace native bismuth and bismuthinite. “Much of the ore, which is made up of sulphides in a calcite and altered rock gangue, appears to be laminated. The ore is also found massive or scattered through the gangue or along small fracture planes in the walls.” (Drysdale, op. cit., p. 128). Vein gangue mineralogy includes calcite, diopside, quartz, plagioclase, minor K-feldspar and biotite, and secondary actinolite (sample R96-39a, Appendix 5). Host rocks to the veins are commonly altered to diopside-garnet skarn, and may contain disseminated sulphides.

Fluid Inclusion Data

Fluid inclusions from three samples from the Columbia waste dump were studied (Appendix 9). Sample R96-39a is a clinopyroxene-plagioclase? skarn retrograde altered to actinolite (Appendix 5), and cut by stringers of pyrrhotite, minor chalcopyrite, quartz (2) and trace magnetite. Fluid inclusions in the quartz are secondary and include aqueous (H2O-NaCl) Type I, carbonic (CO2-trace CH4/N2) Type V and multiphase (H2O-NaCl-unknown phases) Type VI inclusions (Appendix 9a).

Homogenization temperatures for Type I inclusions are 237°C and 246°C with corresponding salinities of 4.4 and 4.7 eq. wt. % NaCl. Homogenization temperatures for Type VI inclusions are slightly higher at 269°C and 301°C. A second assemblage (3-1, Appendix 9a) contained Types I and V inclusions, with the Type I inclusions having a salinity of 4.4 eq. wt. % NaCl and homogenizing at 237.5°C. Type V carbonic inclusions are essentially pure CO2 with less than 2 mol. % CH4/N2.

Sample R96-42b comprises massive arsenopyrite, pyrite, pyrrhotite, minor chalcopyrite and (2) quartz in a crudely banded, folded and almost gneissic-textured altered rock. Euhedral arsenopyrite overprints and is later than the other sulphides and quartz. Secondary? fluid inclusions include aqueous (H2O-NaCl) Type I, carbonic (CO2-trace CH4/N2) Type V, and multiphase (H2O-NaCl-unknown phases) Type VI.

Type I homogenization temperatures range from 288°C to 346°C with corresponding salinities from 10.7 to 16.6 eq. wt. % NaCl. Type VI fluid inclusions homogenize between 157°C and 303°C. The presence of observable CO2 phases at room temperature is typical of deep depositional environments. The absolute minimum depth of trapping for secondary Type I fluids is 1.0 to 1.7 km based on boiling curves for NaCl solutions under hydrostatic conditions (after Haas, 1971).

In summary, CO2 (Type IV) inclusions in sample R96-42b probably indicates deep (>4 km) deposition.

OTHER MAIN VEIN DEPOSITS

The Josie (082FSW147) vein trends west-southwest, north of and approximately parallel to the Le Roi vein. It comprises three main veins, the Hamilton, the North Annie and Annie. The main ore shoot pitches steeply to the west; it has well-defined contacts, similar to the War Eagle.

The mineralogy of the Josie vein is comparable to the Le Roi vein, dominated by pyrrhotite and chalcopyrite. A sample of the vein (R96-74, Appendix 5) has massive pyrrhotite intergrown with minor chalcopyrite and magnetite, with late coarse subhedral pyrite crystals. Analysis of this sample returned relatively high manganese content (1248 ppm) and high La (240 ppm) and Se (290 ppm). Massive fine-grained sphalerite was observed in veinlets and blebs from samples from the 275 metre level.

Skarn alteration comprises amphibole, calcite and garnet. Dump samples are commonly biotite hornfelsed, silicified or rarely skarn-altered Rossland sill.

Annie (082FSW 148) may be the western faulted extension of the Josie vein or the extension of a number of smaller veins between the Le Roi and the Josie. It is mainly within Rossland sill west of the north-trending Josie and Tramway dikes. The Annie vein is similar to the Le Roi veins and con-
sists of massive pyrrhotite with some chalcopyrite in west-trending discontinuous shear zones.

A number of Main veins are in Rossland monzonite east of those described above. In general, veins within the monzonite have lower gold grades than those in the Rossland sill to the west, even though they may still comprise massive sulphide.

**The Iron Colt (082FSW100)** is the most eastern extension of the Main vein system. Limited production, mainly in 1995, recovered 21,586 grams of gold. Recent work by Antelope Resources included geophysical surveys, diamond drilling and some underground exploration. Samples from a dump are dominantly Rossland monzonite, many which have undergone pervasive carbonate alteration or less intense albitic alteration. Other samples have a pronounced green cast due to pervasive propylitic alteration. Disseminated pyrite is also common. Vein samples include massive to semi-massive pyrrhotite with minor arsenopyrite and chalcopyrite in a calcite-quartz-albite gangue. An analysis of one of these samples (R96-40B; Appendix 6) returned 15.8 ppm gold, 7.8% As and high cobalt content (3755 ppm).

**The Iron Horse (082FSW099)** is located due west of Iron Colt. There is little available information on this segment of the Main vein. It consisted of massive sulphide with low gold grades; in 1903, limited production recovered 746 grams of gold from 27 tonnes of ore. Sulphide-rich samples on a dump are dominantly Rossland monzonite, many which have undergone pervasive carbonate alteration or less intense albitic alteration. Other samples have a pronounced green cast due to pervasive propylitic alteration. Disseminated pyrite is also common. Vein samples include massive to semi-massive pyrrhotite with minor arsenopyrite and chalcopyrite in a calcite-quartz-albite gangue. An analysis of one of these samples (R96-40B; Appendix 6) returned 15.8 ppm gold, 7.8% As and high cobalt content (3755 ppm).

**Virginia (082FSW098)** is also in Rossland monzonite, west of Iron Horse. It trends east-northeast parallel to the main Centre Star vein system. Farther west and on strike is the **Iron Mask (082FSW096)** vein. It had considerable production from 1897 to 1899 and after consolidation with other properties by Consolidated Mining and Smelting Company in 1907. Although the Main vein system trends to the west, Drysdale (1915) reported that considerable production came from cross fractures that intersected the main veins. These mineralized cross fractures were, apparently, more pronounced in the upper levels of a number of deposits near the intersections of the Centre Star-Le Roi vein system and the War Eagle vein.

**DISCUSSION: MAIN VEIN DEPOSITS**

The distribution of veins is schematically shown on Figure 4-8. They extend westward from within the Rossland monzonite into the Rossland sill, commonly following the contact of monzonite and sill, or the margins of porphyrite dikes.

The pronounced metal and mineralogical zoning in North and South belt veins is less apparent in the Main vein system. However, in common with these other veins, more eastern Main veins formed at deeper structural levels than those in the west. More eastern exposures, such as the Iron Colt, have more intense alteration in the host rocks, with dispersed pyrite and more pronounced carbonate alteration and biotite hornfelsing. At depths, carbonate and silica alteration as well as biotite hornfelsing increase in the Le Roi vein. As well, small wispy sulphide veins extend into the country rock, in contrast to the better-defined and more continuous veins in western exposures (War Eagle). Shearing along veins is more pronounced in the more western Le Roi-Centre Star vein than in eastern veins. Farther west, these sheared veins diffuse into “shattered and minutely fractured” masetediments of the Elise Formation (Drysdale, 1915, p. 51).

Although the Main veins are dominated by massive pyrrhotite and chalcopyrite, gold content appears to vary with either structural depth or host lithology. Eastern veins, though still mainly massive sulphide, typically have lower gold content than those in the more western Main veins. Arsenopyrite, more common in eastern exposures in the North belt, is also found in the Iron Colt, the most eastern portion of the Main veins.

**SOUTH BELT**

The principal veins in the South belt trend approximately east-west and dip steeply north or south. They are within siltstones, lapilli tuff and augite porphyry of the Rossland Group several hundred metres south of the Rossland monzonite. More northern and eastern veins in the South belt are similar to the typical copper-gold mineralization of the Main veins and North belt, whereas western and southern veins contain appreciably more lead, zinc and silver, and are within the “outer zone” of Thorpe (1967). White (1949) distinguished a third “transitional” vein type in the South belt which is gradational in mineralogy and metal content between the Main Rossland veins and those of the South belt. Figure 4-13 illustrates the geology of the South belt vein area, and distinguishes the main vein types.

The Lily May, located in 1887, was the first vein to be discovered in the Rossland camp. The Mayflower (1889), Homestake (1890) and Bluebird (1900) were subsequently discovered. Production from most of these veins is limited, generally between tens to hundreds of tonnes (Appendix 3); Bluebird, the largest producer, mined 7,239 tonnes, mainly in the middle to early 1970s producing a total of 3,911 kg silver, 12,857 grams of gold, as well as lead, zinc and minor copper.

The separate crown granted claims of the South belt were largely assembled by Rossland Mines Ltd. in 1947 and from then through to 1956 they underwent considerable exploration, underground development and some production from the Bluebird-Mayflower zone. Exploration in the 1960s included mainly geophysical work and soil surveys. From 1972-1980, Ross Island Mining Co., formerly Rossland Mines Ltd. leased the group of claims covering the South belt veins, referred to as the Bluebird-Homestake...
claim group, to Standonray Mines with resultant mining of the Bluebird vein.

From 1981-1986, Bryndon Ventures Ltd. (previously Ross Island Mining Co. Ltd.), established a grid on the Bluebird-Homestake group, carried out a VLF electromagnetic survey, 530 metres of trenching and 631 metres of diamond drilling. Work continued in 1987-1988 under an option agreement with Antelope Resources Ltd. and operator, Pacific Vangold Mines Ltd, and funding in part by the provincial government Mineral Exploration Incentive Program (FAME program) (York-Hardy et al., 1988). Limited diamond drilling on a number of the veins continued through the early 1990s by Antelope Resources or Pacific Vangold Mines in an attempt to define additional reserves.

Three main vein zones are recognized in the South belt (Yorke-Hardy et al., op. cit.). The most northern, the ‘Homestake-Gopher’ trends east-west, parallel to the southern margin of the Rossland monzonite, the ‘North shear zone’ just to the east trends east-northeast, and the ‘Bluebird-Mayflower’ parallels the Homestake-Gopher vein system 200-300 metres farther south (Figure 4-13). Shearing along vein margins and brecciated ore textures indicate that the veins follow fault zones; however, displacements on these are minimal.

Figure 4-13. Geology of the Rossland South belt vein system (after Fyles, 1984; Höy and Andrew, 1991).
The Homestake-Gopher vein strikes approximately 100° and dips steeply north. It has been traced along strike for 650 metres, from the Gopher in the east to the Homestake farther west. In the early 1900s, 236 tonnes of ore were mined from the Homestake with a recoverable grade of 317 g/t silver and 3.9 g/t gold. Assays of a number of samples of vein material from the Homestake dump are given in Appendix 6.

The Homestake vein is mainly within the Rossland sill, close to its western contact with the Elise Formation. The sill adjacent to the vein is altered to chlorite, and veined with carbonate-quartz; minor epidote-amphibole skarn, with early pyrrhotite, and lesser chalcopyrite, arsenopyrite, galena and magnetite (Appendix 5). Pyrrhotite appears to be early, and is locally pervasively altered to marcasite. Sulphides are streaked due to shearing, and locally recrystallized producing ‘sieve’ textures with porphyroblasts of arsenopyrite and pyrite in other sulphides (Thorpe, 1967). Gangue minerals include quartz, epidote (clinozoisite?), biotite and actinolite. Elsewhere, sericite with biotite, tourmaline, chlorite and carbonate occur in the veins.

The eastern extension, the Gopher vein, is similar to the Main Rossland veins. It contains mainly pyrrhotite, chalcopyrite, sphalerite and minor arsenopyrite, bismuth and bismuthinite in quartz-calcite gangue.

Fluid Inclusion Data

An analyzed sample of the Homestake vein (MI-123) consists of quartz intergrown with sulphides and chlorite as well as crushed and broken quartz fragments. The sample is cut by a calcite-quartz vein.

Secondary? fluid inclusions in the early quartz, intergrown with sulphide, includes aqueous (H2O-NaCl) Type I, salt-saturated (H2O-NaCl) Type III, carbonic (CO2-trace CH4/N2) Type V, multiphase (H2O-NaCl - unknown phases) Type VI and mixed aqueous and carbonic (H2O-CO2-NaCl) Type IV (Appendix 9). In one inclusion assemblage, the Type I inclusion has a salinity of 7.5 eq. wt. % NaCl and homogenizes at 262°C and the Type IIIA inclusion homogenizes at 255°C with a salinity of 31.1 eq. wt. % NaCl; the Type V CO2 inclusion homogenizes at 24.1°C. In a second assemblage, Type IV fluid inclusions CO2 homogenizes at 28.5°C and H2O at 300.8°C. An estimate of minimum fluid pressure using volume ratios of liquid - to - vapour and homogenization temperatures for CO2 and H2O (Type IV) inclusions is 1262 bars, corresponding to a depth of about 4.8 km.

Bluebird (082FSW145) and Mayflower (082FSW146)

The Bluebird and its probable eastern extension, Mayflower, are located several hundred metres south of the Homestake-Gopher vein. The vein zone trends approximately 120-130°, and dips to the north at 50–65°; however, within this zone, some individual vein shoots strike east-northeast, towards the North-Maid of Erin system. The vein zone can be traced or extrapolated for at least 600 metres, from the Mayflower in Rossland sill in the southeast to the Bluebird in argillaceous siltstones in the northwest (Figure 4-13). The Hattie Brown (082F/SW359) occurs to the northwest along the structure; however, there is little reported data on this deposit, other than it is apparently a silver-bearing galena vein occurrence.

The Bluebird vein comprises mainly pyrite, sphalerite, galena and pyrrhotite with variable arsenopyrite and minor to trace chalcopyrite, boulangerite and stibnite in a quartz-calcite gangue (Photo 4-15a). Pyrrhotite is early, occurring as relict grains or inclusions in other sulphides. Vein boundaries are sharp, in contrast to wispy or disseminated vein textures noted in deeper level vein deposits. Vein textures vary from brecciated, with quartz cutting sulphides, to massive or less commonly crudely banded or streaked sulphides (Photo 4-15b). Commonly, angular hornfelsed siltstone clasts and grains occur in sulphide matrix, yielding brecciated textures. These fragments are typically altered to fine-grained sericite, carbonate and quartz. Late calcite-quartz veinlets cut the sulphide vein.

The grade recovered during mining was 540 g/t silver and 1.8 g/t gold. An assay of a semi-massive sphalerite-arsenopyrite-galena hand sample returned 260 g/t silver and 4.45 g/t gold (R96-66A; appendices 5 and 6).
A second sample assayed 280 g/t silver and 4.96 g/t gold (Appendix 6).

The **Mayflower** vein is a rich massive sulphide vein located along the abandoned rail line southeast of Bluebird (Figure 4-13). Although the vein/shear structure trends towards Bluebird, individual sulphide veins within it trend to the northeast. It is possible therefore that these ore shoots are dilation or extensional veins within a left-lateral shear zone that trends easterly or east-southeasterly.

Mayflower is within the Rossland sill near its eastern contact with dominantly augite flows of the Elise Formation. It is described by Drysdale (1915, p. 168): “the vein strikes north 60 degrees east.... The ore is very similar to the Bluebird mine but more massive. Blende (sphalerite), galena, a little arsenopyrite, and pyrrhotite occur in the ore which in places is well banded.” Magnetite is also common, and tetrahedrite, with high silver content, and a ruby silver (?)pyrargyrite are also reported (Thorpe, 1967). Boulangerite also occurs in the Mayflower vein, as it does in all the South belt veins other than Homestake. Dominant gangue minerals are quartz and carbonate, with minor chlorite.

In contrast to vein textures at the Bluebird, sulphides in the Mayflower vein are typically finer grained and commonly crudely banded or sheared. Vein boundaries are not as distinct, and sulphides may occur disseminated in intermediate host rocks resulting in gradational vein contacts. As well, brecciation is less intense in the Mayflower. These textures suggest emplacement at deeper structural levels, in a transitional brittle-ductile environment.

**Fluid Inclusion Data**

Sample M3-145 consists of angular and brecciated, hornfelsed siltstone clasts in a matrix of pyrite, galena and minor chalcopyrite in a quartz gangue. Euhedral quartz in quartz overgrowths contain both primary and secondary? inclusions (Appendix 9).

Primary inclusions include aqueous (H₂O-NaCl) Type I, carbonic (CO₂-trace CH₄/N₂) Type V and multiphase (H₂O-NaCl-unknown phases) Type VI inclusions. Homogenization temperatures for Types I and VI fluid inclusions range from 286°C to 310°C; salinity for Type I inclusions is low at 7.9 eq. wt.% NaCl. Secondary fluid inclusions in the anhedral quartz are characterized by aqueous (H₂O-NaCl) Type I and multiphase (H₂O-NaCl-unknown phases) Type VI inclusions. Homogenization temperatures for Types I and VI fluid inclusions range from 245°C to 248°C, with 17.8 eq. wt. % NaCl salinities for Type I.

**ROBERT E. LEE (082FSW131) AND NORTH (82FSW128)**

These veins, referred to as the “North shear zone” by Yorke-Hardy *et al.* (1988), trend southwestward, from the Robert E. Lee claim within augite phyric lapilli tuffs and pyroclastic breccias of Unit Je7l just south of the Rossland monzonite, through the Maid of Erin or North deposit near the eastern extension of the Homestake-Gopher vein, into Rossland sill south of Gopher (Figure 4-13). In contrast with other veins of the South belt, this vein is more typical of the Main Rossland veins, dominated by pyrrhotite and containing appreciable chalcopyrite.

The North showing has received considerable recent exploration by Antelope Resources Ltd., including trenching, mapping, sampling and diamond drilling (Yorke-Hardy *et al.*, op. cit.). This work was concentrated largely southwest of the Maid of Erin vein occurrence. Chip samples across one meter intervals in four of six trenches across the structure returned values averaging 12 g/t Au and 33 g/t Ag. As well, six drill holes tested the vein, with the best intersection consisting of 2 meters grading 22.7 g/t Au and 31.2 g/t Ag (Sampson, 1986).

The Robert E. Lee vein trends approximately 070° and dips steeply to the north. It ranges up to approximately 1 metre in thickness. The vein is mainly massive sulphide, consisting of arsenopyrite partially replaced by pyrrhotite (Thorpe, 1967), with less pyrite and chalcopyrite, minor sphalerite and trace bismuth, in a fine-grained grey quartzitic gangue. Hostrock samples on the dump are green...
bendite-hornfelsed metavolcanics that locally contain wispy, irregular sulphide veinlets and disseminated sulphides.

Assays of samples from the Robert E. Lee dump are given in Appendix 6. A massive pyrrhotite sample, containing sphalerite and minor chalcopyrite and arsenopyrite, contained 0.34% Cu, 2.28% Zn, 17 ppm Ag and 3.4 ppm Au.

**OTHER SOUTH BELT VEIN OCCURRENCES**

A number of other isolated vein occurrences are known in the South belt south of the Rossland monzonite. The Curlew vein (082F/SW154) is south of and parallel to the Bluebird vein. It is similar to the Bluebird vein, with pyrite, sphalerite, galena and arsenopyrite and some stibnite, chalcopyrite, pyrrhotite and boulangerite in a quartz gangue.

The Richmond (082F/SW143), Lily May (153) and Zilor (223) are all located west of the Bluebird vein. They are typical of the South belt veins, comprising mainly galena and sphalerite, with pyrite, pyrrhotite and variable but generally minor chalcopyrite. Boulangerite and marcasite occur in the Richmond vein, and magnetite and minor stibnite in the Lily May. Limited production from 1934 to 1939 recovered 1312 g/t Ag and 28 g/t Au, and 11 tonnes of a galena-rich sample from Richmond contained 0.34% Cu, 2.28% Zn, 17 ppm Ag and 3.4 ppm Au.

**Fluid Inclusion Data, Lily May (082FSW153)**

Fluid inclusion data from quartz in a quartz-carbonate-sulphide vein are presented in Appendix 9, sample M3-153. Inclusions are characterized by aqueous (H2O-NaCl) Type I, carbonic (CO2-trace CH4/N2) Type V and mixed aqueous and carbonic (H2O-CO2-NaCl) Type IV fluid inclusions.

A single Type I inclusion has a salinity of 11.7 eq. wt. % NaCl and homogenizes to the liquid phase at 392.5°C.

**DISCUSSION: SOUTH BELT VEINS**

A systematic mineral and metal zoning is apparent in veins of the South belt (Figure 4-13). In general, veins farther from the Rossland monzonite contain mainly galena, sphalerite and pyrite in contrast to pyrrhotite-chalcopyrite ± sphalerite veins closer to the intrusion. Furthermore, veins change in both tenor and texture to the west. The Robert E. Lee and Gopher, the most easterly veins, are fairly typical of the Main Rossland gold-copper veins, although both contain minor sphalerite. Sphalerite and pyrite become more prominent to the west and are the dominant sulphide minerals at Homestake. Similarly, the Bluebird-Mayflower vein changes systematically to the west; pyrrhotite is the dominant iron sulphide at Mayflower whereas pyrite predominates at Bluebird. As well, sulphides at Mayflower are typically finer grained and sheared, with locally gradational contacts with country rock, in contrast to brittle brecciated textures at Bluebird.

These changes are comparable to those noted in the North belt veins, although developed at higher structural levels largely within a brittle regime. They support a model that involves westward tilting of the Rossland vein system so that deeper levels are now exposed farther east and shallower levels, associated with brittle faulting, in more western exposures. These differences also suggest that mineralization is related to the Rossland monzonite, as the transition between brittle and ductile shearing tends to parallel the southern margin of the intrusion.

Sulphides in many veins of the South belt are sheared producing banded or gneissic textures. This is most evident in more eastern exposures, such as at the Mayflower, but is common in most galena and sphalerite-bearing veins that developed or were deformed in a semi-ductile regime. Galena typically forms textures referred to as ‘steel galena’ while other less ductile sulphides such as pyrite and pyrrhotite become finely granulated. At higher structural levels, brittle brecciated textures develop. These textures imply vein formation pre-shearing.

**GOLD-QUARTZ VEINS**

A number of high grade gold-quartz veins are concentrated in the Little Creek valley just west of the town of Rossland. They have been described by Drysdale (1915) and Stevenson (1935). Fyles (1984) discussed their local setting, and Ash (2001) has discussed their origin in light of their regional tectonic setting. This report overviews their geology, based mainly on these previously published papers as well as company assessment reports, and attempts to place them in relation to other deposits of the Rossland camp.

The veins are mainly within a panel of fault-bounded massive greenstone and ultramafic rocks that trend north in the Little Sheep creek valley just west of Rossland (Fyles, 1984). The age of the greenstones is not known. Fyles (1984) tentatively correlated them with the Elise Formation but Ash (2001) noted that they are distinct from the Elise. The greenstones are fine grained and dense with local to pervasive chloritic alteration, silicification and chloritization. Fibrous amphibole, magnetite and serpentine? are common within them. An exposure on the Cascade Highway comprises hornfelsed mafic volcanics, highly brecciated with plagioclase phric clasts and locally a sulphide matrix. The ultramafic rocks have been described above; they are mainly variably serpentined diorites and wehrlites of inferred oceanic affinity (Ash, 2001).

The ultramafic rocks are inferred to have been tectonically emplaced along east-directed thrust faults. The age of this thrust faulting is not known but is correlated with Middle Jurassic compressive deformation recognized in more eastern exposures of the Rossland Group (Höy and Andrew, 1990b). The thrust belt is the loci for late normal faults and intrusion of Eocene dykes, intrusive plugs and mafic volcanic rocks of the Marron Formation. These faults have been
reactivated to produce steeply-dipping late faults with inferred west-side-down movement (Fyles, 1984); the OK fault to the west places Eocene Marron Formation against Pennsylvanian-Permian Mount Roberts Formation, and the Jumbo fault to the east separates the greenstones from the Elise Formation that contains “abundant intrusions and widespread thermal metamorphism…taken as evidence that rocks east of the fault represent a deeper thermal regime” (Fyles, 1984, p. 31).

The gold-quartz veins are on the I.X.L (082FSW116), O.K. (117), Midnight (119) and Dominion (Snowdrop -115) crown-granted claims. They were discovered in 1891 and had relatively continuous but minor production between 1899 and 1974, totaling 1 081 816 grams of gold (Appendix 3). The I.X.L. produced 811 746 grams of gold with a recovered grade of 153 g/t and the Midnight, 245 311 grams with a recovered grade of 43 g/tonne. During the 1930s this work was done by a number of lessees. In 1969, work by Howe International and Cinola Tull Mines consisted of 1 766 metres of surface and underground drilling, 235 metres of development drilling and bulk sampling. Work on the Midnight Mine claim group in 1993-1994, which incorporated the past-producing crown-granted claims, included some geological mapping, geophysical work and drilling (Smithson, 1995). This work continued through 1996 under option to Minefinders Corporation Ltd. with considerable underground rehabilitation, drilling and sampling (Smithson, 1996).

The veins are quartz-ankerite-gold veins that typically range from a few centimetres to 0.5 metres but locally up to 2 metres in width. According to Fyles (1984), the mineralized parts of the veins “pinch and swell and change attitude”. They are commonly discontinuous with total length and down-dip extensions of the “strongest mineralized zones” less than 100 metres. The principal vein on the Midnight trends 160° and dips 65° west; on the Snowdrop the veins trend northeast and dip 50° southeast (Fyles, op. cit.). Sulphide mineral content of the veins is variable though generally minor; sulphides include pyrite, galena, sphalerite and minor chalcopyrite. Reported gangue minerals include quartz, ankerite, calcite and, in one sample, prehnite (Thorpe, 1967).

In addition to the spectacular high-grade veins, Smithson (1995; 1996) reported that “mineralization at the Midnight Mine occurs as disseminations in broad zones of carbonate-altered ultramafics that are intruded by a north-trending lamprophyre dike swarm… High grade gold zones and gold-bearing quartz veins occur adjacent to some of the pre-mineral dikes within both ultramafic and adjacent volcanic rocks… Silica-carbonate alteration of the serpentinitized ultramafic was encountered across broad zones that contain low grade gold mineralization”. Tabulation of assay results from Holes 1, 2 and 3 shows a total of 95.3 metres averaging 1.74 g/t Au; this included 40 metres in Hole 1 (1.7 g/t Au), 7.5 metres in Hole 2 (1.78 g/t Au) and 47.8 metres in Hole 3 (1.7 g/t Au).

**DISCUSSION**

The gold-quartz veins in Little Sheep Creek are located west-southwest of, and on direct strike with the Main veins of the Rossland camp. They are in a structural panel that is down-dropped relative to the Main veins. This led Fyles (1984, p. 52) to suggest that they may be an “upper extension of the same or a similar mineralizing system as the copper-gold deposits of the main camp”. This view is implicit in the thesis of Thorpe (1967) who included these veins in his regional thermal and zonation study of the Rossland camp.

Relatively low-temperature sulphide assemblages, dominant quartz-carbonate gangue with locally prehnite, and brecciated textures support the interpretation that these are lower temperature than the Rossland Main veins, supporting a model for higher level emplacement.

The age of these veins is not known but can be reasonably deduced to be a similar age as the Main veins (see below). They must be contemporaneous with or postdate shearing along the margins of the serpentinites as they occur within the serpentinites and the greenstones immediately to the north. Intense regional compressive deformation in the Rossland-Trail area is post-deposition of the Toarcian Hall Formation and mainly pre-intrusion of the Middle Jurassic (ca. 165-170 Ma) Nelson suite; Höy and Dunne (1997) argued that the 174-178 Ma Silver King intrusive suite are early to synkinematic plutos. As the Rossland veins are in shear zones within the Rossland monzonite (ca. 167 Ma), shearing must have continued after intrusion of the monzonite. Hence, it is probable that the gold-quartz veins are late synkinematic, post-intrusion of the Rossland and Rainy Day plutos.

**DISCUSSION: ROSSLAND AU-CU CAMP**

**AGE RELATIONS**

Re-Os dating of massive molybdenite mineralization in the intrusive-breccia skarn complex on the western slopes of Red Mountains indicates it is 162.9±0.9 Ma. This age is in agreement with a U-Pb zircon age of ca. 162.3±1.2/-2.5 Ma for the brecciated quartz diorite dikes within the complex. The similar Re-Os and U-Pb ages provide one example showing high precision and robustness of dating molybdenite mineralization by Re-Os methods (Stein et al., 1997; Selby and Creaser, 2001).

U-Pb dating of the Rainy Day pluton, a small quartz diorite stock just south of the molybdenite mineralization and inferred to be the source of this mineralization (Fyles, 1984) indicates an upper age limit of 174.6 Ma and a lower age of 166.3 Ma. Field relations indicate that the Rainy Day pluton is younger than the Rossland monzonite, dated at ca. 167 Ma; hence, it is concluded that the date of the most concordant fractions, ca. 166 Ma, is the age of the Rainy Day pluton. Furthermore, the similar but slightly younger quartz diorite dikes in the intrusive breccia complex may be late phases of the pluton.

Copper-gold veins in the Rossland camp and polymetallic veins of the South belt are within and along the
MAGMATIC CONTROLS

The close spatial association of Cu-Au veins with the Rossland monzonite and zonation of both vein mineralogy and alteration assemblages relative to the monzonite indicate a genetic link. This zonation is particularly evident in the South belt where pyrrhotite-chalcopyrite veins occur closer to the intrusion whereas dominantly galena-sphalerite-pyrite veins are farther south.

Pb isotopic analyses of a number of the South belt veins also support a magmatic influence. Data from these veins, as well as a number of other polymetallic veins elsewhere in the Rossland Group (Cluster 2 in Appendix 8), suggest relatively radiogenic lead and an upper crustal lead source with a minor component of mantle lead; the data define an elongated Pb isotopic mixing trend from the Jurassic to the late Precambrian. These veins are all within or along the margins of Jurassic plutons that are interpreted to have facilitated mixing of upper crustal lead with mantle lead.

Analyses of fluid inclusions in quartz in Rossland veins also suggest that these veins may be hydrothermal-magmatic. Three generations of vein quartz are recognized in many of the samples (see, for example, War Eagle, above and Appendix 9). Early cloudy quartz grains, characterized by abundant small inclusions that define a 'wispy' texture, are cut by the main sulphide veins that have a clear quartz gangue. These are cut by late anhedral quartz and calcite veins that contain only minor sulphides. This paragenesis reflects the main stages of vein development throughout the camp: early prograde skarn alteration, followed by massive sulphide veins and finally late quartz-pyrite veining.

Fluid inclusions in vein quartz associated with massive sulphide mineralization include aqueous, multiphase (H$_2$O-NaCl), mixed aqueous and CO$_2$ bearing and occasional salt-saturated or CO$_2$-rich inclusions. The composition, salinity and homogenization temperatures of these inclusions are similar to those in other intrusion-related gold systems (Appendix 9, Figure 8). In particular, high salinity fluids associated with main stage mineralization is suggestive of a hydrothermal-magmatic source, and CO$_2$ inclusions are typical of fluids proximal to deeper level intrusions. Calculated pressures are relatively high, suggesting emplacement at depths up to 11 km.

MINERALIZATION, GEOCHEMISTRY AND CAMP ZONATION

A simplistic camp zonation, developed along the northwestern margin of the Rossland monzonite, consists of a ‘central’ zone dominated by pyrrhotite and chalcopyrite, an ‘intermediate’ zone with veins that contain arsenopyrite, pyrite, cobalt, bismuth minerals and molybdenite in addition to pyrrhotite and chalcopyrite, and an ‘outer’ zone with veins of galena, sphalerite and tetrahedrite (Thorpe, 1967). The Cu-Au veins change systematically in tenor, alteration and structural style from deeper levels in the east to more shallow levels farther west. This is evident in many individual veins, with progressive change along strike to the west from pyrrhotite-arsenopyrite-chalcopyrite assemblages, to assemblages dominated by pyrrhotite-chalcopyrite, then pyrite-sphalerite-chalcopyrite and finally, brittle pyrite-sphalerite-galena.

The interpretation that molybdenite mineralization developed after and probably unrelated to copper-gold vein mineralization allows refinement of zonation patterns in the camp and a better understanding of fluid chemistry and migration. Massive molybdenite mineralization, although overlapping the western extension of several of the North belt and Main veins, is generally separated from these veins and trends more northerly. Molybdenite mineralization in the Coxey, Novelty, Mountain View and Giant deposits is associated with high concentrations of a variety of elements, including As, Ba, W, Ni, Co and Bi. In addition, U, La, Ce and Nd concentrations are also anomalously high. Gold and copper content in these deposits is variable and, at the Giant deposit, is largely concentrated in a crosscutting, west-trending vein that is similar to the Main veins.

Hence, it is probable that at least two separate mineralizing events produced the camp zonation patterns: an earlier Cu-Au dominant system and a later Mo-dominant system. Figure 4-14, based on analyses of hand samples tabulated in Appendix 6, illustrates a revised Rossland camp zonation. Within the Main and North belt veins, Cu/Cu+Zn and Au/Cu ratios increase at deeper levels and closer proximity to the Rossland monzonite. Due to more limited sampling, metal zonation in the molybdenite camp is not well defined. However, Mo appears to be dominant in more northern deposits, Mo-Co-Ni in a central zone, and Mo-Bi in the most southern deposits. Two distinct trends in the zonation pattern of absolute Mo values, a southwesterly trend parallel to the Main veins and a more northerly trend parallel to the molybdenite skarn complex (Figure 4-14d), are also suggestive evidence for two distinct but overlapping mineralizing systems.

FLUID CHEMISTRY, EVOLUTION AND HISTORY

Due to lack of fluid inclusion data and limited sampling there is little direct evidence on the nature of the fluids forming the molybdenite complex; hence, they are not discussed further. However, considerable information about temperature, chemistry and evolution of fluids forming the Rossland sulphide veins and related polymetallic veins in the South
belt can be determined, either directly through fluid inclusion studies or indirectly through mineralogy and chemistry of the veins themselves or their alteration halos.

Temperatures

Temperatures of ore deposition can be estimated by considering the stability fields of coexisting sulphides. For example, arsenopyrite and pyrite, occurring together in veins of the South belt, restrict temperatures to below approximately 490°C (Clark, 1960a; Kretschmar and Scott, 1976; Sharp et al., 1985). Arsenopyrite and pyrrhotite, occurring together in eastern exposures of the Main veins and in the North belt, are stable to much higher temperatures.

Despite considerable discussion and caution regarding the applicability of sphalerite and arsenopyrite geothermometry, the compositions of these minerals do provide further constraints to formational temperatures. Temperature estimates based on arsenopyrite compositions, formed under an assumed pressure of 1000 bars, ranged from above 600°C for the Evening Star and “S.E. of Cliff”, above 525°C for Cliff, 510-540°C for Novelty, 480-510°C for Giant and Gertrude, 465-500°C for Bluebird, to 430-460°C for the Robert E. Lee (Thorpe, 1967). Based on Fe and Mn content in sphalerite, Thorpe (op. cit.) suggested temperatures from the Evening Star might have been above 545°C and from the Bluebird deposits in the South belt, between 440-450°C.

Native bismuth, common as a late mineral in many of the deposits, is only stable at temperatures below its melting point at approximately 270°C. However, it is possible that bismuth may have been deposited in a higher temperature mineral, such as a sulphosalt, and retrograded to native bismuth during late-stage, low temperature veining (Thorpe, op. cit.).

Gangue and contact alteration assemblages further constrain temperature estimates of ore formation. Pre-ore prograde diopside-garnet-plagioclase skarn assemblages indicate metamorphic temperatures greater than approximately 500°C and silicate assemblages associated with vein mineralization, specifically amphibole and biotite, indicate somewhat lower temperatures, above approximately 450°C.

Homogenization temperatures of fluid inclusions in quartz associated with sulphide veining range from 150 to approximately 370°C. The higher temperatures are from aqueous Type I inclusions in the Evening Star and Columbia-Kootenay veins and are interpreted to record minimum fluid temperatures.

In summary, copper-gold in the Main veins was probably deposited from solutions above 500°C, after a thermal peak that may have reached temperatures of 600°C. Lead-zinc-silver veins in the South belt are lower temperature, generally forming below 450°C. Brittle textures in South belt veins suggest even lower temperatures. Fluid inclusions in late quartz veins (based on only one sample from the War Eagle deposit) have low homogenization temperatures, ranging up to 300°C.

Figure 4-14. Simplified maps of the Rossland camp, showing metal zonation patterns, from assay data listed in Appendix 6; (a) Cu/Cu+Zn (b) Au/Cu*10³ (c) Mo.
Chemistry

Eastern extensions of the Main veins, in deeper structural levels and within metasediments, illustrate a paragenetic evolution from early siliceous biotite hornfelsing, overprinted by intense prograde skarn alteration, and followed by retrograde skarn and massive sulphide mineralization, and finally late pyrite-calcite veining. Early prograde skarn alteration involves metasomatism by Si, Mg and K dominated fluids, producing mainly quartz, diopside, plagioclase, K-feldspar and garnet, whereas the main stage of vein mineralization is associated with hydrolysis and development of quartz and hydrous Fe-Mg silicates including amphibole, biotite, epidote and chlorite. Late veins are dominantly pyrite, calcite and quartz, reflecting evolution to more Ca-rich fluids.

Progressive changes in fluid chemistry (and trapping temperatures or pressures), based on fluid inclusion studies in quartz associated with these stages of vein development are not readily apparent, mainly due to limited number of analyses of both the early and late stage veins. Quartz in prograde skarn assemblages is characterized by small inclusions that produce ‘wispy’ textures characteristic of high pressures; due to their small size most are unsuitable for analysis. In one sample, however, this early quartz contains aqueous and rare multiphase assemblages, the latter suggesting possibly highly saline solutions.

Fluid inclusion data from veins associated with the main stage of sulphide deposition indicate fluids with moderate and high salinities of 4-20 and 37-41 eq. wt. % NaCl (and homogenization temperatures of 150 to 377°C and pressures of 1500 to 2900 bars).

The coexistence of aqueous, salt-saturated and CO$_2$ inclusions suggests that phase separation may have occurred from an original supercritical H$_2$O-NaCl-(CO$_2$) fluid producing salt-saturated brine and a gas phase. However this is not supported directly by fluid inclusion evidence of similar homogenization temperature ranges and homogenization to the vapour phase of Type III inclusions. Phase separation would, however, support transport of metals, including gold, as mainly chloride complexes. The zonation from copper dominant to zinc dominant veins along strike is additional evidence for chloride complexing; zinc and lead transport in hydrothermal fluids is dominantly as chloride complexes.

It is also possible that some of the carbonic (CO$_2$-rich) fluids may be metamorphic in origin, as proposed by Newberry et al. (1995) for some Alaskan intrusion-related gold deposits. However, a dominant magmatic origin for Rossland vein fluids is favoured because (1) Elise sediments are generally noncalcareous and (2) skarn mineralogy suggest Ca metasomatism and CO$_2$ fluid introduction on vein margins.

Fluid inclusions in late quartz-(calcite) veins (based on only one sample from the War Eagle deposit) may be similar, with aqueous, carbonic, and multiphase inclusions. However, the mineralogy of these veins suggests lower temperatures and/or more oxidized fluids.

The high sulphide content of the veins indicates that the fluids were acidic. The abundance of pyrrhotite in the Main veins, restriction of hematite as a late replacement mineral, and presence of carbonic (CO$_2$+CH$_4$) fluid inclusions suggest that the ore-forming fluids were reduced. However, the relatively high copper content is more typical of more oxidized fluids. Although the Rossland monzonite commonly contains accessory magnetite, Fe$_2$O$_3$/FeO ratios indicate that phases of the intrusion range from oxidized to reduced.

In contrast, the slightly younger Rainy Day pluton is more reduced, and is associated with molybdenite and tungsten mineralization. This suggests magmatic evolution, with progressive reduction in oxidation state from more mafic monzodiorite phases typical of the Rossland monzonite to quartz diorites of the Rainy Day pluton. Late veins, and South belt veins more distal from the Rossland monzonite, both with pyrite, may have been deposited from lower temperature, more oxidized fluids. Again, this may reflect fluid evolution perhaps caused by mixing with meteoric fluids.

Copper-gold mineralization in intrusion-related systems is typically associated with I-type, magnetite-bearing plutons with relatively high oxidation states. This contrasts with more reduced, S-type granitic systems that host tin, tungsten and molybdenite deposits (e.g., Newberry, 1998; Thompson et al., 1999; Ray et al., 2000). However, Rowins (2000) and Thompson et al. (op. cit.) have suggested that some copper-gold deposits are related to reduced, ilmenite-bearing I-type granitic rocks, a model supported for gold-copper veins of the Rossland camp.

In summary, metals that formed the Rossland veins were transported mainly as chloride complexes in a relatively hot, saline, probably acidic magmatic-hydrothermal fluid.

Deposition

Precipitation of metals, carried as chloride complexes, can be caused by a variety of factors, but was probably mainly due to a reduction in temperature, salinity and/or pressure. As well, an increase in the pH of the solution or a decrease in its oxidation state could also promote metal precipitation. It is probable that many of these factors played a role, accounting for the complexity in the fluid inclusions, and the diverse but pronounced mineralogy and metal zonation within the camp.

The zonation of copper-gold to lead-zinc is compatible with a decrease in temperature with distance from the Rossland monzonite. As well, unmixing of original highly saline H$_2$O-CO$_2$-salt solutions, with resultant increase in pH, may have facilitated early copper-gold precipitation. This marked decrease in the solubility of both gold and copper with increasing pH is illustrated in Figure 4-15. Also shown is a proposed fluid evolution path, restricted by precipitation of mainly pyrrhotite and chalcopyrite, and the common occurrence of carbonate gangue in some veins and CO$_2$-rich fluid inclusions.

The prominent structural control to Rossland veins and their brecciated nature implies rock fracturing that would allow sudden pressure drops with resultant metal precipita-
Finally, mixing of saline hydrothermal-magmatic fluids with cooler pore or meteoric fluids, as expected in fractured wallrocks of the Rossland monzonite, would further enhance sulphide deposition.

**STRUCTURAL CONTROLS AND TECTONIC SETTING**

Rossland veins have many characteristics typical of intrusion-related hydrothermal veins. However, their strong preferred alignment and associated shearing are indicative of structural controls as well. Furthermore, a structural control to emplacement of the Rossland monzonite and porphyrite dikes is also clearly evident. The two main vein orientations, west-southwest and west-northwest, suggest a dominant east-west compressive stress. This compression is related to the east-verging thrusts documented immediately to the west; these thrusts emplace oceanic ultramafic assemblages and the Permo-Carboniferous Mount Roberts Formation on to the Rossland Group (Höy and Dunne, 1997). The relatively high pressures recorded in Rossland vein fluid inclusions may be due, in part, to increased lithostatic pressure beneath these thrust plates.

The relative timing of Middle Jurassic intrusions, such as the Rossland monzonite, and tectonic shortening and overlap during thrust tectonics have been documented farther east in the Nelson-Rossland area. There, Nelson-age (165-170 Ma) intrusions are late synkinematic to post-kinematic.

The tectonic setting of the Cu-Au veins has been discussed by many previous workers. For example, Höy et al. (1992, p. 268) concluded that the camp occurs in “a dominantly mafic volcanic pile spatially associated with an oceanic assemblage … is associated with felsic intrusive rocks and ultramafic bodies, and occurs along a major structural break”. Furthermore, we acknowledged that “most (mesothermal) gold mineralization is interpreted to have formed in an accretionary tectonic setting, considerably later than the host volcanic rocks, with fluid flow focused by crustal faults (Kerrick and Wyman, 1990)”. We concluded that despite the apparent similar setting for Rossland Group rocks, additional chronological and isotopic data were necessary to conclude that Rossland mineralization is related to this accretionary or collisional process.

Data presented in this paper supports a model for gold-copper vein mineralization related to intrusion of the ca. 167 Ma Rossland monzonite, late to post intense compressional deformation. Ash (2001) also recognized the importance of crustal structures in localizing the Rossland Cu-Au camp. Ash (op. cit.) concluded that, in common with other lode gold camps in the province, the Rossland camp occurs along a terrane-collisional boundary between ophiolitic assemblages and Rossland arc rocks.

**MODEL SUMMARY**

More eastern veins and related skarn alteration formed at deeper structural levels along the margins of and within the Rossland monzonite. Shearing of hot, crystallized or partially crystallized mafic intrusive material, as is seen along many of the vein margins, would be possible in this environment by increasing fluid pressures to lithostatic pressures (or higher?) and/or by suddenly increasing strain rates (Fournier, 1999). High fluid pressures can only develop beneath an impermeable seal, a barrier that may have developed near the ductile-brittle transition (see Figure 4-12). This seal would allow accumulation of higher temperature and pressure magmatic-hydrothermal fluids in the upper (western) levels of the Rossland monzonite and immediate host rocks. Fluxing of these fluids with the magma concentrated sufficient metals to eventually precipitate massive sulphide veins.

Breaching of the impermeable seal allowed sudden escape of fluids into a brittle environment characteristic of the more western Main veins, North belt veins and most of the South belt veins. This breaching was due to a combination of factors. The buildup of hydrostatic pressure from fluids evolving from the crystallizing magma eventually resulted in hydrostatic pressures greater than the tensile strength of the rock. Tectonic activity enhanced rock fracturing; that this activity is associated with emplacement of the Rossland monzonite is inferred by the east-west alignment of the intrusion and the strong structural control of the porphyrite dykes, the common host for Rossland veins. Intrusion of these dykes may, as well, have provided a breach of the barrier and a conduit for escaping fluids. Resultant rapid drop in hydrostatic pressure, fluid unmixing and possibly mixing with cooler fluids, caused precipitation of metals from the dominantly magmatic-hydrothermal fluids. This reduction in fluid pressure caused the brittle-ductile transition to be depressed to deeper structural levels, thus allowing shearing of the more eastern and Main veins that formed in more ductile environments.
The argument that the Rossland veins are magmatic-hydrothermal veins, related to intrusion of the Rossland monzonite and associated porphyrite dikes, explains some anomalous features. Massive sulphide veins, in contrast to more typical quartz and carbonate-rich mesothermal veins or to veins that show evidence of repeated hydrothermal pulses with associated reintroduction of metals, require that the fluids contained high concentrations of both metals and sulphide. These concentrations are possible in the relatively high temperature and pressure fluids that are documented here. These were supercritical fluids (see Figure 5 in Fournier, 1999) capable of carrying considerable dissolved base and precious metals, particularly if they contained H₂S as well as chloride complexes, as a reduced complexing agent (e.g., Heinrich et al., 1992).

The relatively unusual but extensive skarn alteration associated with deeper levels of the Rossland veins are also readily explained by a magmatic origin. This skarn alteration is zoned around the Rossland monzonite, as is the tenor and alteration assemblages of the veins themselves.

One of the fundamental features of intrusive-related massive sulphide veins appears to be the requirement that the magma intruded ‘hot’ rocks. This allowed the brittle-ductile transition, and impermeable barrier, to be considerably distant from the intrusion and hence allowed a larger volume of rock for concentrations of magmatic-hydrothermal fluids, their fluxing with the intrusion, and resultant concentrations of metals and sulphide species. These elevated geothermal gradients can occur in subvolcanic environments, where high-level magma intrudes a relatively hot volcanic pile (Alldrick and Höy, 1997) or in an area such as Rossland where multiple intrusive phases were emplaced just prior to veining.

This model for Rossland veins is compatible with some of the conclusions of other recent studies of the Rossland camp. Höy and Dunne (1997) argued that the veins appear to be spatially and probably genetically related to the Rossland monzonite, a model developed in large part by Thorpe (1967). Höy and Dunne (op. cit.) suggested, however, that the monzonite is a subvolcanic intrusion, a conclusion that is not supported by U-Pb zircon dating nor fluid inclusion studies that suggest relatively deep emplacement.

The chemistry, mineralogy and form of the Rossland veins is similar in many aspects to some deposits in the Cloncurry Cu-Au district in the Mount Isa area of Australia, summarized by Williams (1999). For example, the Eloise deposit, discovered in 1988 by BHP, is characterized by massive pyrrhotite-chalcopyrite veins that carry appreciable gold and silver.

Alldrick (1996) and Alldrick and Höy (1997) used the term ‘intrusion-related gold-sulphide vein’ to describe the Rossland veins and other similar veins such as Snip, Scottie Gold and Johnie Mountain in Jurassic Hazelton Group rocks in central British Columbia. Their basic model, that massive gold-copper sulphide-rich veins are concentrated along the ductile-brittle transition above an intrusion, is the model still adhered to in this paper. However, their conclusion that these intrusions are subvolcanic or volcanic arc-related intrusions only holds for the more northern veins. We believe that a necessary requirement for this model is relatively ‘hot’ hostrocks or a high geothermal gradient, which may form in a number of settings including a subvolcanic environment but also in areas such as Rossland characterized by extensive plutonic magmatism.

**SUMMARY: ROSSLAND CAMP**

Skarn molybdenum, intrusive-related copper-gold veins, polymetallic veins and lode gold-quartz veins have been extensively mined in the Rossland area. They are in a region that has been tectonically active since Early Jurassic time and which has been intruded repeatedly. Based on field observations and considerable new age dating, the relationships between tectonism, magmatism and mineralization can be constrained more closely and is summarized below (Figure 4-16).

- Sinemurian (ca 200 Ma): tectonic high in the Rossland area, with deposition of Archibald Formation sediments farther east in a structural basin.
- Late Sinemurian (ca. 197-195 Ma): arc volcanism of the Elise Formation, deposited on the Archibald Formation or unconformably on Mount Roberts Formation basement.
- Late Sinemurian(?) intrusion of the subvolcanic Rossland sill complex; (farther east, similar intrusions are associated with alkali copper-gold porphyry mineralization, such as Katie).
- Pliensbachian: minor tectonic activity and uplift; (early synkinematic intrusions recognized farther north, such as the ca 184 Ma Alwyn Creek stock).
- Toarcian: Sediments of the Hall Formation deposited unconformably on the Elise Formation.
- Early Middle Jurassic: intense compressional deformation, tectonic emplacement of ultramafic rocks just west of Rossland; (to the north and east, intrusion of synkinematic ca. 174-178 Ma Silver King plutons).
- Middle Jurassic (ca. 167 Ma): intrusion of the Rossland ‘monzonite’ and diorite porphyrite dikes; (Nelson and Trail plutons); syn to late-kinematic *Rossland Cu-Au and polymetallic veins*; [Second Relief veins and skarn mineralization (ca. 169 Ma) north of Salmo].
- Middle Jurassic (ca. 166-162 Ma): intrusion of Rainy Day pluton, quartz diorite dikes on Red Mountain; brecciation, skarn alteration and molybdenite mineralization on Red Mountain.
- Late Cretaceous: Sophie Mountain deposited unconformably on Rossland Group.
- Eocene: extension and westward tilting to expose oblique view of Rossland camp.

In summary, deposits in the Rossland area record two main periods of mineralization, both related to intrusion of Middle Jurassic plutons. East-trending copper-gold and polymetallic veins of the Rossland camp are spatially and genetically related to the 167 Ma Rossland monzonite and
associated east-trending diorite porphyrite dikes. These veins are parallel to and within the 'Rossland break', a zone of fractures, faults and intrusions that mark a pronounced change in the structural grain in the Rossland area, probably related to east-west compression associated with crustal-scale thrust faulting.

Due to Eocene tilting, the Rossland camp provides an oblique view through a major, intrusive-related gold-copper and polymetallic vein camp. More eastern deposits were formed at deeper structural levels than those in the west, resulting in systematic changes in the structural style, mineralogy and tenor of veins and related deposits from east to west.

The molybdenite breccia-skarn complex, mainly to the west of and structurally above the Rossland veins, is related to 162-163 Ma quartz diorite dikes that may be late phases of the compositionally similar ca. 166 Ma Rainy Day pluton.