Geology of the Kettle River Area, Almond Mountain Project, Southern British Columbia (NTS 082E/07)

T. Höy, Consultant, Sooke, BC, thoy@shaw.ca

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Introduction

The Almond Mountain project, funded by Geoscience BC, includes geological mapping and compilation of a large part of the 1:50 000 scale Almond Mountain map area (NTS 082/07), located in the Monashee Mountains of southern British Columbia (BC). The project is an extension to the west of mapping, compilation and mineral-potential evaluation of the east half of the 1:250 000 scale Penticton map area (NTS 082E), which included the Grand Forks (NTS 082E/01), Deer Park (NTS 082E/08) and Burrell Creek (NTS 082E/09) map areas (Figure 1; Höy and Jackaman, 2005, 2010, 2013). This project, and the continuation to the north in the Christian Valley map area (NTS 082E/10) in 2016, focuses mainly on the structural, stratigraphic and magmatic controls of base- and precious-metal mineralization in areas dominated by Tertiary[1] extensional tectonics.

The Almond Mountain project involved mainly geological mapping at a scale of 1:20 000 in the western part of the study area (Figure 2), which is dominated by Tertiary faulting that produced a complex north-trending graben filled with Eocene volcanic and sedimentary rocks. These unconformably overlie Paleozoic basement rocks, and Mesozoic and Eocene intrusive rocks. The graben hosts a variety of mineral occurrences, most notably base- and precious-metal veins that have similarities to deposits in the Beaverdell mining camp to the west and the Greenwood camp to the southeast.

Geological and Exploration History

The results of geological mapping in the vicinity of the Almond Mountain map area (NTS 082E/07) are shown in Figure 2. The area appears on the Kettle River map sheet (east half), mapped at a scale of 1:253 440 (1 inch to 4 miles) by Little (1957), and is included in the Penticton map area (NTS 082E), mapped and compiled at a scale of 1:250 000 by Tempelman-Kluit (1989). The geology of areas immediately to the east mapped at a scale of 1:50 000 has been published by Höy and Jackaman (2005, 2010 and 2013), based on new mapping and on compilation of previous studies, most notably those of Drysdale (1915), Preto (1970), Acton et al. (2002) and Laberge and Pattison (2007), and in the northern part of the area, extending into the Beaverdell camp, by Reinecke (1915).

Geological mapping in the Almond Mountain map area in 2014 and 2015 was focused along the western side of the area shown on 1:20 000 scale TRIM map areas 082E/036 and 082E/046. This work is based on approximately 40 days of fieldwork as well as compilation of mapping by Reinecke (1915), Greig and Flasha (2005), and Massey and Duffy (2008a, b). Further work will include compilation in digital format of all regional geological, geophysical and geochemical data collected under the National Geochemical Reconnaissance and the BC Regional Geochemical Survey programs. This will be combined with mineral occurrence and geology databases to produce 1:20 000 and 1:50 000 scale maps, suitable for directing and focusing mineral exploration.

Exploration in the Almond Mountain map area was initially based on the successful discovery and exploitation of the base- and precious-metal deposits in the Beaverdell and Greenwood camps, and more recently of gold deposits in the Republic District of northern Washington. Mining in the Beaverdell camp, located approximately 5 km west of the map area (Figure 2), operated from 1913 to 1991 and, based on MINFILE information (BC Geological Survey, 2015), produced approximately 99.2 million g Ag (35 million oz.) and 481 941 g Au (17 000 oz.) from narrow, high-grade lead-zinc veins. Deposits in the Phoenix mine area in the Greenwood camp, 30 km to the southeast (Figure 2), produced more than 2.5 million g Au (910 000 oz.) and 116.7 million g Ag (5.9 million oz.) until its closure in 1978, and several other deposits in the camp continue to be actively explored (e.g., Dufresne and Schoeman, 2014). Exploration elsewhere continues to be active, particularly

[1] *'Tertiary' is an historical term. The International Commission on Stratigraphy recommends using 'Paleogene' (comprising the Paleocene to Oligocene epochs) and 'Neogene' (comprising the Miocene and Pliocene epochs). The author used the term 'Tertiary' because it was used in the source material for this paper.*

Keywords: *geology, regional compilation, Republic District, Jurassic–Eocene intrusions, Eocene extensional tectonics, Penticton Group, base- and precious-metal mineralization*

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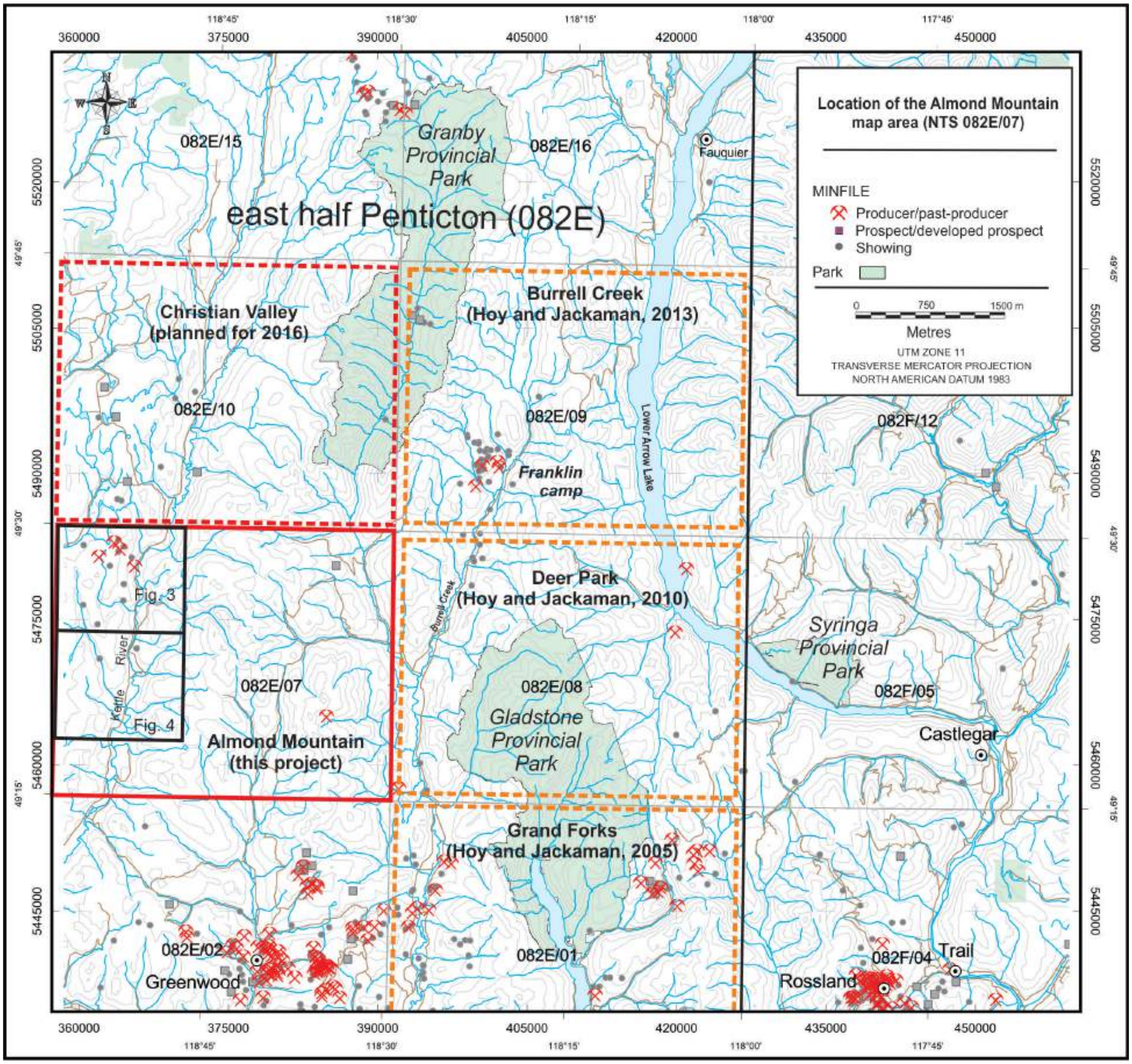


Figure 1. Location of the 1:50 000 scale Almond Mountain map area (NTS 082E/07) in southern British Columbia; modified from BC MapPlace (BC Geological Survey, 2015).

with the recent discovery of new zones of epithermal-gold mineralization in a similar geological setting at the Brett property, approximately 30 km west of Vernon (Caron, 2014).

Exploration in the immediate area is summarized mainly from MINFILE data and from provincial government assessment reports. This exploration resulted in the discovery of a number of base- and precious-metal veins and breccia zones largely restricted to the graben in the western part of the map area. Work on these has included considerable geological mapping, soil sampling, ground geophysical surveys and limited drilling (summarized in Greig and Flasha, 2005).

Regional Geology

The Almond Mountain area is underlain by Quesnel terrane rocks intruded by a variety of igneous rocks ranging in age from Jurassic to Eocene. Paleozoic metasedimentary and metavolcanic rocks within the Quesnel terrane form a subterrane that can be subdivided into two distinct successions, the oceanic Okanagan subterrane, which includes the Knob Hill Group and Anarchist Schist, and the arc-related Harper Ranch subterrane (Wheeler et al., 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

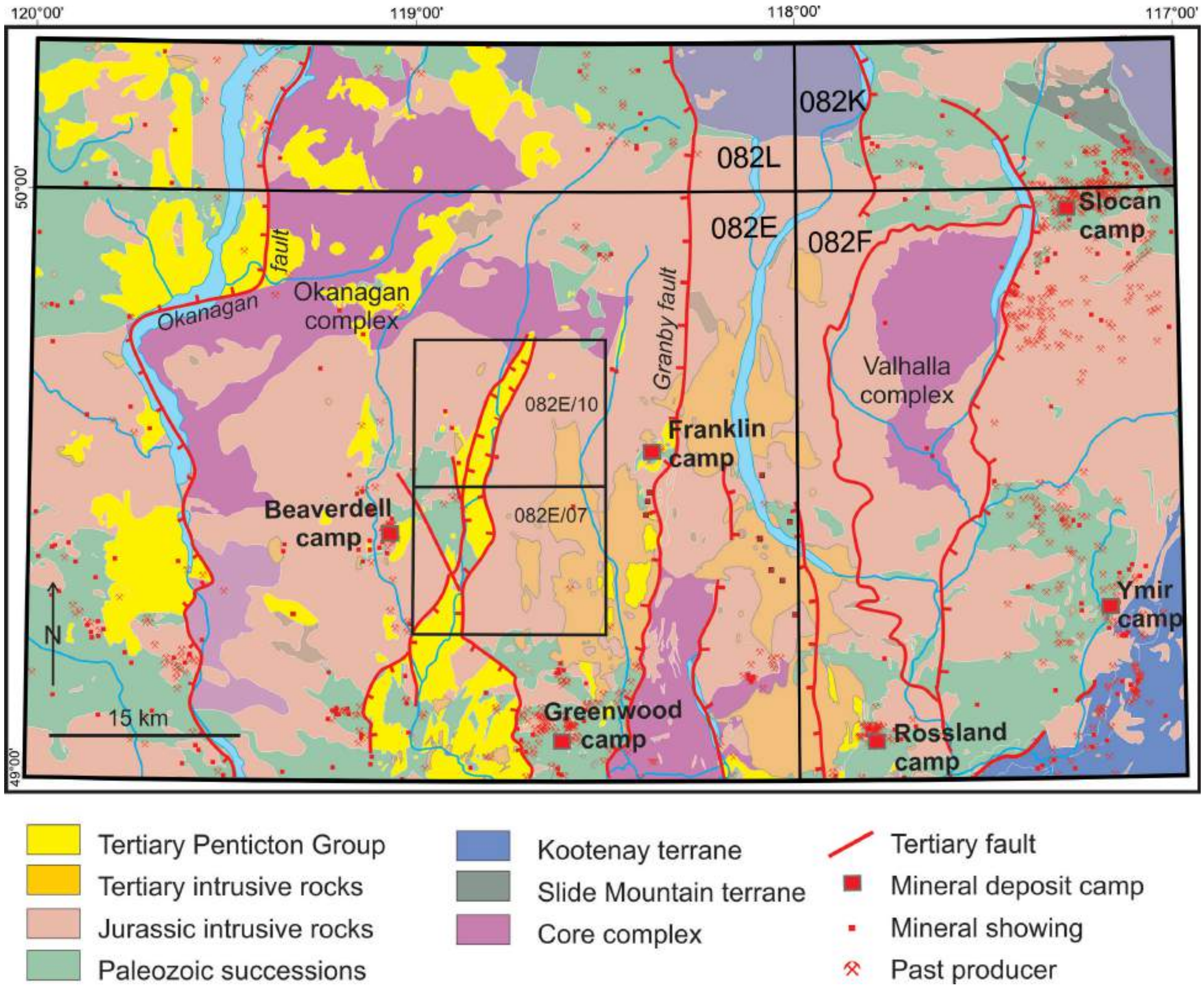


Figure 2. Geology of part of the Penticton area, showing the location of the Almond Mountain (NTS 082E/07) and Christian Valley (NTS 082E/10) map areas in southern British Columbia (modified from Tempelman-Kluit, 1989).

margin of the Quesnel terrane (Höy and Dunne, 2001). Jurassic granodiorite of the Nelson plutonic suite, and Jurassic and Eocene (?) granite and granodiorite of the Okanagan batholith underlie a large part of the Penticton map area (Tempelman-Kluit, 1989).

Regional extension during the Tertiary had a profound effect on the physiography and metallogeny of south-central 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 (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), resulted in the intrusion of alkalic plutons of the Eocene Coryell intrusive suite; the formation of north-trending grabens filled with Eocene and younger coarse sediments and alkalic volcanic rocks; and the localization of both base- and precious-metal deposits. These include the veins in the Beaverdell camp immediately west of the Almond Mountain area and numerous structurally controlled mineral occurrences throughout the Kettle River area.

Geology of the Kettle River Area

The Kettle River area lies along the western margin of the Almond Mountain map area ((NTS 082E/07; Figure 1). It is underlain by a complex north-trending graben that exposes Paleozoic metasedimentary and metavolcanic rocks intruded by Jurassic diorite and granodiorite. These are overlain unconformably by an Eocene sedimentary and volcanic succession that constitutes the graben fill. Eocene stocks, including alkalic rocks of the Coryell suite and megacrystic granite, are locally exposed within the graben, as is a suite of generally north-trending dikes. A number of base- and precious-mineral veins, related to Eocene extension, are found within the graben.

Wallace Group

The Wallace group was initially defined by Reinecke (1915) to include Paleozoic metasedimentary and metavolcanic rocks that lie in the northwestern part of the area (Figure 3), extending west toward the town of Beaverdell. These rocks have been assumed to be part of the Anarchist Schist, but because of considerable lithological differences, Massey and Duffy (2008a) preferred to retain the term 'Wallace group', a usage that is adopted in this paper.

The Wallace group in the Kettle River area is described by Massey and Duffy (2008a). They noted that a considerable part of the area that is underlain by Wallace group rocks in original mapping (Reinecke, 1915) includes younger Jurassic and/or Tertiary rocks. Other workers in the area, notably Greig and Flasha (2005), also realized the difficulty in distinguishing between Paleozoic metavolcanic rocks and recrystallized or finer grained, younger intrusions. The distribution of the Wallace group, as shown in Figures 3 and 4, is based, in part, on mapping undertaken during this study and on attempts to reconcile previous work.

A large part of the Wallace group comprises interbedded, laminated argillite and siltstone (unit Pw). These are commonly hornfelsed and recrystallized, masking original sedimentary structures. Siltstone beds are tan to grey, whereas argillite beds are dark grey to black. Some sections of laminated 'siltstone' are light green and may represent thin, mafic tuffaceous layers. Disseminated pyrite and quartz-carbonate veins, with minor pyrite, are common and, in areas of interbedded plagioclase-phyric 'flows', the presence of malachite staining and chalcopyrite was noted.

Massey and Duffy (2008a, b) differentiated a limestone and a greenstone member in the Wallace. The informally named 'Larse Creek limestone member' (unit Pl; Massey and Duffy, op. cit.) occurs in the northern part of 1:20 000 scale TRIM map area 082E/046, immediately south of Beaverdell Creek (Figure 3). This distinctive, light grey-weathering limestone, with numerous calcite-quartz veins and pods, ranges from massive to well bedded, to locally intensely folded (Figure 5).

The limestone is overlain by massive mafic flows of the informally named 'Crouse Creek member' (unit Pv; Massey and Duffy, op. cit.). The flows locally include vague amygdules and feldspar or pyroxene phenocrysts. Interbeds of siltstone or laminated mafic tuffaceous rocks are common. Massive mafic flows are also mapped as a separate unit on the eastern side of the Kettle River (Figures 3 and 4) and are referred to as part of the Crouse Creek member, although direct correlation is not known. As well, the large section of undifferentiated Wallace group in the central part of both map areas (unit Pw) contains considerable mafic volcanic rocks, but it is possible that it includes sections of younger undifferentiated, fine-grained intrusive diorite.

Minor- and trace-element analyses of volcanic rocks of the Crouse Creek member and within the siltstone/volcanic-rock section suggest that these Paleozoic rocks are a calc-alkaline volcanic-arc succession (Massey, 2010). They differ considerably from the tholeiitic rocks of the Knob Hill Group or the Anarchist Schist (Massey, op. cit.) and may be part of the arc-related Harper Ranch subterrane.

Triassic–Jurassic Intrusive Rocks

Middle Jurassic and Triassic granodiorite and diorite underlie a considerable part of the Almond Mountain map area. In the Kettle River area (Figures 3 and 4), Jurassic(?) diorite occurs as two isolated stocks between the Crouse Creek and Christian Valley faults in the northern part of the map area. Isolated bodies of granodiorite in the northwestern part of the map area (unit Jgd in Figure 3) are part of the Westkettle batholith (Reinecke, 1915), which hosts many of the veins in the Beaverdell camp as well as some veins in the central part of the Kettle River area. These intrusive rocks have been correlated with the Jurassic Nelson plutonic suite, as defined by Tempelman-Kluit (1989) and Little (1961). However, U-Pb zircon analysis of the Westkettle batholith, from a sample located just west of 1:20 000 scale map area 082E/049, returned a date of 213.5 Ma (Massey et al., 2010), similar to a Triassic age obtained from an intrusion in the Christina Lake area, informally named the 'Josh Creek diorite' (Acton et al., 2002). Additional samples of these units, as well as from other intrusions in the Kettle River area, are being submitted to the geochronology laboratory of the University of British Columbia for testing by the $^{40}Ar/^{39}Ar$ method of age determination.

Unit Jgd comprises dominantly light grey to medium grey, medium- to coarse-grained granodiorite and lesser quartz diorite (Figure 6). Quartz content ranges up to 20% and the mafic minerals, hornblende and biotite, from typically 10 to 30%. These rocks are locally altered to pale green, and veined with quartz, chlorite and epidote.

Diorite (unit Jd) is exposed in two irregular stocks in the central part of the northern 1:20 000 map area (082E/046). The southwestern stock includes medium-grained to locally porphyritic diorite and lesser granodiorite composed mainly of plagioclase, hornblende and up to 20% quartz. It is fractured and chlorite altered adjacent to the Crouse Creek fault. Porphyritic granodiorite contains euhedral to subhedral phenocrysts of white feldspar up to several centimetres in size in a granular feldspar-hornblende-quartz matrix. The northeastern stock is similar, but includes a distinctive unit, termed a "hornblende crowded feldspar diorite" by Greig and Flasha (2005). The diorite is host to many of the base- and precious-metal veins in the Triple

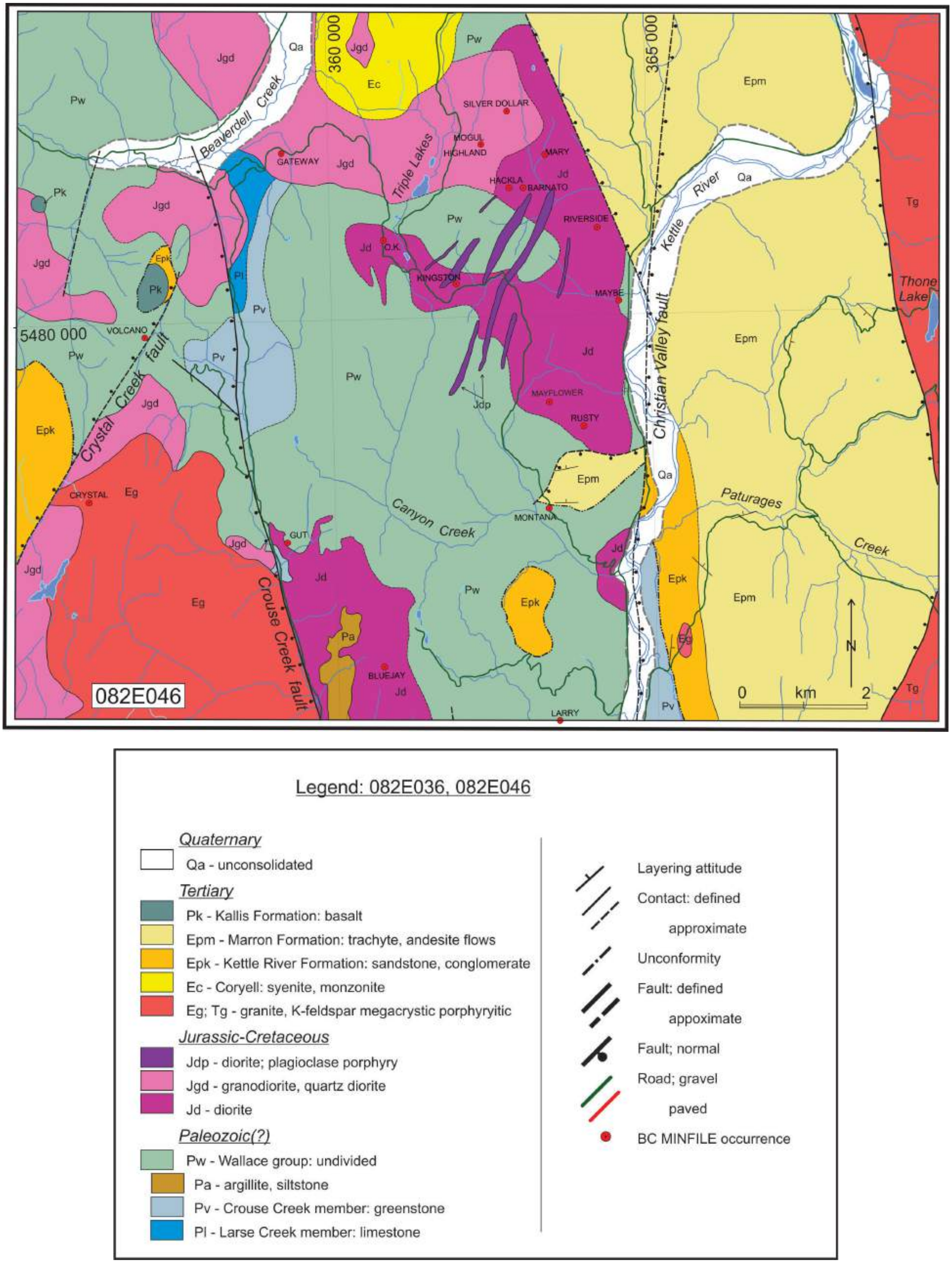
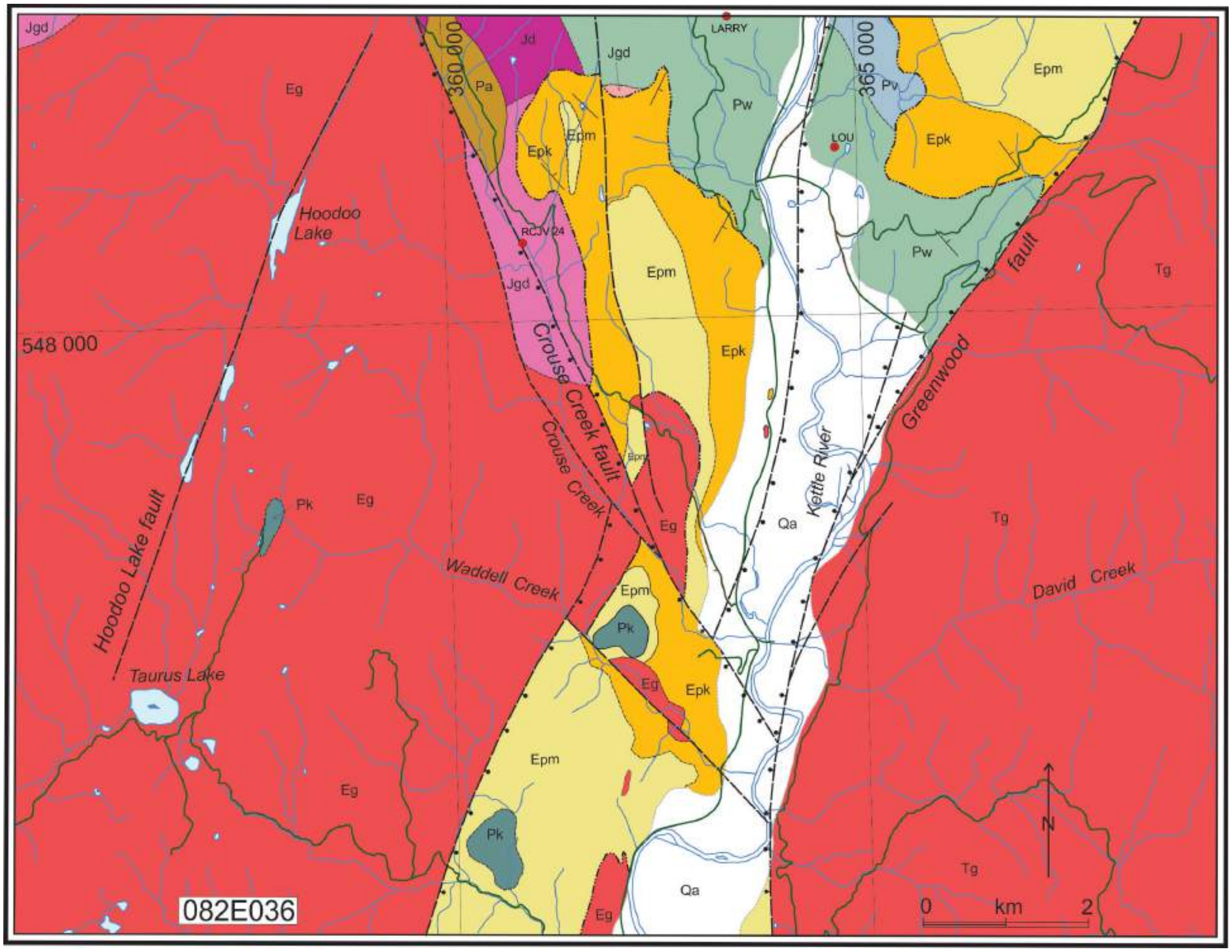


Figure 3. Geology of 1:20 000 TRIM map area 082F/046, showing location of selected mineral occurrences in the Kettle River area.



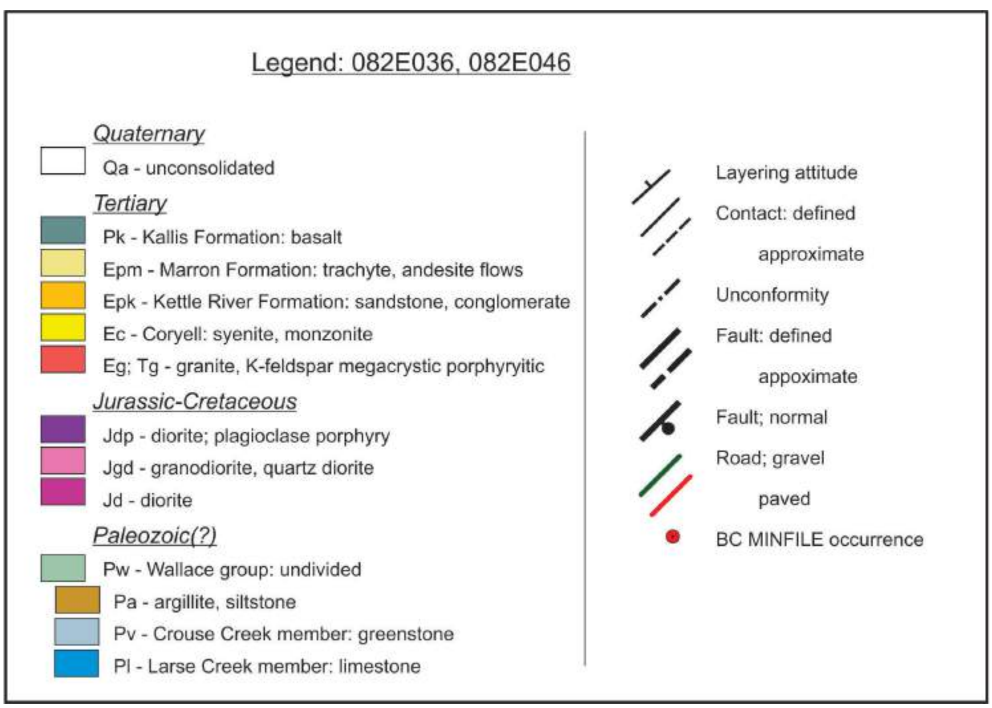


Figure 4. Geology of 1:20 000 TRIM map area 082F/036, showing location of selected mineral occurrences in the Kettle River area. Not all units and symbols shown on the legend, which accompanies Figures 3 and 4, appear on this figure.

Figure 5. Banded grey and white limestone of the Larse Creek member, Wallace group, Kettle River area.

Figure 6. Medium-grained, relatively fresh granodiorite of unit Jgd, from the Kettle River area.

Lakes area (Figure 3). Similar plagioclase porphyry is exposed near the mouth of Canyon Creek (Figure 3).

Numerous, generally north-northeast-trending dikes and small stocks (unit Jdp) cut the diorite stock and host Wallace group rocks in the Triple Lakes area. These include fine-grained to porphyritic diorite, lithologically similar to unit Jd, and plagioclase porphyry latite and hornblende-plagioclase porphyry dikes. The ages of these dikes are not known; some have a distinctive pink cast, suggesting the presence of fine-grained K-feldspar in the matrix, and may be part of the alkalic Eocene intrusive suite.

Porphyritic Granite (unit Eg)

Distinctive coarse-grained megacrystic granite occurs west of the Crouse Creek fault and in isolated exposures to the east and south. The granite is correlated with the 'Cretaceous' Valhalla complex intrusions of Little (1957) and, in subsequent papers, these intrusions are generally referred to as 'Jura-Cretaceous' (e.g., Tempelman-Kluit, 1989). In the Kettle River area, the megacrystic granite intrudes the Wallace group and Middle Jurassic granodiorite and is unconformably overlain by Eocene Penticton Group rocks. 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 hornblende $^{39}Ar/^{40}Ar$ date of 52.8 ±1.6 Ma (Höy, 2013) for a similar granite in the Burrell Creek area. Hence, pending further radiometric analysis, the Kettle River megacrystic granite is assigned an Eocene age, following the lead of Massey et al. (2010).

The granite is typically medium to coarse grained, with large, pink, euhedral K-feldspar phenocrysts set in a granular matrix of K-feldspar, plagioclase and up to 10% biotite and hornblende. It is generally fresh, although bleached and fractured beneath the sub-Tertiary unconformity, and chlorite-altered, fractured and veined adjacent to the Crouse Creek fault.

Granite (unit Tg)

Granite and granodiorite of the 'Cretaceous and/or Jurassic' Okanagan batholith underlie a large part of the Almond Mountain map area, east of the Greenwood fault and west of the Kettle River area in the footwall of the Okanagan fault (Tempelman-Kluit, 1989). Based on lithological similarities to the porphyritic granite (unit Eg) and the Eocene 'Ladybird' granite in the Deer Park and Burrell Creek areas, unit Tg is assumed to be Eocene in age.

Exposures of the granite immediately east of the Greenwood fault (Figures 3 and 4) comprise mainly medium-grained, massive to porphyritic quartz-orthoclase-plagioclase granite, with minor biotite and hornblende. Porphyritic phases, similar to unit Eg, are common near David Creek in the southern part of the area.

Eocene Coryell (unit Ec)

The alkalic to subalkalic Coryell plutonic suite consists of Middle Eocene intrusions. They underlie a large part of the Almond Mountain map area, but within the Kettle River area are restricted to a small pluton in the northern part of 1:20 000 scale map area 082E/046, referred to as the 'Collier Lake stock' (Massey and Duffy, 2008a). The stock is a porphyritic syenite, with phenocrysts of pink K-feldspar. Its eastern contact is a chilled-margin phase of finer grained material, whereas the southern contact with unit Jgd is coarse grained, suggesting a faulted relationship.

Penticton Group

The Tertiary 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 'McNamara' formations, and dominantly sedimentary rocks of the White Lake and Skaha formations. In the Kettle River area, three units are recognized, a basal succession of conglomerate and sandstone of the Kettle River Formation, the Marron Formation and overlying basalt, referred to as the 'Kallis formation' by Massey and Duffy (2008b).

Kettle River Formation (unit Epk)

The Kettle River Formation and overlying Marron Formation occur within a well-defined, north-trending graben that extends from the Rock Creek area west of the Greenwood camp (Figure 2) through the western part of the Almond Mountain map area, and northward into the Christian Valley map area. In the Kettle River area, it also occurs in several isolated exposures immediately west of Kettle River.

The formation is well exposed on the eastern side of the Kettle River, near Paturages Creek (Figures 3, 4), where it unconformably overlies volcanic rocks of the Wallace group. It comprises a basal unit of coarse conglomerate, with large rounded boulders of dominantly granite and greenstone in a medium green grit-sandstone matrix. The basal part of the Kettle River Formation in the southern exposure on the western side of the Kettle River is also a coarse conglomerate, with dominantly granitic clasts in a fine- to medium-grained grit matrix (Figure 7). In the Canyon Creek area, 2 to 3 km to the north, the basal part of the Kettle River Formation is a thick (approximately 100 m) succession of immature conglomerate, with coarse angular clasts of dominantly greenstone and diorite typical of the underlying Wallace group and unit Jd.

Basal conglomerate grades upward into coarse-grained, tan-coloured grit, sandstone and siltstone that form the bulk of the Kettle River Formation (Figure 8), which is typically well bedded and light coloured, forming white cliffs visible from a distance (Figure 9). Thin shale or argillite beds occur locally, and plagioclase-phyric flows, typical of the Marron Formation, occasionally occur in the upper part of the Kettle River Formation. Elsewhere, coarse grit or sandstone directly overlies Jurassic granodiorite or, near the mouth of Crouse Creek (Figure 4), the megacrystic granite of unit Eg. Here, the grit is derived entirely from the granite and it is difficult to determine the exact location of the contact between the two units as the granite is very friable, weathered and bleached.

The Kettle River Formation is similar to basal successions of the Penticton Group described elsewhere, including the Springbrook Formation in the White Lake basin (Church, 1973) and the Kettle River in the Greenwood area, where it is described as a "discontinuous basal conglomerate, above which is white to buff, locally plant bearing arkosic sandstone, siltstone, and minor shale and conglomerate, all largely derived from acid volcanic and granitic rocks" (Little and Monger, 1966, p. 67).

Figure 7. Coarse conglomerate that forms the basal part of the Kettle River Formation, in southern British Columbia; note large angular to subrounded clasts of granodiorite, which is similar to that shown in Figure 6, and a medium-grained, chlorite-altered groundmass.

Figure 8. Interbedded conglomerate and grit layers in the base of the Kettle River Formation, in southern British Columbia. These grade up into bedded to massive grit and sandstone, more typical of the Kettle River Formation.

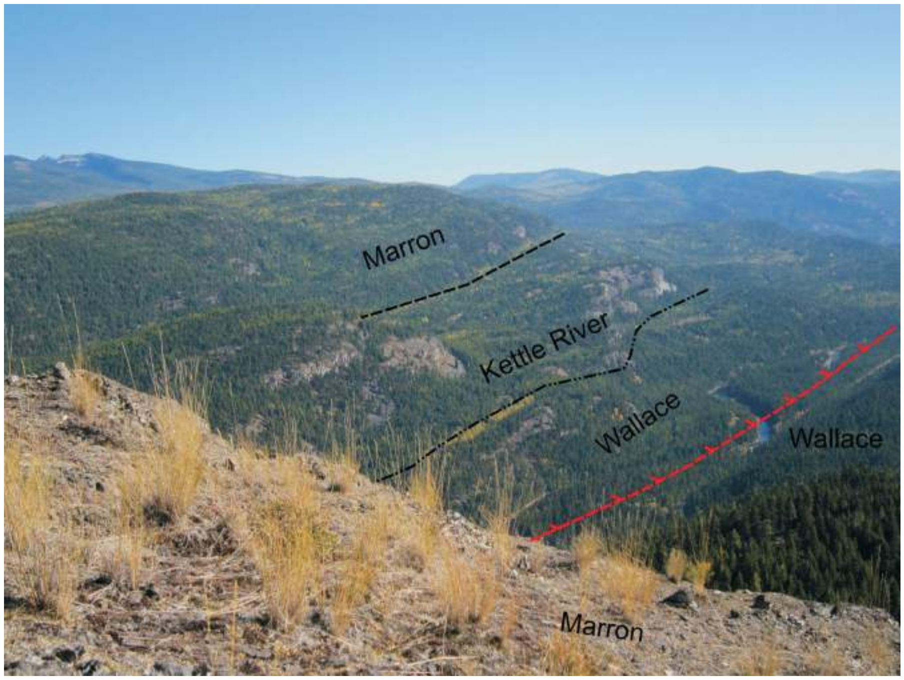


Figure 9. View to the southeast, looking across the Kettle River, in southern British Columbia. Note cliff forming exposures of the Kettle River Formation on the near slopes; these unconformably overlie volcanic rocks of the Wallace group and are in turn overlain by Marron Formation volcanic rocks approximately 5 km in the distance. An east-dipping Tertiary normal fault follows approximately the Kettle River valley.

Marron Formation (unit Epm)

The type section of the Marron Formation in the White Lake basin area is described by Church (1973) and is correlated with a similar section in the Greenwood area (Church, 1986). The Marron Formation directly overlies the Kettle River Formation or, locally, older pre-Tertiary 'basement' rocks. In the Burrell Creek area, the contact between the Kettle River and Marron is locally unconformable (Höy, 2013), and hence the absence of the basal part of the Kettle River Formation may record either nondeposition or erosion prior to volcanism of the Marron Formation.

The Marron Formation comprises a thick succession of volcanic rocks that varies in composition from alkalic basalt to trachyte, and ranges from lava flows to well-banded mafic tuffs and blocky tephra. In contrast with Wallace group flows, volcanic textures, including amygdules, vesicles, phenocrysts and clasts, are well preserved. A section of black to red shales a few tens of metres thick occurs in the central part of the Marron Formation, west of Thone Lake.

Kallis Formation (unit Pk)

The Kallis formation is preserved in isolated topographic highs throughout the area. It lies on the Marron Formation and represents the remnants of widespread Neogene plateau basalt. It consists typically of a black, fine-grained, aphyric or olivine-phyric basalt.

Structure

The structure of the Kettle River area is dominated by north-trending normal faults that record a period of Tertiary extension in south-central BC (Parrish et al., 1988). An earlier deformation, present only locally in the Paleozoic Wallace group, contrasts with penetrative deformation that has been recorded in Paleozoic rocks elsewhere, notably in the Knob Hill Group and Anarchist Schist to the south (e.g., Massey, 2006, 2007). In the Greenwood area, the Paleozoic Attwood Group, Knob Hill Group and Triassic Brooklyn Formation are locally tightly folded within a series of northward-dipping thrust sheets (Fyles, 1990).

The lack of prominent marker units and the abundance of intrusive rocks in most of the Wallace group precludes a detailed structural interpretation of these rocks. As well, hornfelsing and veining adjacent to intrusions further mask both their structures and primary sedimentary features. Tight minor folds were noted in the 'basal' Larse Creek limestone just south of Beaverdell Creek, but a large part of the Wallace group lacks structures or regional metamorphism that could be attributed to a regional deformational event. Thrust faults, similar to those described in the Greenwood area (Fyles, 1990), are also not recognized here; serpentinites that mark the thrust faults and folding characteristic of the thrust sheets at Greenwood appear to be also absent.

A complex north-trending graben, bounded by high-angle Tertiary normal faults, extends from near Rock Creek in the south, through the Kettle River area and into the Christian Valley map area (NTS 082E/10). The Paleozoic Wallace group forms a tectonic high in the Kettle River area, and Tertiary graben fill of the Kettle River and Marron formations onlap Wallace basement rocks and exposed Jurassic and Eocene intrusions.

A west-dipping, north-trending normal fault, the Greenwood fault, forms the eastern margin of the graben. It juxtaposes Tertiary granite on the eastern side against Marron and Kettle River formations and Wallace group rocks on the western side. Exposures of the fault surface were not seen, but observed granite and granodiorite on the eastern side of the fault were locally sheared, with shear zones dipping relatively steeply (40–50°) to the west. The western margin of the graben is marked by an east-dipping normal fault that follows the trend of the Kettle River south to the Crouse Creek area, and there it is offset to the west by the north to northwest-trending Crouse Creek fault.

The Crouse Creek fault (Figure 10) is a brittle structure marked by considerable shearing, brecciation and mainly chloritic alteration (Greig and Flasha, 2005). It trends north-northwest and generally dips at a high angle to the west. The amount of displacement on the fault is not known; it is assumed to be oblique with left-lateral and normal west-side–down movement, based mainly on the relative levels of the Penticton Group exposures at the southern end of the fault. A northwest-trending splay of the Crouse Creek fault, south of Beaverdell Creek (Figure 3), contains a pronounced shear and mylonite zone along it; a prominent topographic linear feature that extends to the southeast, across the Crouse Lake fault and following a branch of Canyon Creek, may mark the extension of this fault.

The northeast-trending Crystal Creek fault has net normal west-side–down movement along it, with Kettle River Formation in its hangingwall juxtaposed with Jurassic and Eocene intrusive rocks to the east (Figure 3). Farther south, the Hoodoo Lake fault defines a pronounced northeast-trending linear feature within the granite. Several exposures immediately northwest of Hoodoo Lake indicate right lateral movement along a steep, west-dipping fault surface.

Numerous other faults and shears, generally too small to be shown on the maps, occur within the central part of the graben. These are marked by outcrop shear zones, brecciation, alteration and, commonly, sulphide mineralization.

Mineralization

An important focus of this study is to determine the relationships, on both a local and regional scale, between base- and precious-metal mineralization and structures, and magmatism. Previous work in the Deer Park and Burrell Creek areas to the east (Höy, 2010; 2013) underscored the importance of Jurassic and Eocene magmatism as well as Tertiary structures, in localizing mineralization. To the west, shear-hosted silver-rich veins in the Beaverdell camp appear to be Eocene in age, whereas the Carmi veins imme-

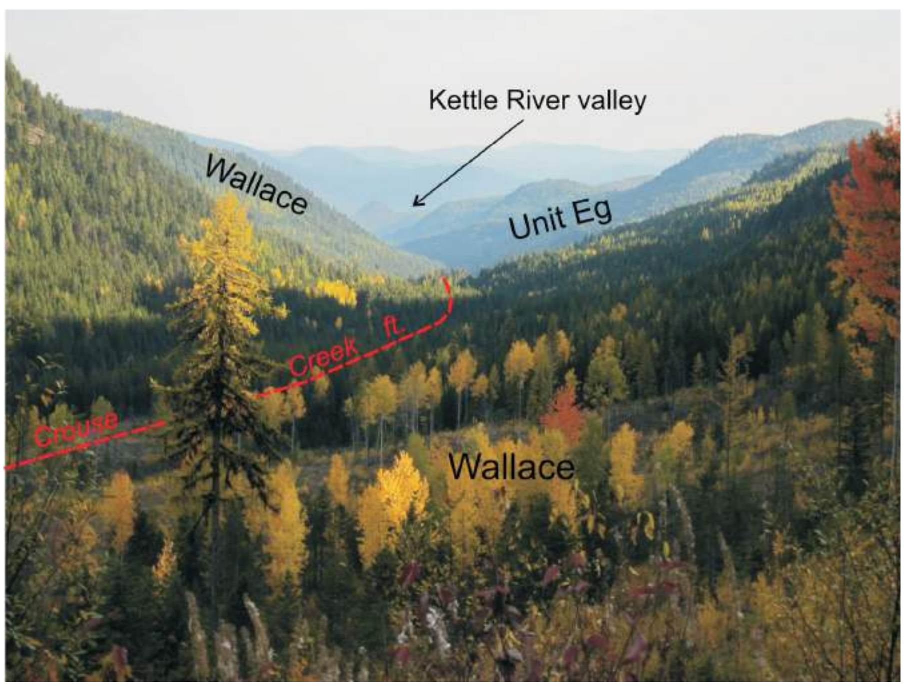


Figure 10. View to the south of the Crouse Creek valley, and location of the Crouse Creek fault in southern British Columbia; the Kettle River valley is approximately 8 km in the distance. Abbreviation: Eg, megacrystic porphyritic granite.

diately to the north have isotopic signatures that suggest they are Jurassic (Watson et al., 1982).

Mineralization within the Kettle River area has been described by Gale (2000), and Greig and Flasha (2005), based mainly on work done on the GK property, owned by Bitterroot Resources, and the Ward area respectively. The following summary is based largely on this work. Mineral occurrences from the BC MINFILE database are plotted on Figures 3 and 4.

Mineralization in the Kettle River area is similar to that in the Beaverdell camp: polymetallic or quartz-gold veins and breccia zones related to late structures that cut Wallace group metavolcanic and metasedimentary rocks, and Jurassic intrusions. The attitudes of host structures are variable, but commonly trend north to north-east, parallel with many of the Eocene extensional faults. Limited production from several of these occurrences, notably the Barnato (MINFILE 082ESE109) and Maybe (MINFILE 082ESE246) deposits, produced a total of 19 626 g Au and 21 398 g Ag from 744 milled tonnes. Further work on the controls of mineralization and dating of hostrocks, as well as an update of the BC MINFILE database, will continue in the 2016 field season.

Summary and Conclusions

The oldest rocks in the Kettle River area, those of the Wallace group, include minor limestone, fine-grained siliciclastic rocks and abundant mafic volcanic rocks. Their age is not known, but is assumed to be late Paleozoic, based mainly on the ages of the possibly correlative Anarchist Schist and Knob Hill Group to the south. However, Massey (2010) argued that the Wallace is part of a calcalkaline volcanic-arc succession, distinct from the dominantly tholeiitic rocks of the Knob Hill and Anarchist.

Two pulses of magmatism are recognized in the Early Eocene: alkalic Coryell syenite and possibly contemporaneous megacrystic porphyritic granite. Since these are not in contact, it is difficult to determine relative ages. Numerous, generally north to northeast-trending alkalic dikes cut older intrusions and the Wallace group in the Triple Lakes area.

The Penticton Group was deposited during Middle Eocene regional extension and faulting, with infill of a narrow, north-trending graben that follows the approximate trace of the Kettle River valley. The Kettle River Formation, a basal succession of dominantly conglomerate and sandstone, filled topographic lows developing in the graben and to the northwest along the approximate trace of Crouse Creek. A thick succession of dominantly mafic flows and tuffs of the Marron Formation continued filling the north-northeast-trending structural basin, locally depositing directly on Wallace group basement rocks or onlapping pre–Early Eocene tectonic highs. These are overlain by olivine-phyric mafic flows of the Kallis formation, now preserved on isolated topographic highs throughout the Kettle River area. Extension continued after deposition of the Kettle River and Marron formations, with continued movement along graben-bounding faults and along younger structures that cut these formations.

Mineralization in the area includes base- and precious-metal veins, breccia zones and disseminated sulphides in mainly Jurassic Wallace group diorite and granodiorite. As noted by Greig and Flasha (2005), mineralization is spatially and probably genetically related to north-northeast trending structures and dikes and, as it locally cuts some dikes that appear to be part of the alkalic Eocene suite, is probably Eocene in age, a model similar to that found in the Beaverdell camp to the west.

On a regional scale, virtually all known mineral occurrences are within a north-northwest trending tectonic high that crosses the north-trending Eocene graben. The topographic high formed prior to deposition of the Penticton Group, which onlaps exposures of the Wallace group and Jurassic–Eocene intrusions, and projects southeast to the highly mineralized Greenwood camp (Figure 2). A similar model for controls of mineralization has been noted in the Franklin camp area, with intrusion of the Jurassic Averill plutonic complex and associated mineralization localized along the intersection of the north-trending Granby fault and other northwest-trending structures (Höy, 2013). Further mapping and identification of these structures in the Penticton map area will help direct and focus future mineral exploration throughout the southern Monashee Mountains and Okanagan Highland of southern BC.

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