Geology of the Northern Extension of the Rock Creek Graben, Christian Valley Map Area, South-Central British Columbia (NTS 082E/10)

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Introduction

The Christian Valley project, funded by Geoscience BC, is a continuation to the north of geological mapping of the Rock Creek graben located in south-central British Columbia (BC) that was begun in 2015 in the Almond Mountain map area (Figure 1; Höy, 2016; Höy and Jackaman, 2016). The project is part of a regional mapping, compilation and mineral-potential evaluation of the east half of the 1:250 000 scale Penticton map area (NTS 082E) that has focused mainly on the structural, stratigraphic and magmatic controls of base- and precious-metal mineralization in an area dominated by Eocene extensional tectonics.

Geological and Exploration History

The Christian Valley area appears on the Penticton map area (NTS 082E), mapped and compiled at a scale of 1:250 000 by Tempelman-Kluit (1989). The area was first mapped by Little (1957) as part of a regional mapping project that covered the east half of the Penticton map area. Considerable mapping at more detailed scales has been done in the western and southwestern portions of the area by Christopher (1978) and Massey and Duffy (2008), and by junior exploration companies that were mainly concentrating on the uranium potential of the area. Geological mapping in the Christian Valley map area in 2016 focused on the western part of the area dominated by the north-trending Rock Creek graben. Additional work will include compilation in digital format of all regional geological, geophysical and geochemical data collected under the National Geochemical Reconnaissance and BC Regional Geochemical Survey programs, Ar-Ar and U-Pb dating of both volcanic and intrusive rocks within the area, an update of the BC MINFILE database, and final publication of the 1:50 000 scale Christian Valley map area.

Keywords: *British Columbia, geology, regional compilation, Eocene stratigraphy and magmatism, Eocene extensional tectonics, uranium, base- and precious-metal mineralization*

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Exploration in the western part of the Christian Valley map area has been directed mainly toward the discovery of uranium deposits and, to a lesser extent, base- and precious-metal mineralization due largely to the successful exploitation of the veins in the Highland Bell mine to the southwest and of base- and precious-metal deposits in the Greenwood camp farther south (Figure 2).

A number of exploration programs for uranium in the area north of Beaverdell Creek and in the Trapping Creek area were conducted during the 1970s, prior to the moratorium on uranium exploration that was enacted in BC in 1980. This work included geological mapping (e.g., McCandless and Hughes, 1977) and a number of core and percussion drilling programs with ancillary radiometric and geochemical sampling surveys (e.g., Okuno, 1972; Inazumi, 1973; Turner et al., 1980). The work focused mainly on uranium deposits hosted in basal sedimentary rocks that underlie Pliocene plateau basalt. In 1978, the BC Geological Survey initiated a study of the potential for uranium mineralization in the district with resultant publication of several reports (Christopher, 1977, 1978). In 1999, exploration work, mainly sampling programs, was renewed on these uranium deposits and continued intermittently through to 2008 (e.g., Brickner, 2003; McLelland, 2008).

Regional Geology

The Christian Valley map area occupies the central part of the Penticton map area in south-central BC. The area is mainly underlain by a variety of igneous intrusive rocks that range in age from Jurassic to Eocene (Tempelman-Kluit, 1989). Basement rocks comprise late Paleozoic metasedimentary and metavolcanic rocks of the Quesnel terrane, which includes the oceanic rocks of the Knob Hill Group and Anarchist Schist, and the arc-related Harper Ranch subterrane (Wheeler and McFeely, 1991). Overlying arc-volcanic rocks include the Triassic Nicola Group, exposed in the Greenwood area to the south and throughout the Thompson Plateau area to the west (Preto, 1979), and the Early Jurassic Rossland Group along the southeastern margin of Quesnellia (Höy and Dunne, 2001).

Regional extension during the Eocene had a profound effect on the physiography and metallogeny of south-central

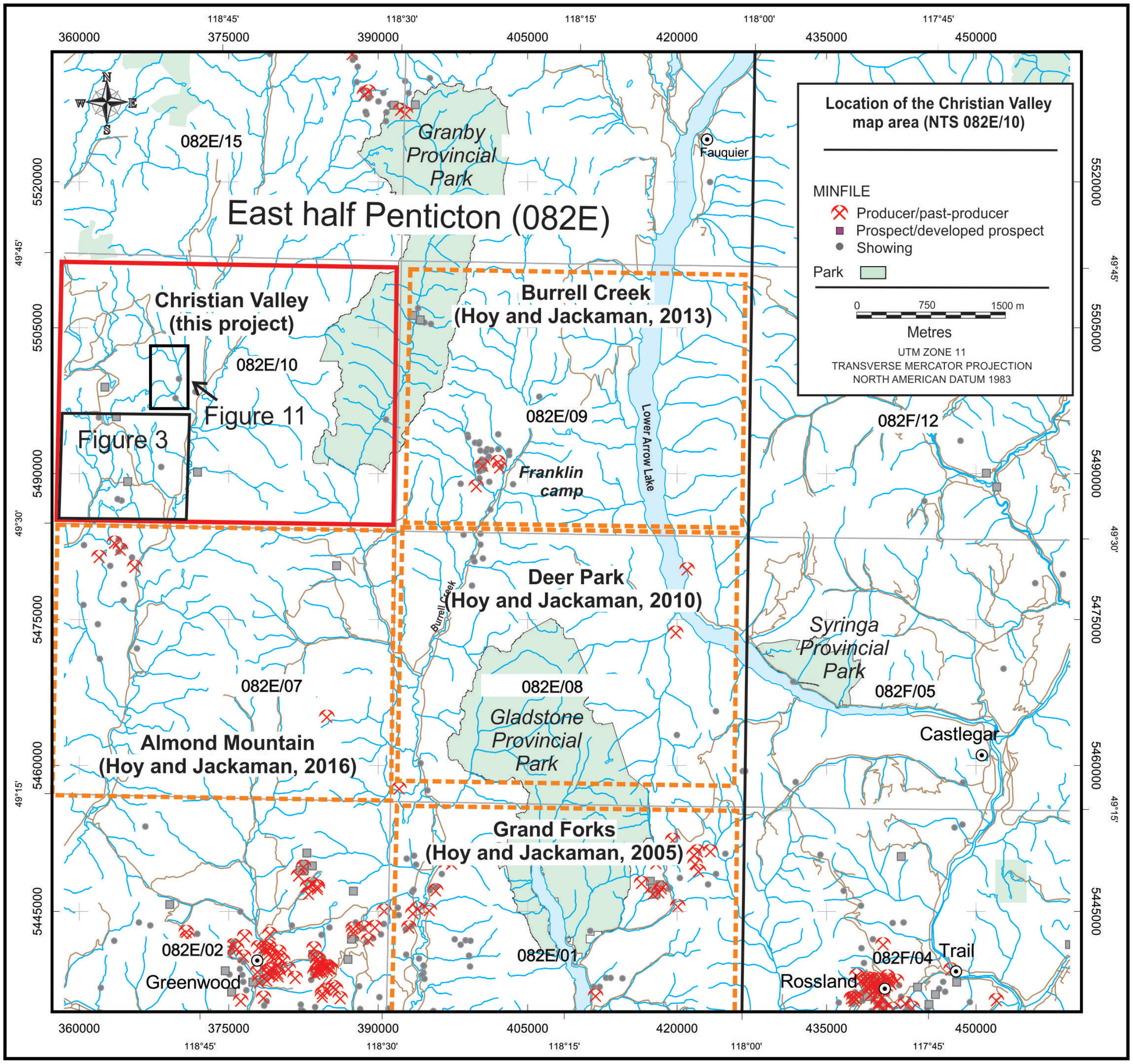

Figure 1. Location of the 1:50 000 scale Christian Valley map sheet (NTS 082E/10) in south-central British Columbia; modified from BC MapPlace (BC Geological Survey, 2016a).

BC, with low-angle detachment faults exhuming Proterozoic and Paleozoic gneissic and platform rocks that formed the metamorphic-core complexes of the southern Monashee Mountains, including the Grand Forks complex in the southeastern part of the Penticton map area (Preto, 1970). Extension in the hangingwall terrane, between the Granby fault at the western margin of the Grand Forks complex and the Okanagan detachment fault to the west (Figure 2) produced north-trending grabens that preserved Eocene volcanic rocks, resulted in the intrusion of Eocene granitic and alkalic intrusive rocks and localized both base -and precious-metal mineralization throughout the eastern portion of the Penticton map area.

Geology of the Christian Valley Area

The Rock Creek graben extends northward through the central part of the Christian Valley map area (Figure 3). The graben in this area is filled with Eocene alkaline volcanic rocks, referred to as the Kamloops Group (Christopher, 1978) and, to the south and west, the Penticton Group (Figure 4; Church, 1973; Fyles, 1990). Older granitic rocks of the Okanagan batholith, and metasedimentary and metavolcanic rocks of the Paleozoic Wallace group (Massey and Duffy, 2008) are exposed west of the graben and the Okanagan batholith, and Eocene Coryell syenite is exposed to the east (Figure 3). The 'Kallis formation' (Massey and

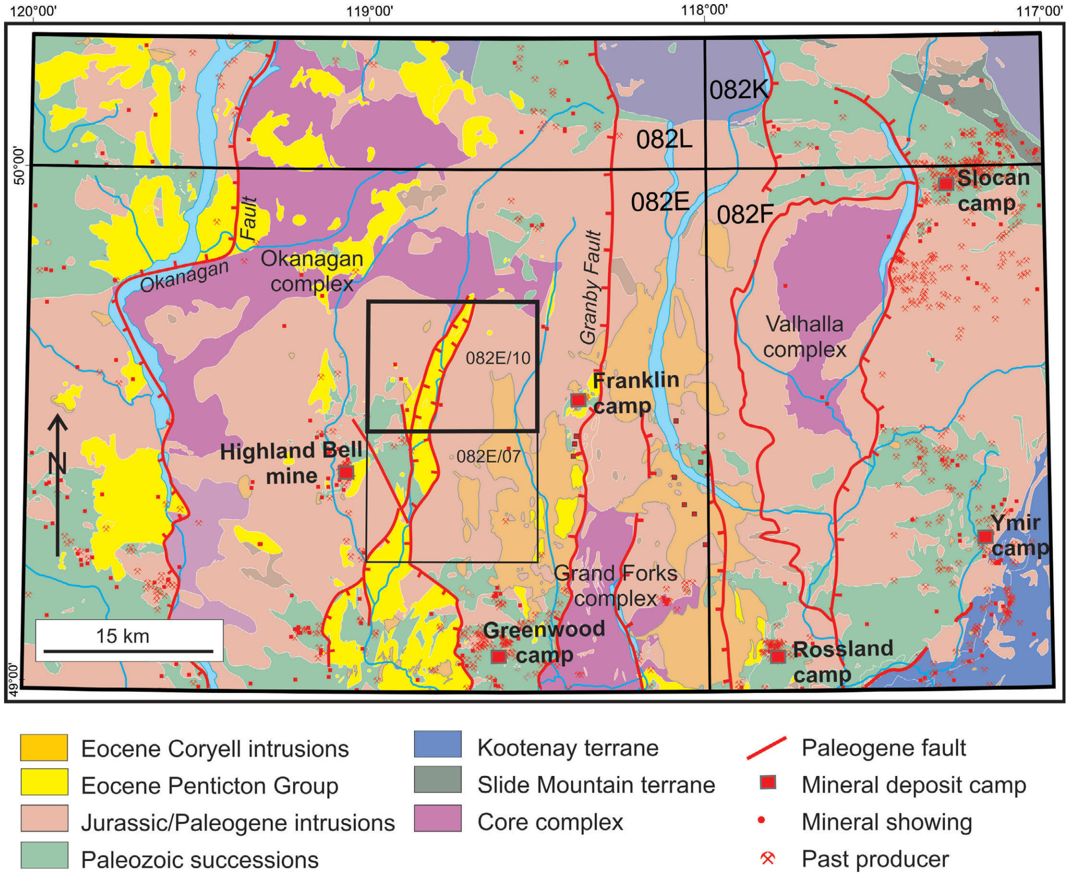

Figure 2. Geology of part of the Penticton map area, showing the location of the Christian Valley (NTS 082E/10) and Almond Mountain (NTS 082E/07) map areas (modified from Tempelman-Kluit, 1989).

Duffy, 2008), remnants of widespread Pliocene plateau basalt, is preserved in isolated topographic highs throughout the area.

Wallace Group

The Wallace group was initially defined by Reinecke (1915) to include Paleozoic metasedimentary and metavolcanic rocks in the Beaverdell area to the southwest. These rocks have been studied in detail by Massey and Duffy (2008) in the Almond Mountain map area; they are poorly exposed in the southwestern part of the Christian Valley map area, where they comprise mainly rusty-weathering argillite and siltstone, and minor greenstone that may represent mafic tuff.

Triassic–Jurassic Intrusive Rocks

'Middle Jurassic' granodiorite (mJg) was originally mapped by Little (1957) in several small stocks in the western part of the Christian Valley map area. These are shown on subsequent geological maps by Christopher (1978), Tempelman-Kluit (1989) and Massey and Duffy (2008). Exposures are foliated to massive biotite-hornblende granodiorite, typical of rocks of the Middle Jurassic Nelson plutonic suite. The Westkettle batholith, which hosts many of the veins in the Highland Bell mine (Reinecke, 1915), is lithologically similar to the granodiorite intrusions in the Christian Valley map area, but has been dated at 213.5 Ma by U-Pb zircon geochronology (Massey et al., 2010). Additional samples of these intrusive rocks have been submitted to the geochronology laboratory of the University of British Columbia for testing by both the $^{40}Ar/^{39}Ar$ and U-Pb methods of age determination.

Granite (Unit Tg)

Granite and granodiorite of the 'Cretaceous and/or Jurassic' Okanagan batholith (Tempelman-Kluit, 1989) underlie a large part of the Christian Valley map area west and east of the Rock Creek graben. These comprise mainly medium-grained, fresh white to pink-tinged quartz-plagioclase-orthoclase granite, with variable but generally minor biotite and hornblende. Porphyritic phases, with large white to pink feldspar crystals, are common in exposures east of the Rock Creek graben (Figure 3). Based on lithological similarities to Eocene 'Ladybird' granite in the Deer Park and Burrell Creek areas to the east, granitic rocks in the Christian Valley map area are assumed to be Paleogene in age. This is supported by a K-Ar date on biotite of 56.3 Ma from a sample of the 'Ladybird' granite located along Trapping

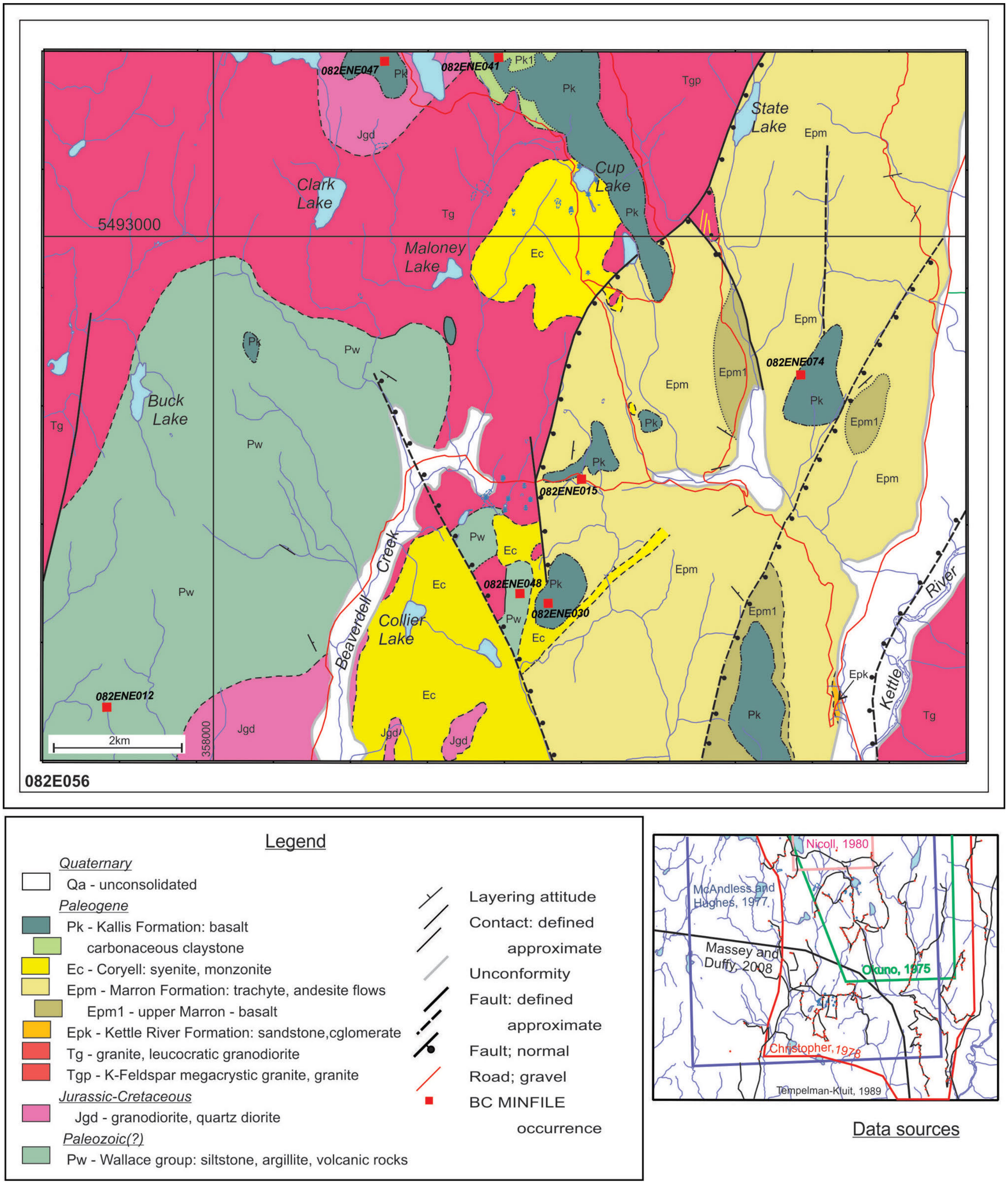

Figure 3. Geology of 1:20 000 TRIM map area 082E/056. Inset shows the data sources in coloured outline and the 2016 traverse locations are indicated by the black line.

Figure 4. Large exposure of the Marron Formation of the Penticton Group in the core of the Rock Creek graben on the eastern shore of the Kettle River in 1:20 000 TRIM map area 082E/057 (UTM 370500E, 5492000N, NAD83).

Figure 5. Unit Tg K-feldspar megacrystic granite from the eastern side of the Rock Creek graben in 1:20 000 TRIM map area 082E/057 (UTM 375153E, 5494488N, NAD83).

Creek in the central part of the Christian Valley (Hunt and Roddick, 1992).

Eocene Coryell Intrusive Suite (Unit Ec)

The alkalic to subalkalic Coryell intrusions occur as a number of small stocks that intrude Okanagan batholith rocks west of the Rock Creek graben and as part of a larger batholith that extends north from the Almond Mountain map area into the southern part of the Christian Valley area, east of the graben. Coryell rocks range from massive to porphyritic, typically varying in composition from syenite to monzonite. A suite of north-trending Coryell dikes are common in the area between Lassie Lake and Trapping Creek.

The Coryell intrudes granitic rocks of unit Tg throughout the Christian Valley map area, and dikes and small syenite intrusions locally cut Marron Formation in the Rock Creek graben. Several of these are shown west of Cup Lake and Collier Lake in Figure 3.

Penticton Group

The Eocene Penticton Group is described and defined by Church (1973) as comprising six formation members: basal Springbrook and coeval Kettle River formations, volcanic rocks of the Marron and Marama formations, and dominantly sedimentary rocks of the White Lake and Skaha formations (Figure 6). In the Christian Valley area, the lower two formations of the Penticton Group are exposed in the Rock Creek graben: a basal succession of conglomerate and siltstone of the Kettle River Formation and dominantly volcanic rocks of the Marron Formation. The overlying 'Kallis formation', separated from the Marron by a regional unconformity, is not included in the Penticton Group.

Kettle River Formation (Unit Epk)

The Kettle River Formation is only exposed in the southern part of the map area, along a roadcut in the Kettle River valley. It comprises coarse conglomerate, with numerous large subrounded clasts of dominantly feldspar porphyry in a granular, green to tan silty or sandy matrix (Figure 7). It is in sharp contact with overlying green andesite and lapilli tuff of the Marron Formation. As the base of this conglomerate is not exposed, it is possible that it represents a coarse clastic unit within the Marron Formation; however, as similar units farther south are located mainly at the base of the Penticton Group (Höy, 2016), this exposure is assumed to be Kettle River Formation.

Marron Formation (Unit Epm)

The Marron Formation comprises a thick package of dominantly alkalic volcanic rocks that are exposed in the Rock Creek graben. The formation overlies the Kettle River Formation and older rocks of the Nelson and Valhalla plutonic suites, or late Paleozoic metasedimentary or metavolcanic rocks of the Wallace group. It is unconformably overlain by basalt of the Pliocene 'Kallis formation'. Subdivision of the Marron Formation within the map area (Figure 3) is difficult due largely to the lack of distinctive marker units and structural complexity caused by the numerous high-angle block faults that occur throughout the graben.

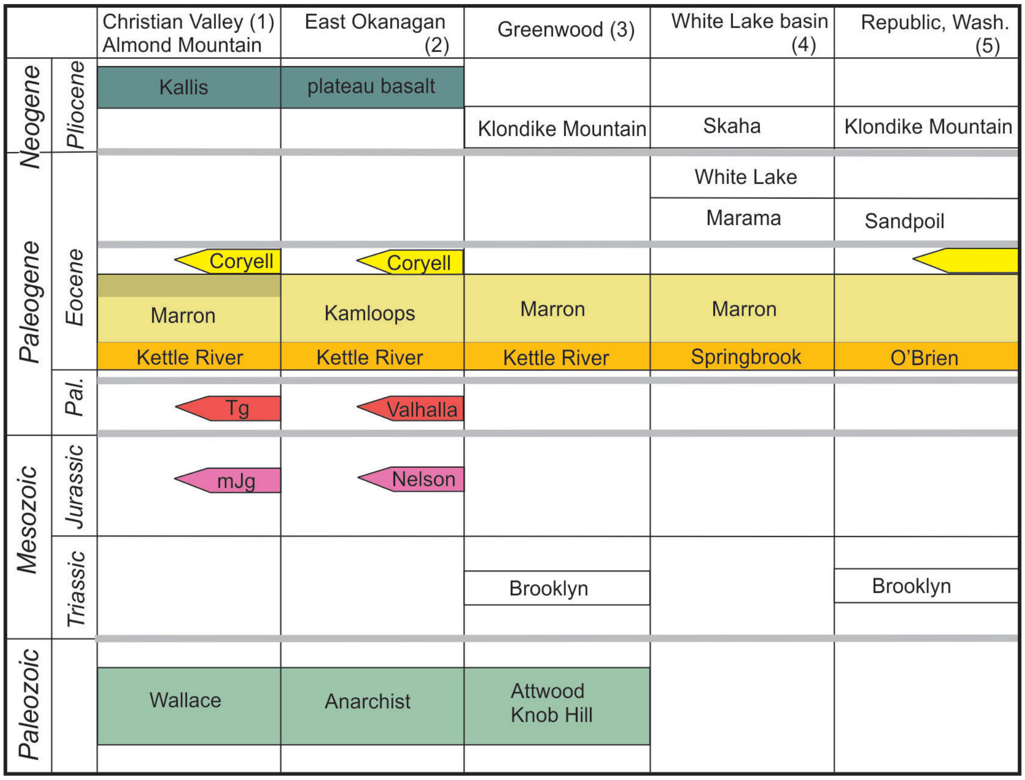

Figure 6. Correlation chart of units in the Christian Valley map area with other successions; note relative ages of intrusive rocks (Coryell, unit Tg, Valhalla, Nelson and unit mJg) and regional unconformities (grey lines). Data sources are shown in 'References' section: (1) this study, Massey (2010); (2) Christopher (1978); (3) Church (1986), Fyles (1990); (4) Church (1973); (5) Cheney and Orr (1987). Abbreviation: Pal, Paleocene.

In general, the Marron Formation (unit Epm) can be subdivided into two units: a basal subunit dominated by green to mauve-tinged tuff and andesitic flows, and an overlying subunit of more massive basalt (subunit Epm1). These units are relatively well displayed along several of the roads that climb westward from the Kettle River valley road in the southeastern part of the map area (Figure 3).

The Marron Formation comprises dominantly pale to medium green, massive to amygdaloidal lava flows; pale to medium green to grey crystal and lithic tuff, occasional well-bedded sandstone and siltstone (Figure 8); and rare conglomerate beds in the central part of the succession. The lower part of the Marron, exposed mainly at lower elevations in the Kettle River valley (Figure 3), is highly vari-

Figure 7. Conglomerate of the Kettle River Formation, exposed in a roadcut in Christian Valley; note chloritic alteration of arkosic matrix (1;20 000 TRIM map area 082E/056; UTM 367706E, 5485601N, NAD83).

Figure 8. Well-layered sandstone beds within the central part of the Marron Formation on 1:20 000 TRIM map area 082E/056 (UTM 366387E, 5487419N, NAD83).

able, with pale green to light grey feldspar-phyric flows (Figure 9) and pale green to mauve-tinged lithic and crystal tuff. It is overlain by a thick section of dominantly pale green crystal and lithic tuff and, less commonly, grey to mauve-tinged tuff and massive plagioclase-pyroxene–phyric flows. Sections of pale salmon pink trachyte flows, commonly with pink K-feldspar and biotite phenocrysts, occur throughout the middle part of the Marron, and thin successions of well-layered green tuffaceous beds, agglomerate, shale and siltstone occasionally occur in the upper part of the formation.

Subunit Epm1, the uppermost unit in the Marron Formation, comprises hard, compact, massive basalt with occasional biotite and pyroxene phenocrysts. Locally, it is unconformably overlain by massive basalt of the 'Kallis formation'.

Discussion

Church (1973) described the type section of the Marron Formation in the White Lake basin area, where five distinctive members are recognized (Figure 6). It is difficult to correlate these members with specific units in the Rock Creek graben, although many of the rock units identified by Church (op. cit.) are recognized here as well. As noted above, this may be due to the difficulty in subdividing the Marron Formation in the Rock Creek graben into distinct, mappable units or, alternatively, the detailed breakdown of the Marron Formation into these constituent members does not apply here. However, it would appear that the uppermost subunit (Emp1) may correlate with the lithologically similar Park Rill member, the uppermost member of the Marron Formation in the White Lake basin (Church, 1973).

The age of the Marron Formation is constrained by the age of the unconformably underlying megacrystic Kettle River granite, which has been mapped in the Almond Mountain map area to the south (Massey and Duffey, 2008; Höy, 2016), and the age of the Coryell suite, which intrudes the Marron in several locations, notably in the western part of the Rock Creek graben as shown in Figure 3. In the Almond Mountain map area to the south, megacrystic K-feldspar granite is bleached and eroded, and overlying Kettle River Formation contains conglomerate and grit that is clearly derived from the granite. A K-Ar date of 49.4 ±1.9 Ma was obtained from a lithologically similar megacrystic granite south of Beaverdell (Church, 1996), and a U-Pb zircon date of 56.0 ±1.0 Ma (Parrish, 1992) as well as a $^{39}Ar/^{40}Ar$ date on hornblende of 52.8 ±1.6 Ma (Höy, 2013) for a similar granite in the Burrell Creek area. Coryell intrusive rocks throughout the Penticton map area have been dated at approximately 51–52 Ma (Parrish et al., 1988). Hence, the Marron Formation is assumed to have been extruded in middle Eocene time, between ~57 and 51 Ma.

'Kallis Formation' (Unit Pk)

The 'Kallis formation' is preserved in isolated topographic highs throughout the area (Figure 10). It unconformably overlies the Marron Formation and older units, and represents the remnants of widespread Pliocene plateau basalt. It consists typically of a black, fine-grained, aphyric or olivine basalt.

Structure

The structure of the Kettle River area in the Christian Valley map area is dominated by the north-trending Rock Creek graben. A west-dipping normal fault along the eastern margin of the graben, juxtaposes Eocene(?) granitic rocks of unit Tg with Marron Formation in the core of the graben. The fault is not exposed as it is covered by alluvium in the floor of the Kettle River valley (Figure 3). The western

Figure 9. Unusual feldspar-phyric flow in the central part of the Marron Formation on 1:20 000 TRIM map area 082E/067 (UTM 370986E, 5499578N, NAD83); plagioclase crystals are up to 1 cm long.

Figure 10. Columnar basalt of the Pliocene 'Kallis formation'; paleochannels at the base of this formation have been explored extensively for uranium (1:20 000 TRIM map area 082E/056; UTM 364970E, 5497380N, NAD83).

margin of the graben in the southern part of the map area (Figure 3) is defined by an east-dipping normal fault that is closely constrained by exposures of Marron Formation within the graben and the Coryell syenite to the west. Farther north, a north-northeast-trending normal fault marks the western margin of the graben, constrained by mainly Paleogene granite (unit Tgp) to the west and the Marron Formation (unit Epm) to the east. These faulted contacts appear to be relatively sharp, with little observed alteration in rocks that are within a few tens of metres of either hangingwall or footwall rocks. However, immediately north, in 1:20 000 scale map area 082E/066, the western margin fault is more complicated, showing several splays that expose altered and sheared Middle Jurassic granodiorite and Wallace group rocks (Figure 11). These altered rocks have been explored for base- and precious-metal skarn and vein mineralization (Whiting, 1985). The internal structure of the graben is more complex than shown in Figure 3. Several, generally north-northwest-trending high-angle faults are recognized within the graben, mainly by offsets and truncation of units.

Movement along the bounding graben faults clearly postdates Marron Formation deposition, supporting a model in which late fault movement down-dropped and hence preserved remnants of more widespread Marron Formation within the north-trending grabens. However, it is possible that movement on the faults began earlier and controlled in part the distribution of Marron Formation rocks throughout the area. Although the Marron is broadly similar in all down-dropped blocks throughout the Okanagan and Boundary areas, correlation of the well-recognized succession of the White Lake basin (Church, 1973) is not possible in other basins, specifically in the Rock Creek graben. As noted above, the fault at the western margin of the graben is locally characterized by several fault splays, shearing, brecciation and alteration. In one of these exposures (Figure 11), highly broken Eocene(?) granite contains large blocks of crushed Wallace group, but is cut by a fresh, unaltered north-trending hornblende-porphyry dike that is lithologically similar to some phases of the Marron Formation and unlike the syenite dikes of the younger Coryell suite (Figures 12, 13). An isotopic date on this dike would constrain the timing of movement on this splay of the fault and conceivably provide evidence for movement during deposition of the Marron Formation.

Mineralization

Most exploration in the Christian Valley map area has been focused on uranium mineralization that occurs near the base of the Pliocene 'Kallis formation'. Exploration peaked in the 1970s and continued until the BC Provincial Government enacted a moratorium on uranium exploration in the province that was in effect from 1980 to 1987, and again after 2008, when the moratorium was reinstated. Limited exploration for base and precious metals, based in part on the successful exploration in the area of the Carmi, Beaverdell and Greenwood mining camps has continued intermittently throughout the Christian Valley map area. Descriptions of these mineral occurrences are taken mainly from Provincial Government assessment reports and BC MINFILE.

Uranium mineral occurrences and deposits in the Kettle River valley area (Figure 3) are generally found in poorly consolidated sandstone and conglomerate that have been preserved below a cap of Pliocene basalt of the 'Kallis formation'. The deposits occur in fluvial sediments that unconformably overlie the Marron Formation, Wallace group or Anarchist Schist, and Jurassic and Eocene intrusive rocks (Christopher, 1977). The Fuki deposits occur within a northeast-trending paleochannel that overlies the Eocene

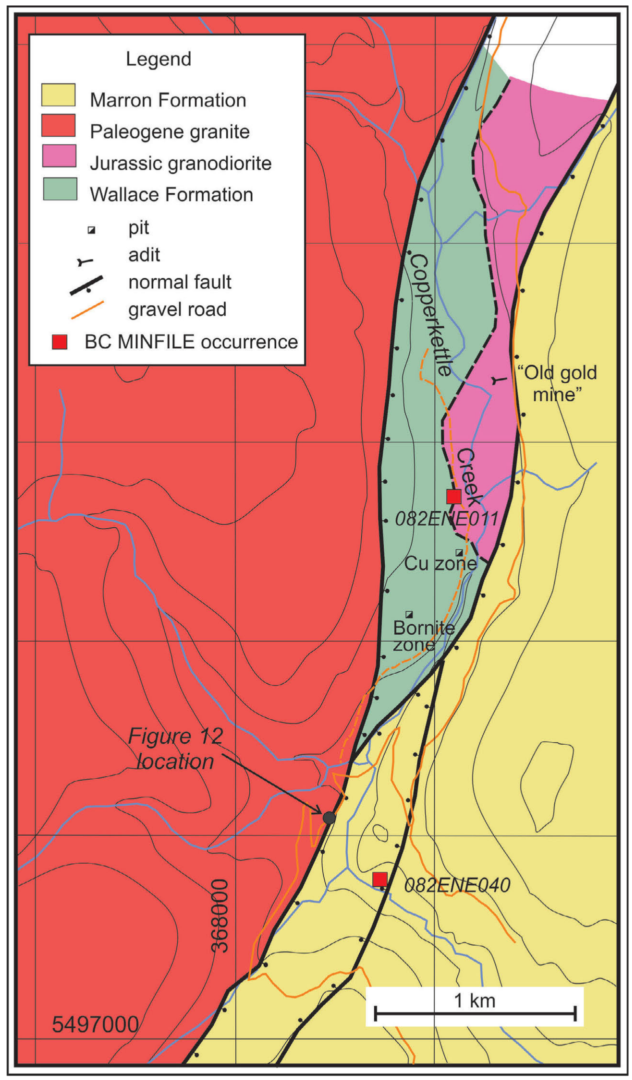

Figure 11. Geology of the western margin of the Rock Creek graben in the Christian Valley, showing several fault splays and exposures of Middle Jurassic granodiorite and Wallace group rocks (1:20 000 TRIM map area 082E/066; UTM 368478E, 5498097N, NAD83), and location of mineralization on the Copket property (modified from Whiting, 1991).

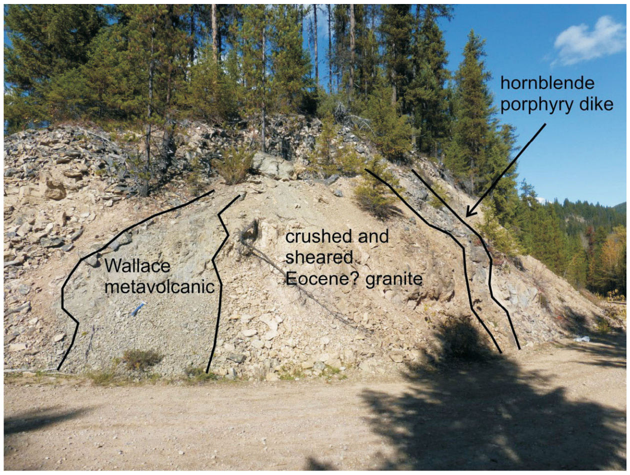

Figure 12. Crushed and sheared Eocene(?) granite in the fault along the western margin of the Rock Creek graben contains blocks of altered and sheared Paleozoic Wallace group metavolcanic rocks, and is cut by a fresh, unaltered hornblende-phyric dike (Figure 13). The age of the dike constrains timing of movement on this splay of the fault; the location of the fault is shown in Figure 11 on 1:20 000 TRIM map area 082E/066 (UTM 368478E, 5498097N, NAD83).

Figure 13. Detail of the hornblende-phyric dike shown in Figure 12, which is lithologically similar to some phases of the Eocene Marron Formation; the dike is located on the western margin of the Rock Creek graben in the Christian Valley.

Marron Formation. Hostrocks are poorly consolidated interbedded arkosic sandstone, siltstone, carbonaceous mudstone and conglomerate that form the lowermost member of the 'Kallis formation' (e.g., Nicoll, 1980; Turner et al., 1980; Brickner, 2003). Secondary uranium mineralization is largely concentrated in the basal conglomerate, occurring as films on pebbles and in the matrix of the conglomerate. Autunite is the only uranium mineral identified.

The Copket (MINFILE 082ENE11, BC Geological Survey, 2016b) and Sand (MINFILE 082ENE040) mineral occurrences are located in the Copperkettle Creek valley, along the western edge of the Rock Creek graben, in an area of extensional north-south faulting and locally intense alteration (Figure 11). The Sand occurrence is a narrow zone of disseminated chalcopyrite, galena and pyrite that was intersected in the Marron Formation in a 1970 diamond drilling program that was focused on locating uranium mineralization (Kikuchi, 1970). There is no reported surface mineralization. The Copket showings comprise a number of shafts, adits, pits and mineralized outcrops that record exploration that dates back to the early 1900s. Two styles of mineralization are documented: copper-gold-silver skarn in Wallace or Anarchist metasediments and limestone along the contact with Jurassic granodiorite, and later copper-zinc mineralization developed along a north-trending Eocene normal fault (Whiting, 1991). These mineralized areas are shown in Figure 11 as the Bornite and Cu zones, respectively. Whiting (1991) notes that considerable alteration, brecciation and disseminated sulphide mineralization occurs in the Jurassic granodiorite and that an "old gold mine" occurs farther along strike, to the north of the Copket mineralization. Altered granodiorite and Wallace metasedimentary rocks, both containing disseminated pyrite, are conspicuous within the fault zone several kilometres farther north of these showings.

Summary and Conclusions

The geology of the Christian Valley area is dominated by the north-trending Rock Creek graben, which is filled with Eocene volcanic rocks of the Marron Formation and bounded by mainly granitic rocks, also of predominantly Eocene age. Remnants of a Paleozoic basement, metavolcanic and metasedimentary rocks of the Wallace group are exposed in a tectonic high in the southwestern part of the area (Figure 3), and in splays of normal faults that bound the western margin of the graben (Figure 11). Several magmatic pulses are recorded throughout the area. Middle Jurassic granodiorite intrudes the Wallace group and two magmatic pulses are recorded in the Paleogene. Massive to megacrystic K-feldspar granite intrudes both Wallace and Jurassic granodiorite and locally forms the basement to unconformably overlying Kettle River and Marron formations. In contrast, Coryell syenite intrudes the granite and locally the Marron Formation within the graben. Hence, the Marron Formation was deposited between these two magmatic pulses, sometime between 57 and 51 Ma ago, which are the respective ages of the two magmatic suites.

The Rock Creek graben may have formed after deposition of the volcanic rocks of the Marron Formation that are preserved in its core, or by growth faulting during their deposition. At least some movement along the bounding graben faults clearly postdates the Marron, supporting a model in which these Eocene volcanic rocks are represented as remnants of widespread volcanism, preserved from erosion in down-dropped blocks (e.g., Cheney, 1994). However, it is equally possible that initiation of graben development occurred earlier and controlled, at least in part, the distribution of Eocene volcanism. Fault zones along the western margin of the graben are locally cut by fresh, undeformed dikes that include both younger Coryell and hornblende-phyric dikes that are lithologically similar to some phases of the Marron Formation. Dating of these dikes, and more robust dating of the Marron Formation and granitic rocks that form the margins of the Rock Creek graben, will help constrain the timing of movement of the bounding faults and the age span of the Marron.

Mineral exploration in the Christian Valley map area has been mainly directed toward finding unconformity-related uranium that occurs in paleochannels beneath Pliocene plateau basalt. Minor exploration for base- and precious-metal mineralization has taken place along the faulted western margin of the Rock Creek graben, with discovery of mineralized skarn in Wallace group rocks adjacent to Middle Jurassic granodiorite, and both vein and disseminated mineralization in both Eocene Marron Formation and older granitic rocks. This suggests that several stages of mineralization occurred during Jurassic and Eocene time, as has been demonstrated in the Highland Bell and Carmi mines to the south (e.g., Watson et al., 1982).

Acknowledgments

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References

BC Geological Survey (2016a): MapPlace GIS internet mapping system; BC Ministry of Energy and Mines, BC Geological Survey, MapPlace website, URL <http://www.MapPlace.ca> [November2016]

BC Geological Survey (2016b): MINFILE BC mineral deposits database; BC Ministry of Energy and Mines, BC Geological Survey, URL <http://minfile.ca> [November2016].

Brickner, R. (2003): Blizzard claims; BC Ministry of Energy and Mines, Assessment Report 27,257, 24 p.

Cheney, E.S. (1994): Cenozoic unconformity-bounded sequences of central and eastern Washington; Washington Division of Geology and Earth Resources, Bulletin 80, p. 115–139.

Cheney, E.S. and Orr, K.E. (1987): Kettle and Okanagan domes, northeastern Washington and southern British Columbia; Washington Division of Geology and Earth Resources, Bulletin, p. 55–71.

Christopher, P.A. (1977): Uranium reconnaissance program (82E, 82L, and 82M); BC Ministry of Energy and Mines, BC Geological Survey, Paper 1977-1, p. 11–14.

Christopher, P.A. (1978): Geology of the East Okanagan uranium area (NTS 082E/10, 11, 14, 15), south-central British Columbia; BC Ministry of Energy and Mines, Preliminary map 29, 1:50 000 scale.

Church, B.N. (1973): Geology of the White Lake basin; BC Ministry of Energy and Mines, Bulletin 61, 120 p.

Church, B.N. (1986): Geological setting and mineralization in the Mount Attwood–Phoenix area of the Greenwood camp; BC Ministry of Energy and Mines, Paper 1986-2, 65 p.

Church, B.N. (1996): Several new industrial mineral and ornamental stone occurrences in the Okanagan-Boundary district (82E, 82L); *in* Exploration in British Columbia 1995, BC Ministry of Energy and Mines, p. 123–130.

Fyles, J.T. (1990): Geology of the Greenwood–Grand Forks area, British Columbia; BC Ministry of Energy and Mines, Open File 1990-25.

Höy, T. (2013): Burrell Creek map area: setting of the Franklin mining camp, southeastern British Columbia; *in* Geoscience BC Summary of Activities 2012, Geoscience BC, Report 2013-1, p. 91–101.

Höy, T. (2016): Geology of the Kettle River area, Almond Mountain project, southern British Columbia (NTS 082E/07); *in* Geoscience BC, Summary of Activities 2015; Report 2016-1, p. 23–34.

Höy, T. and Dunne, K.P.E (2001): Metallogeny and mineral deposits of the Nelson-Rossland area, Part II: The early Jurassic Rossland Group, southeastern British Columbia; BC Ministry of Energy and Mines, Bulletin 109, 195 p.

Hoy, T. and Jackaman, W. (2005): Geology of the Grand Forks map sheet, British Columbia (NTS 082E/01); BC Ministry of Energy and Mines, Geoscience Map 2005-2, scale 1:50 000.

Höy, T. and Jackaman, W. (2010): Geology of the Deer Park map sheet (NTS 82E/08); Geoscience BC, Map 2010-7-1, scale 1:50 000.

Höy, T. and Jackaman, W. (2013): Geology of the Burrell Creek map sheet (NTS 82E/09); Geoscience BC, Map 2013-07-1, scale 1:50 000.

Höy, T. and Jackaman, W. (2016): Geology of the Almond Mountain map sheet (NTS 82E/07); Geoscience BC, Map 2016-07-1, scale 1:50 000.

Hunt, P.A. and Roddick, J.C. (1992): A compilation of K-Ar ages report 21; *in* Radiogenic and Isotopic Studies, Report 5; Geological Survey of Canada, Paper 91-2, p. 207–252.

Inazumi, S. (1973): Diamond drilling report on Donen (281 to 320 inclusive) mineral claims; BC Ministry of Energy and Mines, Assessment Report 4630, 45 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=04630> [November 2016].

Kikuchi, T. (1970): Geological, radiometric and diamond drilling report on Sand, Cup and Lassie mineral claims, Greenwood Mining Division; BC Ministry of Energy and Mines, Assessment Report 2482, 36 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=02482> [November 2016].

Little, H.W. (1957): Kettle River (East half); Geological Survey of Canada, Map 6-1957, scale 1:253 440.

Massey, N.W.D. and Duffy, A. (2008): Boundary project: McKinney Creek and Beaverdell areas, south-central BC; *in* Geological Fieldwork 2007, BC Ministry of Energy and Mines, BC Geological Survey, Paper 2008-1, p. 87–102.

Massey, N.W.D., Gabites, J.E., Mortensen, J.K. and Ullrich, T.D. (2010): Boundary project: geochronology and geochemistry of Jurassic and Eocene intrusions, southern British Columbia (NTS 082E); *in* Geological Fieldwork 2009, BC Ministry of Energy and Mines, BC Geological Survey, Paper 2010-1, p. 127–142.

McCandless, P. and Hughes, B. (1977): Assessment report: combined geological and geochemical survey on the CL#1, Dell and State mineral claims; BC Ministry of Energy and Mines, Assessment report 6319, 81 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=02482> [November 2016].

McLelland, D. (2008): Gamma-ray spectrometer ground verification exploration and prospecting program of the Trapping Creek–Sandrift Lake claims; BC Ministry of Energy and Mines, Assessment Report 27,791, 496 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=27791> [November 2016].

Nicoll, L. (1980): Diamond drilling report on Done, Fuki mineral claims, Greenwood Mining Division, and aerial photography on PB and Donen 361 mineral claims, Osoyoos, Vernon and Greenwood Mining divisions; BC Ministry of Energy and Mines, Assessment Report 8105, 360 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=08105> [November 2016].

Okuno, T. (1972): Diamond drilling report on Donen (281 to 320 inclusive) mineral claims; BC Ministry of Energy and Mines, Assessment Report 3775, 49 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=03775> [November 2016].

Parrish, R.R. (1992): Miscellaneous U-Pb zircon dates from southeast British Columbia; *in* Radiogenic Age and Isotopic Studies, Geological Survey of Canada, Report 5, Paper 91-2, p. 143–153.

Parrish, R.R., Carr, S.D. and Parkinson, D.L. (1988): Eocene extensional tectonics and geochronology of the southern Omineca belt, British Columbia and Washington; Tectonics, v. 72, p. 181–212.

Preto, V.A. (1970): Structure and petrology of the Grand Forks Group, BC; Geological Survey of Canada, Paper 69-22.

Preto, V.A. (1979): Geology of the Nicola Group between Merritt and Princeton; BC Ministry of Energy and Mines, Bulletin 69, 90 p.

Reinecke, L. (1915): Ore deposits of the Beaverdell map area; Geological Survey of Canada, Memoir 79, 172 p.

Tempelman-Kluit, D. J. (1989): Geology, Penticton, British Columbia; Geological Survey of Canada, Map 1736A, scale 1:250 000.

Turner, A.T., Sawyer, D.A. and Cann, R. (1980): Geochemical survey and percussion drilling project, Beverly-Blizzard Group, Greenwood Mining Division, British Columbia; BC Ministry of Energy and Mines, Assessment Report 7822, 267 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=07822> [November 2016].

Watson, P.H., Godwin, C.I. and Christopher, P.A. (1982): General geology and genesis of silver and gold veins in the Beaverdell area, south-central British Columbia; Canadian Journal of Earth Sciences, v. 19, p. 1264–1274.

Wheeler, J.O. and McFeely, P. (1991): Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A, scale 1:2 000 000.

Whiting, F.B. (1985): Copket Group, Greenwood Mining Division; BC Ministry of Energy and Mines, Assessment Report 13,795, 22 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=13795> [November 2016].

Whiting, F.B. (1991): Geological sampling report, Copket Group, Copperkettle Creek; BC Ministry of Energy and Mines, Assessment Report 21,534, 23 p., URL <https://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=21534> [November 2016].