GEOLOGY OF THE ROSSLAND AREA, SOUTHEASTERN BRITISH COLUMBIA
(82F/4E)

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KEYWORDS: Regional geology, Rossland Group, Elise Formation, Archibald Formation, Mount Roberts Formation, Sophie Mountain Formation, Trail pluton, Rossland monzonite, Sheppard intrusions, Rossland tectonic high, growth faults, thrust faults, gold-copper veins.

INTRODUCTION

The Rossland map area extends north from the United States border to include the towns of Rossland and Trail in southeastern British Columbia (Figure 1-2-1). The area has been mapped at 1:50 000 scale by Little (1960, 1963, 1982), at 1:20 000 scale by Höy and Andrew (1991) and in more detail in the vicinity of the Rossland gold camp by Fyles (1984) and Drysdale (1915). The purpose of this paper is to describe and interpret the structural geology and tectonic evolution of the the Rossland area, to subdivide the Elise Formation of the Rossland Group in this area and to investigate tectonic and lithologic controls of gold mineralization in the camp. The geology of individual deposits and occurrences is described in considerable detail by Drysdale (*op. cit.*) and Fyles (*op. cit.*); those with more recent exploration activity will be described in forthcoming papers including *Exploration in British Columbia 1990*.

REGIONAL GEOLOGY

The southern part of the Rossland area is underlain primarily by volcanic rocks of the Lower Jurassic Elise Formation. These rest unconformably on metasedimentary rocks of the late Paleozoic Mount Roberts Formation and are in apparent fault contact with rocks of probable similar age but unknown correlation, referred to as Unit Cs (Fyles and Hewlett, 1959; Little, 1982). Locally, the Elise Formation is unconformably overlain by coarse conglomerates of the Late Cretaceous Sophie Mountain Formation.

Four prominent igneous suites intrude these rocks. The Rossland monzonite is an east-trending intrusive complex centred near the Rossland gold camp. It is 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 and in north-trending felsic dikes; they are also cut(?) by the Coryell intrusions.

UNIT Cs

Rocks assigned to Unit Cs are exposed only in the southeastern part of the Rossland area. The western of the two exposures was mapped in detail (Figure 1-2-2). It includes tan to black-coloured argillite, silty argillite and minor siltstone, a massive light grey limestone, some massive dol-omite and dolomitic siltstone. These rocks are locally sil-icified, sheared, brecciated and veined. 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 units in the Elise Formation, suggests a faulted contact between Unit Cs and the Elise. It is possible 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 North American rocks.

Unit Cs is of probable late Paleozoic age, possibly correlative with the Milford Group (Little, 1982). East of the Rossland area, it is in apparent conformable contact with the Laib and Nelway formations (Fyles and Hewlett, 1959). It is being extensively investigated as part of a Ph.D. thesis by Jon Einarsen at the University of Calgary.

MOUNT ROBERTS FORMATION

The Mount Roberts Formation comprises a succession of dominantly fine-grained siliceous rocks, argillite, carbonate and minor greenstone of Pennsylvanian and possibly Permian age (Little, 1982). It may correlate with the Milford Group farther north (Little, 1982; Klepacki, 1985). In the Rossland area, the formation is exposed near Patterson at the United States border, on the eastern slopes of Mount Roberts, Granite and OK mountains northwest of Rossland, and on the western slopes of Red Mountain within the Rossland mining camp (Figure 1-2-2). These localities are described in considerable detail by Little (1982) and the exposures on Mount Roberts, by Fyles (1984).

The Patterson exposures comprise dominantly fine-grained siliceous siltstone, 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 top of the Mount Roberts Formation.

Exposures 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 faces west. Thicker bedded, graded siltstone and sandstone beds, referred to as the sandstone member by Fyles (1984), are locally interbedded with thin, impure dolomite and limestone lenses. These
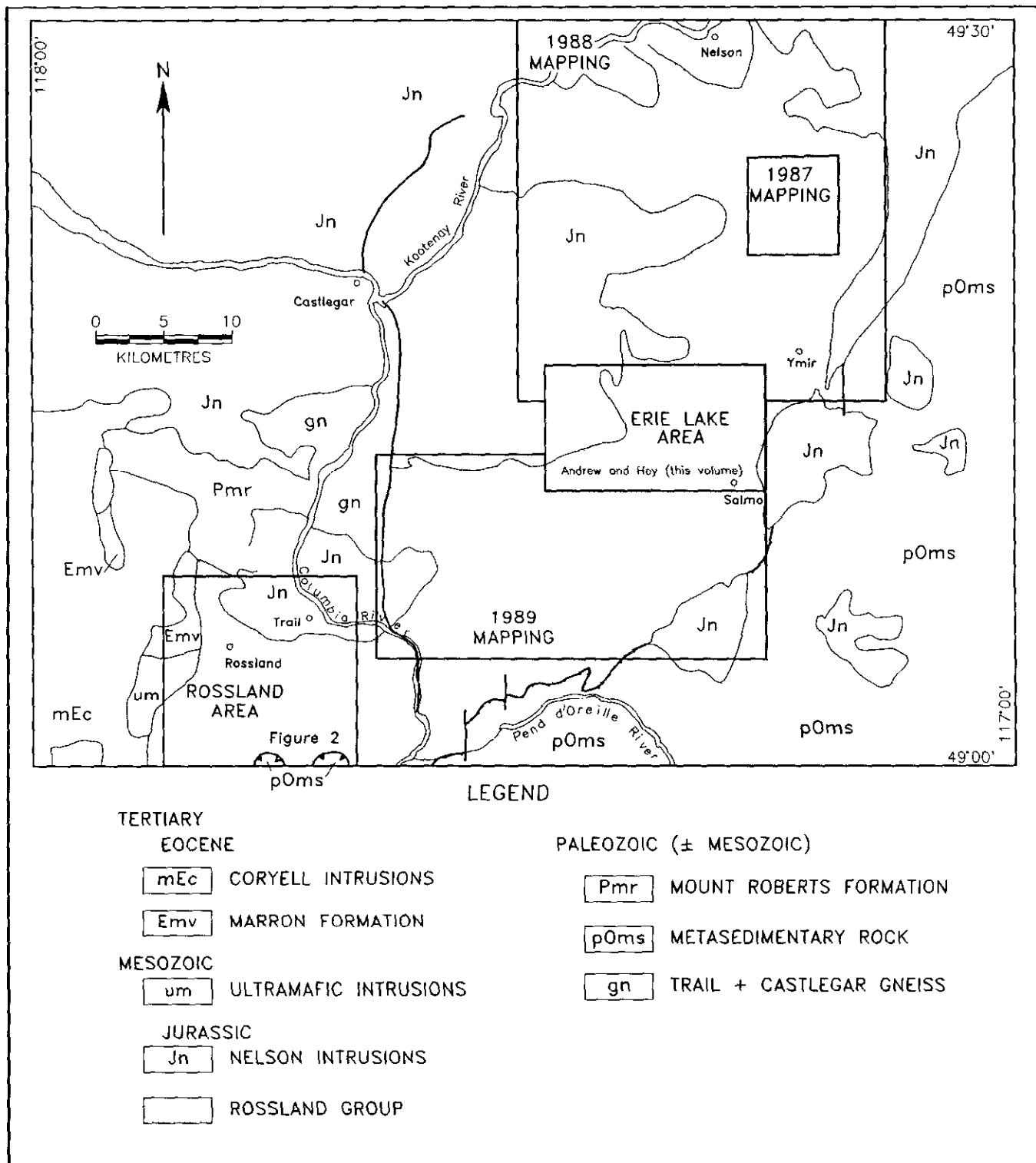
Figure 1-2-1. General location map showing distribution of the Rossland Group in southeastern British Columbia and the Rossland map area.

units also face west and occur directly beneath unconformably overlying volcanic breccias of the Elise Formation.

Siltstones on the western slopes of Red Mountain, which host the Red Mountain molybdenum deposits, are tentatively assigned to the Mount Roberts Formation. They were included in the Rossland Group by Fyles (1984), who noted their structural association with rocks of the Rossland Group and their similarity with Elise Formation siltstones. They include hornfelsed and skarned siltstones and argillites, calcsilicate gneisses suggestive of calcareous protoliths, and some white quartzite layers. Altered diorites within the Red Mountain succession may be sills or dikes; greenstones are recognized in the Mount Roberts Formation farther north (Little, 1982).

The assignment of the Red Mountain succession to the Mount Roberts Formation is based primarily on lithologic similarity. Calcareous rocks and quartzites are relatively common in the Mount Roberts, but are very rare in the Rossland Group. It is suggested that these rocks and a small section of overlying siltstone assigned to the Elise Formation by Fyles (1984), but possibly correlative with the Archibald Formation, are a structural panel thrust onto the Rossland sill. This interpretation infers that a small isolated exposure of Mount Roberts farther north is a klippe that overlies pyroclastic breccia of the Elise Formation (Figure 1-2-2).

ROSSLAND GROUP

The Rossland Group comprises a succession of dominantly coarse to fine clastic rocks of the Archibald Formation, volcanic rocks of the Elise Formation and overlying, dominantly fine-grained clastic rocks of the Hall Formation. These rocks are Early Jurassic in age, bracketed by Sinemurian fossils in the Archibald (Frebold and Tipper, 1970; Tipper, 1984) and Pleinsbachian and Toarcian macrofossils in the Hall (Frebold and Little, 1962; Tipper, 1984). Only the Elise Formation is well exposed in the Rossland area. The Hall Formation is missing, due to nondeposition or to erosion prior to deposition of the unconformably overlying Sophie Mountain Formation. A thin veneer of conglomerate that unconformably overlies the Mount Roberts Formation at Patterson, and was formerly included in the Elise (Little, 1982), is now assigned to the Archibald Formation.

ARCHIBALD FORMATION

The basal sedimentary succession of the Rossland Group, the Archibald Formation, is described in detail by Andrew *et al.* (1990). It comprises coarse conglomerates near Fruitvale, proximal turbidites farther east in Archibald Creek just west of Salmo, and more distal turbidites and argillite to the north, on the east slopes of Erie Creek in the Nelson map area. The only exposures assigned to the Archibald Formation in the Rossland area are a thin succession of conglomerates between the Mount Roberts Formation and overlying lapilli tuffs of the Elise Formation (Figure 1-2-2). These conglomerates were previously included in the basal part of the Elise (Little, 1982); however, their stratigraphic position at the base of the Rossland Group, their sedimentary nature and their inferred paleotectonic setting allow correlation with the Archibald Formation.

The Archibald Formation at Patterson comprises 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 1-2-3). Most commonly, a limestone unit in Mount Roberts lies near 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 plagioclase porphyry 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 Archibald (Plate 1-2-1). The argillaceous matrix is commonly tinged purple, suggestive of subaereal exposure. Bedding, clastsorting 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 nor a tuffaceous matrix.

ELISE FORMATION

The Elise Formation is exposed in an arcuate belt that extends south from Nelson towards Salmo and west to Rossland. It hosts most of the gold deposits of the Rossland Group, including those in the Rossland camp. It comprises a succession of augite-phyric flows, tuffs, some epiclastic deposits and minor siltstone and argillite. In the Nelson area, the formation is readily subdivided into a basal unit of dominantly mafic flows and flow breccias overlain by intermediate pyroclastic rocks (Höy and Andrew, 1989a, b). In the Salmo map area and on the west limb of the Hall Creek syncline in the Nelson area, this distinction is less apparent and mafic flows or tuffs occur throughout the succession (Höy and Andrew, 1990; Andrew and Höy, 1991).

The Elise Formation in the Rossland map area comprises essentially a homoclinal succession that dips north to northwesterly and extends from Patterson in the south to Rossland in the north. Although this succession is offset by numerous north-trending faults, it does not appear to be repeated by thrust faulting. It is not a complete succession as it is developed on the Patterson paleohigh. To the east, in the Goodeve and Sheppard Creek areas, the Elise thickens, due in part to thickening of some units and introduction of others into the succession, but mainly to inclusion of a more complete lower section.

A composite section of the Elise Formation in the Rossland area is illustrated in Figure 1-2-4. Tuffaceous conglomerate (Unit JeI1d) is in gradational contact with conglomerates of the underlying Archibald Formation. The Archibald-Elise contact is placed where either volcanic clasts are first noticed or the matrix becomes tuffaceous. The tuffaceous conglomerates are dominated by clasts of underlying Mount Roberts Formation, including prominent limestone clasts, in a green tuffaceous matrix. Rare augite porphyry and andesite clasts are also noted. The distribution of the basal tuffaceous conglomerate approximately follows
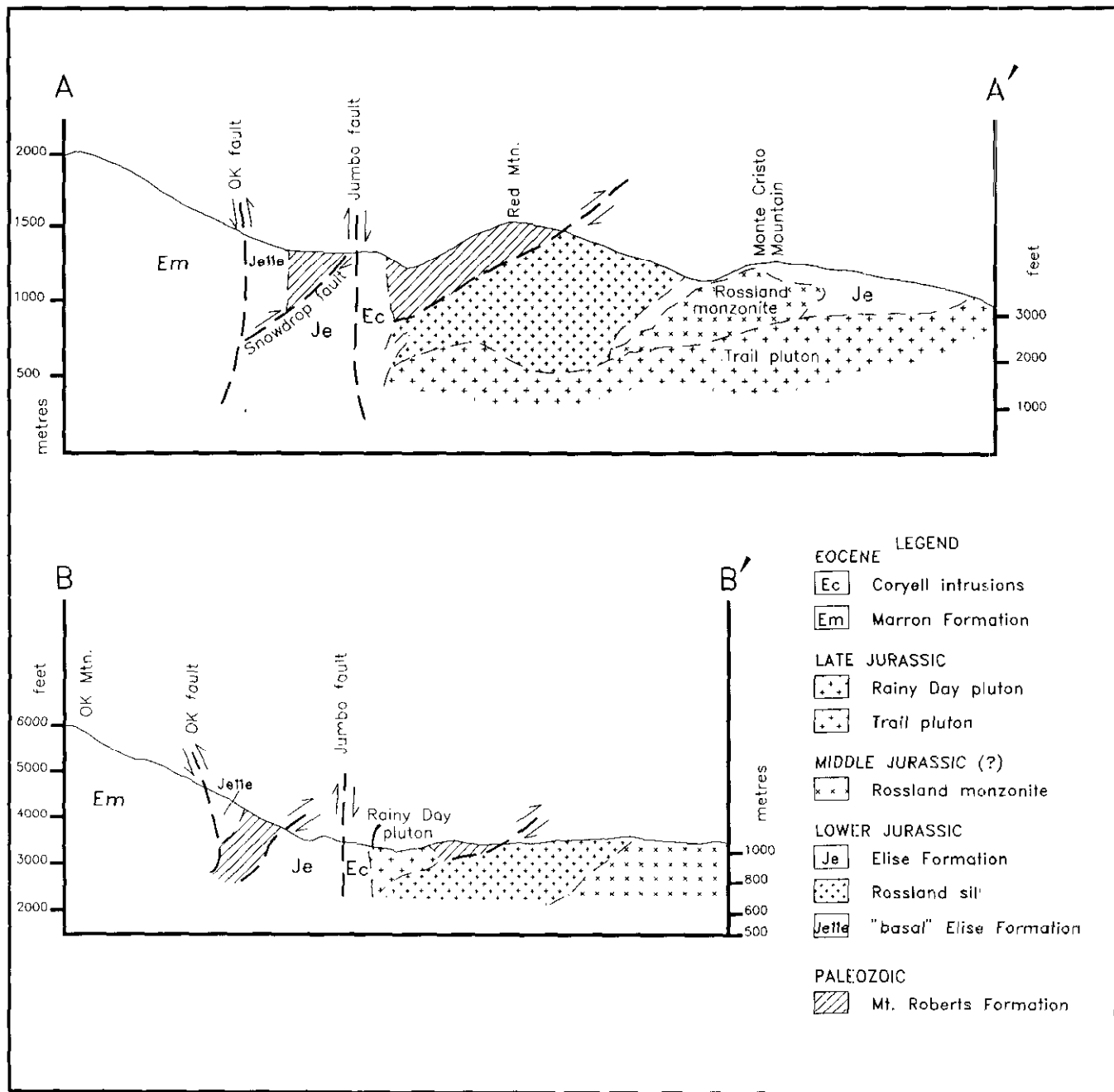
QUATERNARY
Qal alluvium

MIDDLE EOCENE
Ec CORYELL INTRUSIONS
Es SHEPPARD INTRUSIONS
Em MARRON FORMATION

UPPER CRETACEOUS
sm SOPHIE MTN FORMATION
um ULTRAMAFIC INTRUSIONS

JURASSIC
+ NELSON INTRUSIONS
· ROSSLAND MONZONITE
· ROSSLAND SILL (diorite)

ROSSLAND GROUP
Je ELISE FORMATION
Je11e tuffaceous conglomerate, siltstone and mafic volcanic clasts
Je10a siltstone, argillite
Je8 andesite tuff, minor basaltic tuff;
Je8l lapilli tuff; Je8x, crystal tuff
Je7 basaltic tuff; Je7l, lapilli tuff;
Je7x crystal tuff
Je4 mafic flows

ARCHIBALD FORMATION
Ja argillite, siltstone, conglomerate

PALEOZOIC
PENN. –PERM.
/// MOUNT ROBERTS FORMATION
☐ CS UNIT

SYMBOLS
/ / bedding; tops known
    overturned, unknown
/ foliation, cleavage

/ thrust fault

/ normal fault

Höy and Andrew (1991)

Figure 1-2-2a. Geological map of the Rossland area, Rossland-Trail map area (82F/4), southeastern British Columbia (after Höy and Andrew, 1991; Fyles, 1984; Little, 1982 and Drysdale, 1915).

Figure 1-2-2b. Vertical structural sections, Rossland map area; (modified from Fyles, 1984).

that of the underlying Archibald and Mount Roberts formations whereas overlying Elise units thin dramatically as they approach the Patterson paleohigh.

Plagioclase-porphyry lapilli tuff (Unit Je8l) locally overlies the tuffaceous conglomerate. It thickens rapidly just east of Malde Creek. Farther east in the Sheppard Creek area, it is underlain by mafic lapilli tuff and the base of the Elise is not exposed. A sequence of argillaceous siltstone (Unit Je10a) and mafic flows and flow breccias (Unit Je4) overlies the tuffaceous conglomerate. The mafic flows comprise massive augite porphyry, flow breccias and possible minor lapilli tuff; it is the only significant mafic flow suc-

cession in the Rossland area. It appears to pinch out to the west, but can be traced or extrapolated eastward to the Tiger Creek fault. A similar succession of mafic flows east of Tiger Creek may be a faulted repetition of this unit (Figure 1-2-2). The interbedded siltstones are typically thin bedded, rusty weathering distal turbidites. Numerous sedimentary structures, including rip-ups, graded beds and load casts provide reliable top indicators. This sedimentary succession also thins westward, and increases in thickness to the east. Just west of the Tiger Creek fault a sequence of mafic lapilli tuffs is interbedded with the upper part of the siltstone succession (Figure 1-2-2).
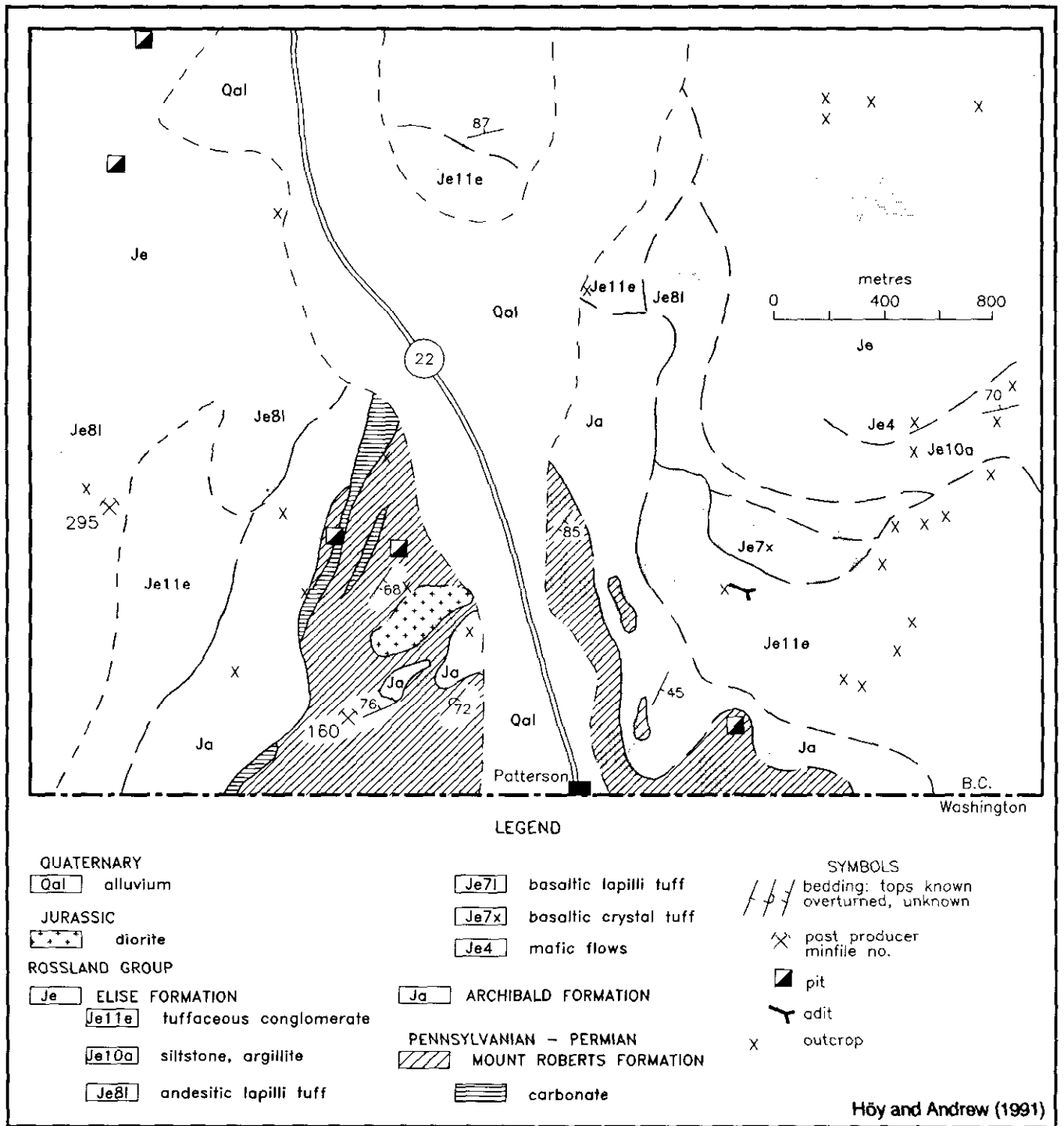
LEGEND

QUATERNARY
Qal   alluvium

JURASSIC
[+ + +]   diorite

ROSSLAND GROUP
Je   ELISE FORMATION
Je11e   tuffaceous conglomerate
Je10a   siltstone, argillite
Je8l   andesitic lapilli tuff

Je7l   basaltic lapilli tuff
Je7x   basaltic crystal tuff
Je4   mafic flows

Ja   ARCHIBALD FORMATION

PENNSYLVANIAN — PERMIAN
MOUNT ROBERTS FORMATION
carbonate

SYMBOLS
bedding: tops known
overturned, unknown

past producer
minfile no.

pit

adit

X   outcrop

Höy and Andrew (1991)

Figure 1-2-3. Geology of the Patterson area showing distribution of the Mount Roberts Formation and unconformably overlying Archibald (?) and Elise formations.
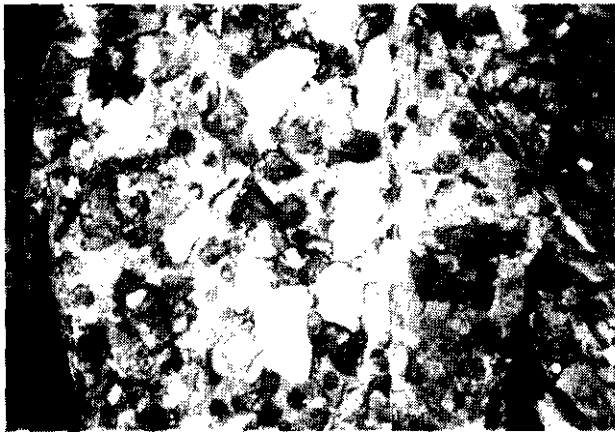
Plate 1-2-1. Limestone breccia of Archibald Formation, Patterson area.
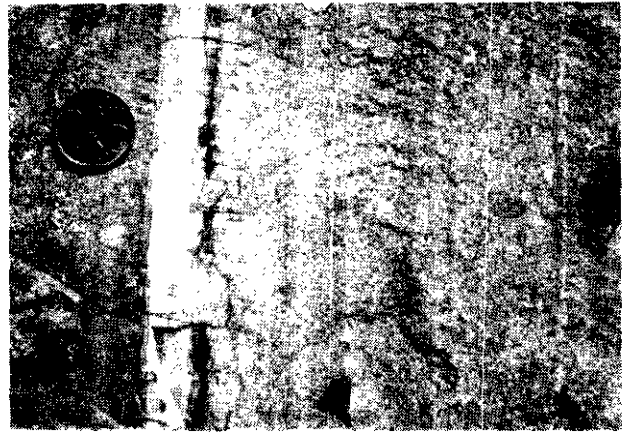
Plate 1-2-2a. Well-bedded, mafic waterlain tuffs of Unit Je7x south of Tamarac Mountain.
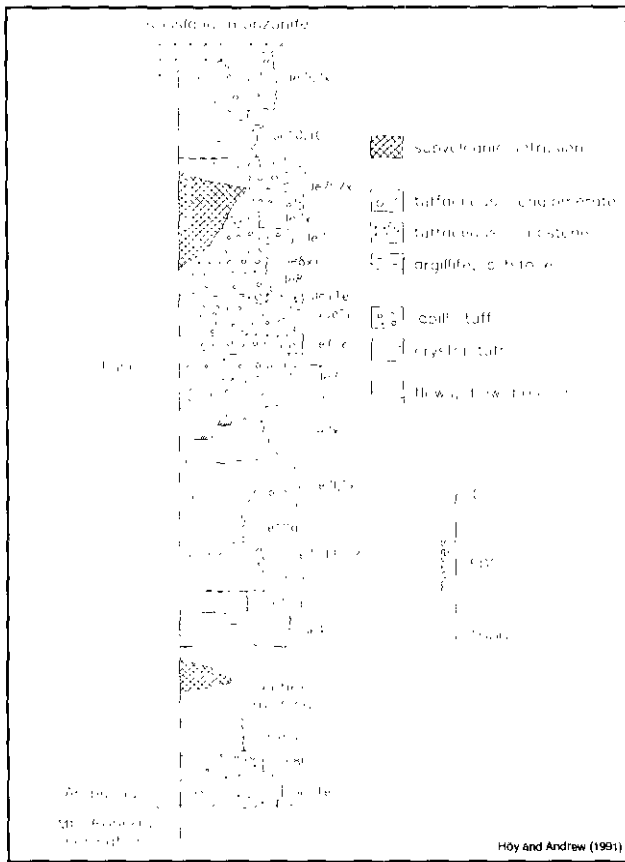

Figure 1-2-4. Composite stratigraphic section of the Rossland Group, Rossland map area.
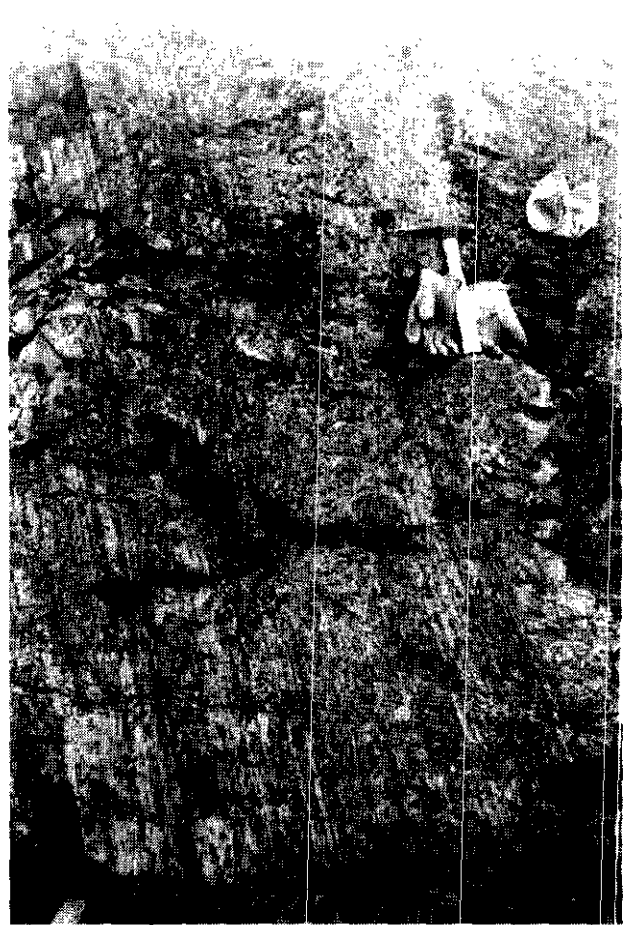

Plate 1-2-2b. Beds of mafic waterlain tuff (Unit Je7x) south of Violin Lake

A distinctive waterlain crystal tuff (Unit Je7x) extends from the western slopes of Tamarac Mountain to the north slopes of Baldy Mountain and in the Lake Mountain and Goodeve Creek areas. It coarsens upward and is supplanted to the east by mafic lapilli tuff (Unit Je7l). Unit Je7x is an interbedded succession of brown-weathering, massive to well-bedded mafic waterlain tuffs, minor tuffaceous sandstone and, at the base, minor argillite and silty argillite

(Plates 1-2-2a and 2b). The crystal tuffs commonly contain small, widely scattered augite porphyry lapilli and numerous plagioclase and augite crystals. Layers of lapilli tuff become more prominent near the top of the succession.

Unit Je7l (Figure 1-2-2) comprises dominantly mafic lapilli tuff, but includes pyroclastic breccia and waterlain

crystal tuffs. Clasts in the tuffs are dominantly augite porphyry; however, a variety of other clasts are noted, including limestone, plagioclase porphyry and green 'siltite' (Unit Je11d, Figure 1-2-3). A prominent, more felsic lapilli tuff, (Unit Je8) is recognized within Unit Je7l both east and west of the Tiger Creek fault. It contains fragments of both plagioclase porphyry and augite porphyry. Some plagioclase-rich crystal tuffs are also included in Unit Je8.

Interbedded argillaceous siltstone and tuffaceous sandstone (Units Je10) occur near the top of the exposed Elise succession, just south of the Rossland monzonite. These host a number of vein deposits (Höy and Andrew, 1991).

The Rossland sill, exposed south of the Rossland monzonite and on the east slopes of Red Mountain, intrudes the upper part of the Elise Formation. It has been described in detail by Fyles (1984). It is an augite porphyry intrusion that hosts a number of the principal orebodies of the Rossland camp. It is overlain (structurally?) to the west by the Mount Roberts Formation and is cut by the Rossland monzonite. A similar, but smaller augite porphyry intrusion is exposed just south of Mount Malde (Figure 1-2-2; Höy and Andrew, 1991).

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 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.

The Hall Formation, the upper sedimentary sequence of the Rossland Group, is also missing in the Rossland area. Rather, conglomerates of the Late Cretaceous Sophie Mountain or Eocene Marron volcanics unconformably overly Elise rocks, suggesting the Rossland area remained a tectonic high through considerable geologic time.

SOPHIE MOUNTAIN FORMATION

The Sophie Mountain Formation (Bruce, 1917; Little, 1960) is exposed on Mount Sophie and on the ridge a few kilometres southeast of Baldy Mountain. A small exposure is also recognized on the ridge north of Lake Mountain (Höy and Andrew, 1991) and in Hudu Creek 2 kilometres from its confluence with Beaver Creek (Andrew et al., 1990). 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.

MARRON FORMATION

The Middle Eocene Marron Formation (Bostock, 1940; Church, 1973; Little, 1982) is exposed on the eastern slopes

of OK Mountain and Mount Roberts just west of Rossland and just 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 stocks and dikes, occur throughout the Rossland area. They are described in considerable detail by Fyles (1984) and Little (1982) and hence will only be briefly described here.

The Rossland monzonite is an east-trending stock with a wide thermal aureole and, locally, a gradational contact with country rocks (Fyles, 1984). It is grey to green, fine to medium grained and comprises dominantly andesine (46%), hornblende (15%), orthoclase microperthite (~13%), augite (~12%), biotite (11%) and quartz (2%) (Fyles, op. cit.). Its age is not known; however, it is cut by the Late Jurassic Trail pluton and hence may be part of a 178 to 180 Ma suite of calcalkaline intrusions in southeastern British Columbia, including the Silver King porphyries in the Nelson area, the Mount Cooper stock (Klepacki, 1985) and the Aylwin Creek stock (W.J. McMillan, personal communication, 1989).

The Trail pluton (Simony, 1979; Little, 1982) is part of the Late Jurassic Nelson plutonic suite. It is dominantly a medium to coarse-grained granodiorite, but locally includes quartz diorite and diorite phases.

The Sheppard intrusions include a number of large stocks and numerous smaller dikes that cut Nelson intrusive rocks and the Late Cretaceous Sophie Mountain Formation. These rocks are commonly fine to medium grained and leucocratic, ranging in composition from granite to syenite. North-trending Sheppard dike swarms are prominent northwest of Waneta on the west side of the Columbia River, in the Baldy Mountain area. They may record Middle Eocene east-west extension.

The Coryell intrusions are generally coarse grained and range in composition from syenite to monzonite and granite. Field relationships and numerous K-Ar dates (Little, 1982) indicate that these rocks are of similar age to the Middle Eocene Marron volcanics. Numerous small intrusions are present throughout the Rossland area; only the largest are shown on Figure 1-2-2.

STRUCTURE

The structure of the Rossland area has been well described by Fyles (1984) and Little (1982). 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, page 29). South of the break, structures trend northeasterly, whereas to the north, they trend northerly.

Detailed mapping, concentrated largely south of Ross-land, has essentially confirmed the structures as outlined by Fyles. However, correlation of both 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 are recognized:

1. extensional tectonics during deposition of lower Rossland Group rocks in Early Jurassic time;

2. east-directed thrust faults and associated minor folding before intrusion of Middle to Late Jurassic plutons;

3. normal faulting in Eocene time.

The Rossland area is underlain by a tectonic high, bounded by growth faults, that is first evident in early Rossland time. The basal sedimentary succession of the Rossland Group, the Archibald Formation, records deposition in a fault-bounded structural basin located just east of the Rossland map area, in the Beaver Creek valley (Andrew et al., 1990). 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 1-2-2, 4) confirming the suggestion of a tectonic high here. Neither the orientation nor the exact position of the bounding growth faults are known; however, the rapid facies changes in Elise rocks just east of Patterson suggest that the late north-trending faults located there may 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.

A period of compressive tectonics, evident throughout the Rossland Group in Middle Jurassic time, is probably related to collision of the eastern edge of Quesnellia with cratonic North America. It produced tight folds, a penetrative cleavage and intense shearing in eastern exposures, and more open, upright folds and thrust faults farther west. In the Rossland area, it is marked by the Waneta fault and a number of east-directed thrust faults and possible associated minor folds. The Waneta fault, initially recognized by Fyles and Hewlett (1959) in the Salmo area, separates rocks of North America (Unit Cs) from those of Quesnellia. The fault has been traced westward to the Rossland area (Little, 1982) where it is covered by Eocene volcanic rocks of the Marron Formation. It is suggested that exposures of Unit Cs farther west are also thrust on younger Elise volcanic rocks (Figure 1-2-2). Both units are sheared and brecciated in the vicinity of the contact.

Thrust faults west and north of Rossland include the Snowdrop fault (Little, 1962; Fyles, 1984) and an inferred fault that separates Mount Roberts Formation from Elise Formation on Red Mountain (Figure 1-2-2). 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).

The Snowdrop fault 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 1-2-2). The thrust fault on Red Mountain is inferred from stratigraphic relationships (see section on Mount Roberts Formation). It is placed at the contact of Mount Roberts with underlying Elise Formation, Rossland sill and Rossland monzonite. The faulted nature of this contact has not been previously recognized despite being exposed at surface and penetrated by numerous drill holes. It is suggested that intense alteration, both thermal and metasomatic, has obliterated evidence of fault movement along the contact.

The age of this compressive deformation is post-Toarcian (ca. 187 Ma), the youngest age of Rossland Group rocks, and pre-intrusion of late Jurassic plutons (ca. 165 Ma). In the Rossland area, the age of east-directed thrusts is bracketed by the age of the Rossland monzonite (Höy and Andrew, in preparation) and the Late Jurassic Rainy Day pluton.

Steeply dipping, generally north-trending normal(?) faults occur throughout the Rossland area. A number of these, including the OK and Jumbo faults (Fyles, 1984) and the Violin Lake fault (Little, 1982) have been recognized previously. The OK fault is a listric normal fault that is overturned to the east at higher stuctural levels (Sections A-A', B-B', Figure 1-2-2). Marron Formation rocks in the western block have been down-dropped in excess of 600 metres (Fyles, op. cit.). The Jumbo fault dips steeply east and has an inferred normal displacement of 600 to 700 metres. This movement is based on correlation of the Mount Roberts Formation on the eastern slopes of Mount Roberts with similar rocks on Red Mountain, and on the Snowdrop fault with the inferred thrust on Red Mountain.

The Violin Lake fault is a vertical structure with an unknown amount of displacement on it (Little, 1982). 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 1-2-2). 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 Formation, and a western splay of the Tiger Creek fault truncates

Sheppard intrusions in the Mount Sophie Formation (Figure 1-2-2). These faults are undoubtably related to an Eocene extensional event in southern British Columbia (Parrish *et al.*, 1988; Corbett and Simony, 1984).

In summary, structures in the Rossland area record similar tectonic events as elsewhere in the Rossland Group: extensional tectonics and growth faults during deposition of the lower part of the Rossland Group in Early Jurassic time; compressional tectonics that initially occured in eastern exposures, as Quesnellia impinged on rocks of North America, and continued with east-directed thrusts and folds in more western exposures in Middle Jurassic time; and Middle Eocene extensional tectonics.

ECONOMIC GEOLOGY

The Rossland mining camp is the second largest gold-producing camp in British Columbia, with recovery of more than 84 000 kilograms of gold and 105 000 kilograms of silver between 1894 and 1941. These deposits are in three main groups referred to as the north belt, the main veins and the south belt. Mineralization in the Rossland camp also includes molybdenum deposits on the western slopes of Red Mountain. These deposits have been described by a number of authors, including Drysdale (1915), Gilbert (1948), Little (1963), Stevenson (1935) and Fyles (1984): the paper by Fyles summarizes much of the previous work and describes the molybdenum mineralization in considerable detail. The following report only summarizes the geology of these deposits; it is taken largely from Fyles: more complete geology descriptions and interpretations will appear in forthcoming papers.

MOLYBDENUM DEPOSITS

Molybdenum deposits on Red Mountain (Plate 1-2-3) produced 1 748 871 kilograms of molybdenum from approximately 1 million tonnes of ore between 1966 and 1972 (MINFILE). 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). We correlate this succession with the Mount Roberts Formation and suggest that it has been

Plate 1-2-3. View of open-pit molybdenum mine on Red Mountain, town of Rossland and Lake Mountain in distance.

thrust over the underlying Rossland sill prior to intrusion of Middle to Late Jurassic plutons.

Molybdenum occurrences are spatially associated with the Jurassic Trail and Rainy Day plutons. In the Nelson map area, both skarn and porphyry molybdenum mineralization occur along the margins of Nelson plutonic rocks (Höy and Andrew, 1989a). Local crosscutting pyrrhotite-chalcopyrite veins on Red Mountain indicate that the mineralization is earlier than the copper-gold mineralization (Fyles, *op. cit.*).

GOLD-COPPER AND GOLD VEINS

The Rossland gold-copper veins are dominantly pyrrhotite with chalcopyrite in a gangue of altered rock with minor lenses of quartz and calcite. In the north belt, a zone of discontinuous veins extends eastward from the northern ridge of Red Mountain to Monte Cristo Mountain. The veins trend east and dip north at 60° to 70°. The largest, on the Cliff and Consolidated St. Elmo claims, is in the Rossland sill; it is 1 to 2 metres thick and is exposed for almost 100 metres strike length. Some veins in the north belt cross the molybdenum breccia zone on Red Mountain.

The main veins form a continuous well-defined fracture system that trends 070° from the southern slopes of Red Mountain northeastward to the eastern slopes of Columbia Kootenay Mountain. More than 98 per cent of the ore shipped from the Rossland camp was produced from these veins and more than 80 per cent from deposits in a central core zone between two large north-trending lamprophyre dikes. These deposits include the Le Roi, Centre Star, Nickel Plate, Josie and War Eagle orebodies.

The main vein system consists of a series of veins, commonly en echelon, that dip steeply north. They are mostly within the Rossland sill or the Rossland monzonite, crosscut lithologies and early structures, but appear to be cut by the late north-trending faults and associated dikes.

The principal veins in the south belt trend 110° 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. In addition to the typical copper-gold mineralization of the main veins and north belt, some veins in the south belt also contain sphalerite, galena, arsenopyrite and boulangerite.

High-grade gold veins also occur approximately 4 kilometres southwest of Rossland in the Little Sheep Creek valley. They are in "greenstones" of the Rossland Group adjacent to a small body of serpentinite. Gangue minerals include quartz and ankerite; sulphides are not common, but include pyrite, chalcopyrite and galena.

SUMMARY

Both skarn-porphyry molybdenum and copper-gold vein deposits have been extensively mined in the Rossland area. They are in an area that has been tectonically active since Early Jurassic time and has been intruded repeatedly by plutonic rocks. Molybdenum mineralization, associated with intense brecciation and skarning, appears to be related to intrusion of Middle to Late Jurassic plutons, including the Trail and Rainy Day plutons. These intrusions postdate east-

directed thrust faults and related folds in the Rossland area. East-trending copper-gold veins cut these earlier structures, but are earlier than the north-south, Eocene extensional faults. The veins are parallel to and within the "Rossland break", a zone of fractures, faults and intrusions that marks a pronounced change in the structural grain. These structures, the anomalous thickness of the upper Elise Formation, prominent facies changes in Elise rocks and the higher concentration of intrusions suggest the influence of deep crustal structures, structures that may have controlled the distribution of metallic mineral deposits.

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REFERENCES

Andrew, K.P.E., Höy, T. and Drobe, J. (1990): Stratigraphy and Tectonic Setting of the Archibald and Elise Formations, Rossland Group, Beaver Creek Area, Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1989, Paper 1990-1, pages 19-27.

Andrew, K.P.E. and Höy, T. (1991): Geology of the Erie Lake Area with Emphasis on Stratigraphy and Structure of the Hall Formation, Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1990, Paper 1991-1, this volume.

Bostock, H.S. (1940): Keremeos, British Columbia; *Geological Survey of Canada*, Map 341A.

Bruce, E.L. (1917): Geology and Ore Deposits of Rossland, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 4.

Church, (1973): Geology of the White Lake Basin; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 61.

Corbett, C.R. and Simony, P.S. (1984): The Champion Lake Fault in the Trail-Castlegar Area of Southeastern British Columbia; *in* Current Research, Part A, *Geological Survey of Canada*, Paper 84-1A, pages 103-104.

Drysdale, (1915): Geology and Ore Deposits of Rossland, British Columbia; *Geological Survey of Canada*, Memoir 77.

Frebold, H. and Little, H.W. (1962): Paleontology, Stratigraphy, and Structure of the Jurassic Rocks in Salmo Map-area, British Columbia; *Geological Survey of Canada*, Bulletin 81.

Frebold, H. and Tipper, H.W. (1970): Status of the Jurassic in Canadian Cordillera of British Columbia, Alberta, and Southern Yukon; *Canadian Journal of Earth Sciences*, Volume 7, pages 1-21.

Fyles, J.T. (1984): Geological Setting of the Rossland Mining Camp; *B.C. Ministry of Energy, Mines, and Petroleum Resources*, Bulletin 74, 61 pages.

Fyles, J.T. and Hewlett, C.G. (1959): Stratigraphy and Structure of the Salmo Lead-Zinc Area; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 41, 162 pages.

Gilbert, G. (1948): Rossland Camp; *in* Structural Geology of Canadian Ore Deposits; *Canadian Institute of Mining and Metallurgy*, Jubilee Volume, pages 189-196.

Höy, T. and Andrew, K.P.E. (1989a): The Rossland Group, Nelson Map Area, Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1988, Paper 1989-1, pages 33-43.

Höy, T. and Andrew, K.P.E. (1989b): Geology of the Rossland Group, Nelson Map Area, Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1989-1.

Höy, T. and Andrew, K.P.E. (1990a): Structure and Tectonic Setting of the Rossland Group, Mount Kelly - Hellroaring Creek Area, Southeastern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1989, Paper 1990-1, pages 11-17.

Höy, T. and Andrew, K.P.E. (1991): Geology of the Rossland-Trail Area, Southeastern British Columbia (82F/4); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1991-2.

Klepacki, D.W. (1985): Stratigraphy and Structural Geology of the Goat Range Area, Southeastern British Columbia; unpublished Ph.D. thesis, *Massachusetts Institute of Technology*, 268 pages.

Little, H.W. (1960): Nelson Map-area, West-half, British Columbia; *Geological Survey of Canada*, Memoir 308, 205 pages.

Little, H.W. (1963): Rossland Map-area, British Columbia; *Geological Survey of Canada*; Paper 63-13.

Little, H.W. (1982): Geology, Rossland-Trail Map-area, British Columbia; *Geological Survey of Canada*, Paper 79-26, 38 pages.

Parrish, R.R., Carr, S.D. and Parkinson, D.L. (1983): Eocene Extensional Tectonics and Geochronology of the Southern Omineca Belt, British Columbia and Washington; *Tectonics*, Volume 7, pages 181-212.

Simony, P.S. (1979): Pre-Carboniferous Basement near Trail, British Columbia; *Canadian Journal of Earth Sciences*, Volume 16, Number 1, pages 1-11.

Stevenson, J.S. (1935): Rossland Camp; *Minister of Mines, British Columbia*, Annual Report 1935, pages E4-E11.

Tipper, H.W. (1984): The Age of the Jurassic Rossland Group of Southeastern British Columbia; *in* Current Research, Part A, *Geological Survey of Canada*, Paper 84-1A, pages 631-632.

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