

Porphyry, Base-Metal and Gold Potential in the Boundary Area, Southern British Columbia (NTS 082E)

T. Höy, Geological Consultant, Sooke, British Columbia, thoy@shaw.ca

R. Friedman, The University of British Columbia, Vancouver, British Columbia

J. Gabites, The University of British Columbia, Vancouver, British Columbia

Höy, T., Friedman, R. and Gabites, J. (2020): Porphyry, base-metal and gold potential in the Boundary area, southern British Columbia (NTS 082E); in Geoscience BC Summary of Activities 2019: Minerals, Geoscience BC, Report 2020-01, p. 23–34.

Introduction

The Boundary area in southern British Columbia (BC) has an extended history of exploration and mining, particularly in the Greenwood, Franklin and Beaverdell camps, where intermittent production of base and precious metals continued from the late 1890s to the early 1990s. Exploration continues to be active throughout most of the area, although it is largely concentrated in the Greenwood camp for a variety of deposit types, including epithermal gold, skarn and base- and precious-metal vein deposits.

This project is a continuation and enhancement of systematic 1:50 000 geological mapping of the eastern half of the Pentiction map area (NTS 082E) that has resulted in publication of six maps (Figure 1): Grand Forks (NTS 082E/01), Greenwood (NTS 082E/02), Almond Mountain (NTS 082E/07), Deer Park (NTS 082E/08), Burrell Creek (NTS 082E/09) and Christian Valley (NTS 082E/10). The focus of the project has been to determine the ages of and controls on the various types of deposits that occur throughout the eastern half of the Pentiction map area and to provide updated regional base maps and deposit models that may direct ongoing and future exploration. All new radiometric ages reported in this paper were obtained by J. Gabites (Ar-Ar) or R. Friedman (U-Pb) at the University of British Columbia; some of this data has been previously released in a summary report by Höy et al. (2019) and included in a regional compilation map by Höy and Jackaman (2019).

A large part of the Pentiction map area is underlain by poorly dated granitic and alkalic intrusive rocks that have been variously assigned to largely undifferentiated granodiorite of the Jurassic ‘Nelson’ Complex, granite of the Okanagan batholith or Coryell syenite. However, numerous small, generally unrecognized, high-level stocks occur within some of the intrusive complexes and these have the potential to

host metallic-mineral deposits. The 2018–2019 project was largely directed toward examining several examples of mineral occurrences related to these stocks to determine their age and thereby provide impetus for further exploration within areas that are largely underlain by these undifferentiated batholiths. Efforts focused on several areas and work included sample collection for radiometric dating, geological mapping and data compilation. In this paper, the Franklin camp, the Beaverdell–Carmi–Tuzo Creek area, the Lightning Peak camp and the Midas–Bulldog area (Figure 1) are briefly described. These areas highlight the range in ages and the variety of deposit types throughout the district, with mineralization related to small Jurassic, Cretaceous, Paleocene and Eocene stocks respectively, and host-rocks that range from granite to syenite.

Franklin Camp

Introduction

Mineralization in the Franklin mining camp, located in the southern part of the Burrell Creek map area (Figure 1), was discovered in the early 1900s (Drysdale, 1915). The only significant deposit in the camp, the Union mine, produced 122 555 t grading 14.1 g/t Au and 353.4 g/t Ag, primarily in the early 1930s. Recent exploration in the camp has included soil sampling, geological mapping and prospecting by Tuxedo Resources Ltd. in 2001–2004 (Caron, 2004), and rock sampling, trenching and limited diamond drilling by Solitaire Minerals Inc. in 2004 (Caron, 2005).

The geology in the vicinity of the Franklin camp is shown in Figure 2. The area is in the hangingwall of the Granby fault and underlain by dominantly Jurassic rocks that intrude metavolcanic and metasedimentary rocks of the late Paleozoic Franklin group. These are locally intruded by Eocene Coryell syenite stocks and numerous dikes. Eocene Pentiction group conglomerate and feldspathic grit of the Kettle River formation and overlying Marron formation alkalic volcanic rocks unconformably overlie the Paleozoic metasediments and Jurassic intrusions. Mineralization is spatially related to the Averill Plutonic Complex, a suite of mafic alkalic intrusions that was originally interpreted as

This publication is also available, free of charge, as colour digital files in Adobe Acrobat® PDF format from the Geoscience BC website: <http://www.geosciencebc.com/updates/summary-of-activities/>.

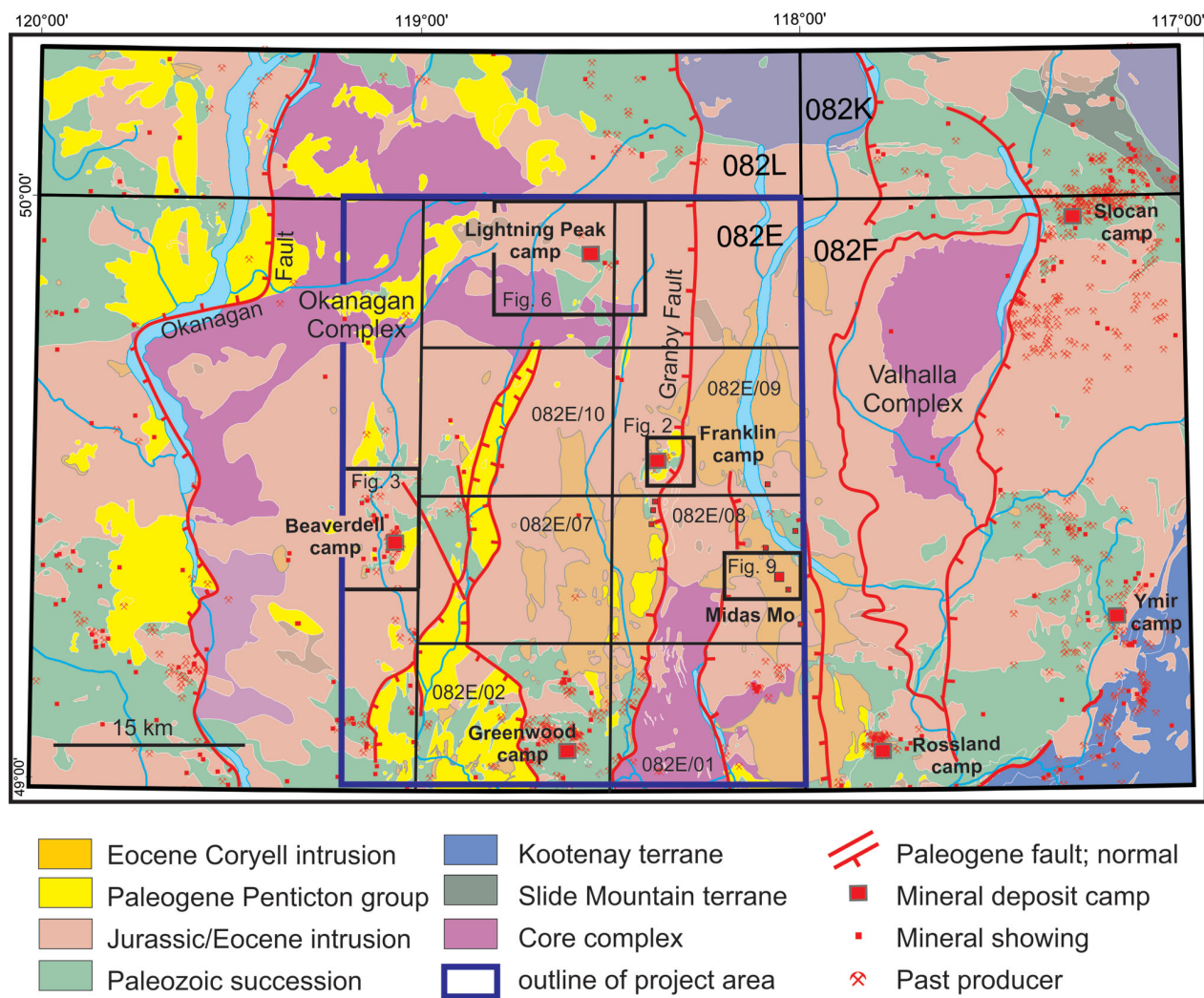


Figure 1. Regional terrane map of the Boundary area of British Columbia, showing the location of mineral occurrences, study areas covered in this paper and published 1:50 000 Geoscience BC maps (locations of figures 2, 3, 6 and 9 are also outlined).

Eocene in age based in large part on its similarity to Coryell intrusive rocks (Drysdale, 1915) but is now recognized as Jurassic, based on a K-Ar date reported in Keep (1989) and several new Ar-Ar dates that range from ca. 176 Ma to 161 Ma (Höy et al., 2019).

Several styles of mineralization are recognized in the camp. These include skarns in altered late Paleozoic metasediments and metavolcanic rocks of the Franklin group, minor platinum-group minerals (Pt, Pd) in the Averill Complex, and base- and precious-metal mineralization in shears and faults (Drysdale, 1915).

Discussion on the Franklin Camp

The Averill Plutonic Complex is a zoned alkalic intrusion within the dominantly calcalkaline, middle to early Jurassic plutonic suite in the eastern half of the Pentiction map area. Other exposures of smaller mineralized Jurassic intrusions are common throughout the area. For example, the ca. 179.9 Ma Greenwood stock (Massey et al., 2010) hosts sev-

eral deposits and showings. Also, numerous precious- and base-metal vein occurrences in the northwestern part of the Almond Mountain map area east of Beaverdell, which are hosted by Middle Jurassic granodiorite and diorite, are assumed to be related to these early intrusions. These deposits appear to have a regional structural control, aligned along prominent northwest structural trends that are marked by the alignment of late faults and orientations of host intrusive rocks. They are within relative structural highs; the Franklin camp is in the hangingwall of the Eocene Granby fault and occurrences east of Beaverdell are within a north-northwest-trending, fault-bounded structural zone that crosses the more northerly trending Rock Creek graben (Höy and Jackaman, 2016).

Beaverdell Area

The Beaverdell area (Figure 1) is located immediately west of the Almond Mountain map area (NTS 082E/07), straddling the West Kettle River (Figure 3). The area includes

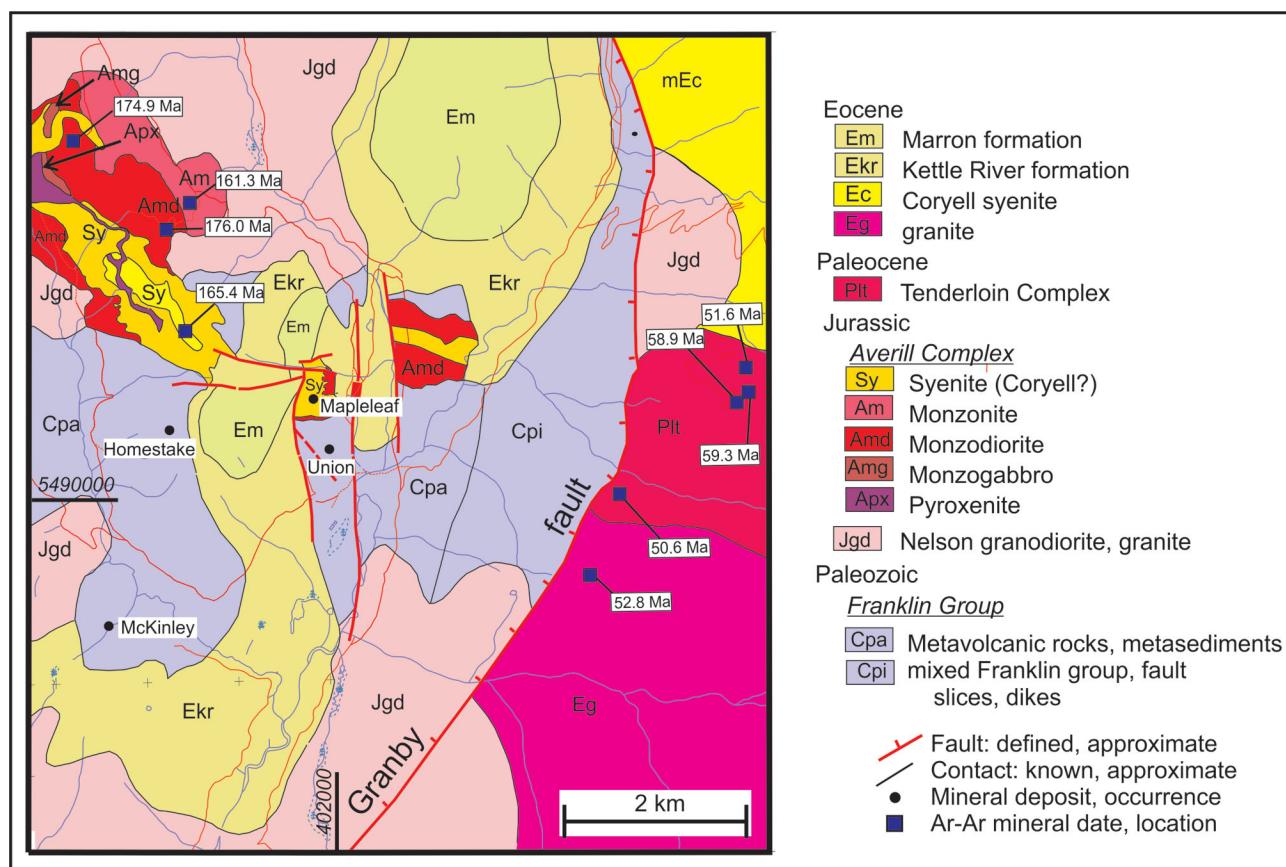


Figure 2: Geology of the Franklin mining camp and surrounding area; all dates are Ar-Ar mineral dates from Höy et al. (2019). Map is modified from Keep (1989) and Höy and Jackaman (2013).

the past-producing Beaverdell silver-lead-zinc camp and several gold occurrences, including Carmi (MINFILE 082ESW029; BC Geological Survey, 2019) in the north. Two prominent molybdenite porphyry deposits also occur in the area, the Carmi deposit just north of Carmi township and the Tuzo Creek deposit south of Beaverdell.

The Beaverdell area was mapped initially by Reinecke (1915) and this work largely provided the basis for later regional compilation maps by Cairnes (1940), Little (1961) and Tempelman-Kluit (1989). The area east of Beaverdell was mapped more recently by Massey and Duffy (2008a, b). This paper and map (Figure 3) are a compilation of those previously published maps, several provincial assessment reports, mapping by the senior author this past field season and new radiometric dates.

The area is underlain mainly by Middle Jurassic granodiorite that has intruded Late Paleozoic metasedimentary rocks, referred to as the ‘Wallace formation’ by both Reinecke (1915) and Massey and Duffy (2008b). Massive to porphyritic granite of the Paleogene Okanagan batholith intrudes and surrounds the Jurassic exposures as well as forms several small, isolated stocks within the central mass of granodiorite (Figure 3). These stocks are the loci for mineralization in the main deposits or camps within the area.

Beaverdell Camp

Mineral deposits in the Beaverdell camp were mined intermittently from 1913 to 1991, producing approximately 99.2 million grams of silver (35 million oz.) and 481 941 grams of gold (17 000 oz.) from narrow, high-grade lead-zinc veins. Mineralization and associated alteration occur mainly within Middle Jurassic granodiorite but extend into a small granitic stock that is essentially centred on the town of Beaverdell. The Ar-Ar dating method using hornblende yielded an age of 168.4 Ma for a sample of the Middle Jurassic granodiorite and the same method using muscovite yielded an age of 59.2 Ma for an unaltered sample of the Beaverdell stock (Figure 3). Supporting evidence for a Paleocene age for mineralization in the camp is provided by galena lead-isotope data that indicated a ca. 0.05 Ga age (Watson et al., 1982).

Carmi Area

The Carmi area, located approximately 8 km north of Beaverdell, hosts a variety of mineral occurrences and deposits. These include base- and precious-metal veins as well as the Carmi molybdenum deposit (MINFILE 082ENE036). Gold-bearing veins within the Westkettle batholith and host Paleozoic Wallace formation have been

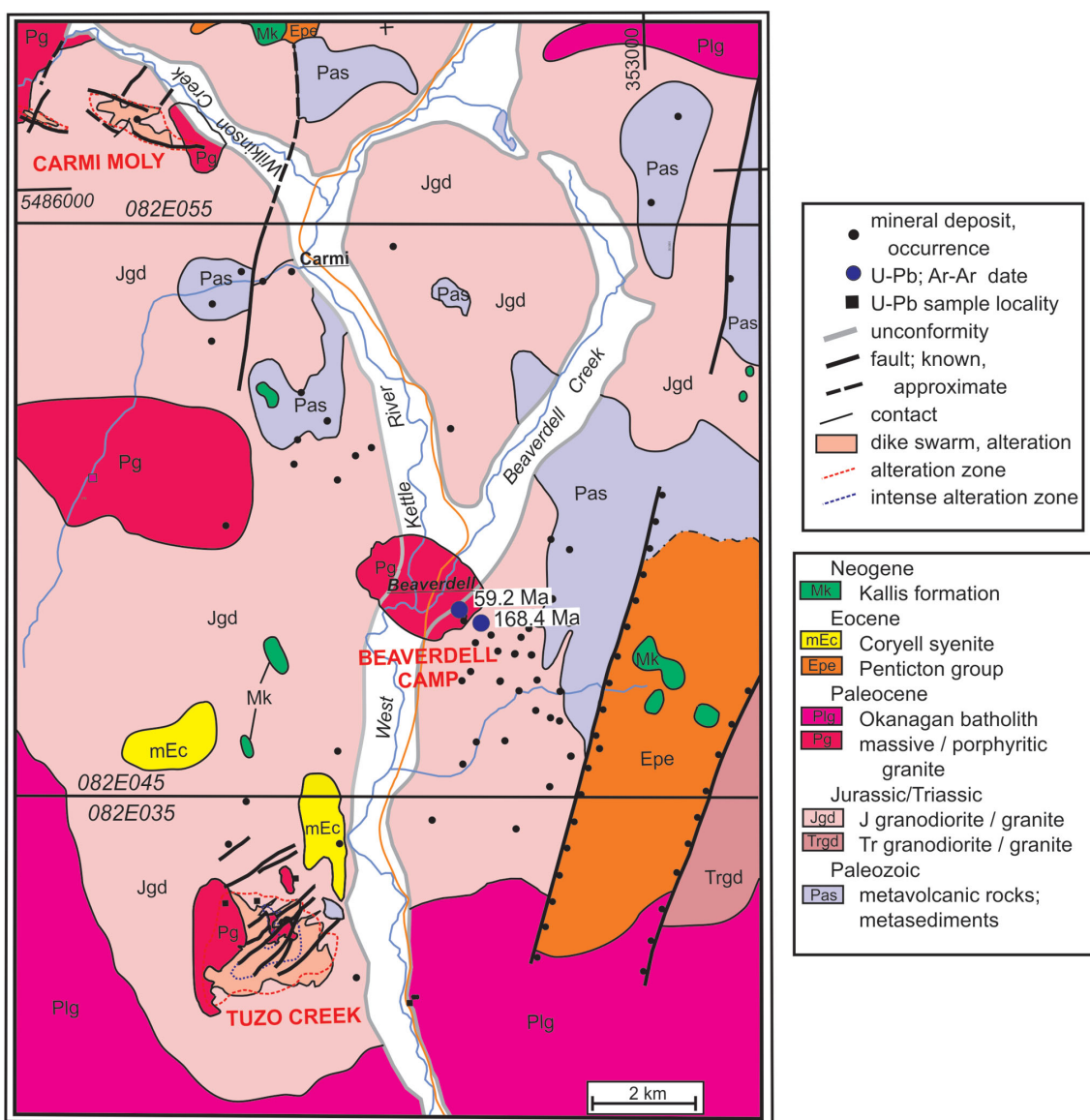


Figure 3: Geology of the Beaverdell camp, Carmi and Tuzo creeks areas. Geology modified from Reinecke (1915), Leary (1987) and Massey and Duffy (2008b); Ar-Ar radiometric dates are from Höy et al., (2019).

interpreted to be Jurassic in age based on galena lead-isotope data (Watson et al., 1982).

The Carmi molybdenum deposit was discovered in 1960 by Kennco Exploration Ltd. and since then has been explored fairly intensely by various companies, defining two zones referred to as the 'E zone' and the 'Lake zone' (summarized in Leary, 1987). Recent work, including diamond drilling, has defined an open pit indicated resource of 12.96 Mt grading 0.058% Mo and an inferred resource of 27.38 Mt grading 0.066% Mo (Reynolds, 2009).

The deposit is within an area largely underlain by Middle Jurassic granodiorite (Figure 3) that is cut by monzonite to granodiorite dikes and an underlying granitic stock (Leary,

1987). A late quartz monzonite stock, lithologically similar to phases of the Beaverdell stock, occurs immediately east of the Carmi molybdenum deposit and a similar stock along the western edge of the Lake zone. Molybdenum-copper mineralization comprises molybdenite with pyrite, magnetite, chalcopyrite and minor bornite in west-northwest-trending shear and breccia zones in Jurassic granodiorite and within the younger quartz monzonite stocks and dikes. The age of mineralization is assumed to be Paleocene based on correlation of the younger intrusive phases with the Valhalla Complex (Okanagan batholith; Leary, 1987). A sample of medium-grained, equigranular quartz monzonite from the E zone has been submitted for radiometric dating; the results will more closely constrain the age of mineralization in the Carmi molybdenum deposit.

Tuzo Creek

A molybdenite deposit (MINFILE 082ESW058) has been explored in the Tuzo Creek area, west of the West Kettle River, approximately 7 km south-southwest of Beaverdell (Figures 3, 4). The deposit was discovered in 1961 by Kennco Explorations (Canada) Ltd. and drilled by Amax Exploration Inc. from 1964 to 1966 and by E&B Explorations Ltd. in 1981. The property was the subject of an M.Sc. thesis, which remains to date the most comprehensive study of the deposit (Leary, 1970).

The regional geology in the vicinity of the deposit is shown in Figure 3. A generally north-trending porphyritic granite/quartz monzonite stock, the Tuzo Creek stock, is lithologically similar to Okanagan batholith rocks farther west (Figure 5). It intrudes the Middle Jurassic Westkettle batholith that also hosts the Beaverdell stock and quartz monzonite intrusions at Carmi. A small syenite stock, similar to many phases of the Eocene Coryell intrusive suite, is exposed a few kilometres northeast of the Tuzo Creek stock.

A large zone of molybdenite mineralization, associated with pyrite and specular hematite, quartz stockwork and veining, and widespread zones of argillic and potassic alteration, occur within and along the eastern side of the Tuzo Creek quartz monzonite. Leary (1970) described several phases of hydrothermal activity and mineralization, spatially and temporally associated with prominent southwest-trending shear and breccia zones, and both pre- and postmineral dikes and 'sills'. Leary (op. cit.) concluded that molybdenite mineralization, controlled by the dominant southwest-trending shears, occurred during and immediately after intrusion of the porphyritic stock, followed locally by minor overprinting of galena-sphalerite-pyrite quartz veining.



Figure 4: View to the south-southwest, from a waste dump in the Beaverdell camp to the Tuzo Creek deposit located on the rounded hill in the centre left of the photo.

Discussion on the Beaverdell Area

Two porphyry molybdenite deposits occur within small Paleocene(?) stocks that are located along the margins of the Paleogene Okanagan batholith in the central part of the Penticton map area. The stocks intrude Middle Jurassic granodiorite in the central part of the Okanagan batholith. Approximately 6 km south of the Tuzo Creek deposit, the Chenier copper-porphyry occurrence appears to share a similar setting, associated with Paleocene(?) megacrystic K-feldspar dikes that intrude Middle Jurassic granodiorite (Kennedy, 2006; Höy, 2007). The Beaverdell silver-lead-zinc camp is associated with a similar granitic stock, dated at 59.2 Ma (muscovite Ar-Ar dating) that intrudes Jurassic granodiorite.

The deposits within the Beaverdell–Carmi–Tuzo Creek area are structurally controlled. On a regional scale they appear to be in a structural zone that extends northwest from the Greenwood area, crossing the Rock Creek graben and into the Beaverdell area, where Jurassic rocks and Paleozoic metasediments of the Wallace formation are exposed. A number of northwest-trending faults parallel the zone, and these seem to have localized the intrusion of small outlying Paleocene stocks. On property scales, the deposit areas are



Figure 5: Sample of fresh porphyritic granite of the Tuzo Creek stock; note subhedral K-feldspar phenocryst in a granular quartz, K-feldspar, plagioclase matrix.

characterized by numerous shears and faults, commonly with little displacement; many of these are schematically shown in both the Carmi and Tuzo Creek areas (Figure 3). These faults typically have two prominent trends, north-northeasterly parallel to the trend of the Eocene Rock Creek graben extensional faults farther east and northwesterly, parallel to the trend of the regional structural high.

Lightning Peak

The Lightning Peak gold camp is located in the northern part of the Penticton map area (Figure 1), between the Kettle River and the northern headwaters of the Granby River (Figure 6). Regional maps show the area to be underlain by undifferentiated Middle Jurassic intrusive rocks with occasional small scattered exposures of basement Monashee

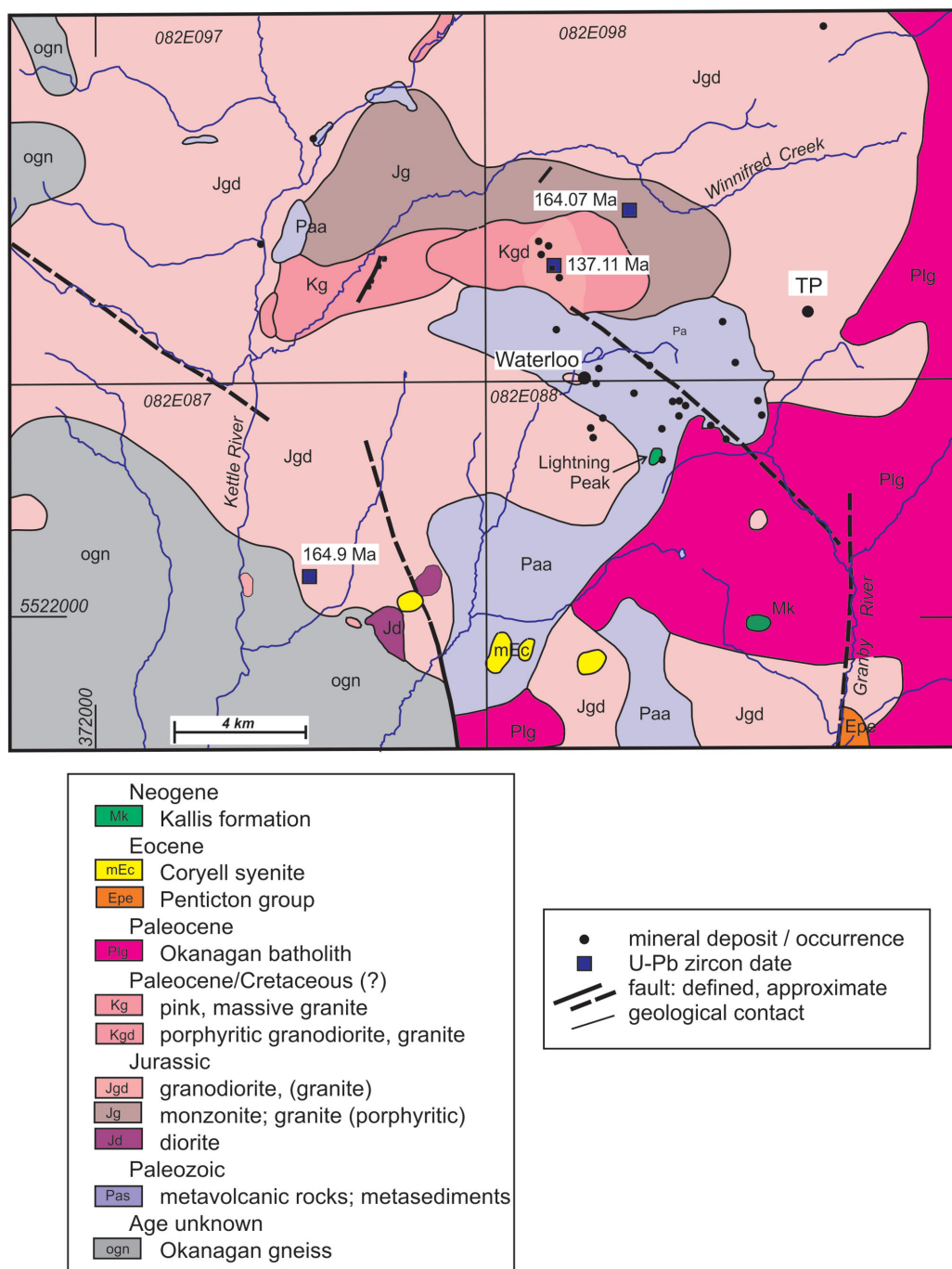


Figure 6: Geology of the Lightning Peak camp and surrounding area; geology is modified from Cairnes (1931) and Tempelman-Kluit (1989); U-Pb zircon dates were obtained at The University of British Columbia (R. Friedman, unpublished data, 2019).

gneiss and, to the southeast, Paleozoic volcanic and sedimentary rocks of the Harper Ranch group (Cairnes, 1931; Little, 1957; Tempelman-Kluit, 1989). This paper focuses mainly on gold-vein occurrences that occur in the porphyritic granodiorite (unit Kgd) shown in the central part of the 1:20 000 scale TRIM map 082E/098 (Figure 6).

The first claims in the Lightning Peak area (Figure 7) were staked in 1897 and, by the early 1900s, many of the showings were being developed and worked (Cairnes, 1931). Work has continued intermittently to the present and has included considerable diamond drilling, underground exploration in the 1930s and 1940s and a small amount of production. Recent work on the property (Callaghan and York-Hardy, 1996; Peterson, 2013) was concentrated mainly on the southern showings, referred to as the ‘Waterloo tenures’, which are hosted by Paleozoic Harper Ranch group rocks (Figure 6).

Mineral Occurrences and Deposits

The first comprehensive report of mineralization in the Lightning Peak camp describes two main vein types (Cairnes, 1931). East-west trending veins in shear zones, such as the Waterloo mine area (MINFILE 082ENE017; Figure 6), have been traced in surface and underground for several hundred metres within limestone and metasediments of the Harper Ranch group. The veins comprise mainly galena, sphalerite, pyrite and chalcopryite, with high silver content in the form of ruby silver, argentite and native silver, in a gangue of quartz and minor calcite (Figure 8). A second style of veins, more common to the north, are north-trending gold-quartz veins that have been traced locally for several hundred metres. They occur in a light grey, megacrystic Cretaceous granodiorite (unit Kgd; Figure 6) and farther south, in Paleozoic rock commonly within or parallel to quartz-porphyry dikes. These veins

contain variable amounts of pyrite and generally only minor galena and sphalerite.

The veins in the northern part of the Lightning Peak camp are hosted by an east-trending, generally leucocratic granodiorite stock that commonly contains large euhedral pink to tan K-feldspar phenocrysts up to 4 cm in length. Minor amounts of fresh to chloritic biotite and hornblende occur in a medium-grained matrix of plagioclase, quartz and K-feldspar. The stock appears to have a gradational contact in the north, with massive to porphyritic pink granite or monzonite (unit Jg) that also commonly contains large subhedral pink K-feldspar phenocrysts and, to the west, with massive pink granite (unit Kg). These units are not easily differentiated but all appear to be intrusive into the more typical, massive Middle Jurassic granodiorite (Figure 6).

Uranium-lead zircon ages are shown for several of the intrusive phases in Figure 6. The leucocratic (‘white’) granodiorite that hosts the north-trending gold veins has a Early Cretaceous age of 137.11 Ma, whereas the granite to the north has a Middle Jurassic age (164.07 Ma) similar to the host granodiorite (164.9 Ma). Hence, gold-bearing quartz veins hosted by the white granodiorite are no older

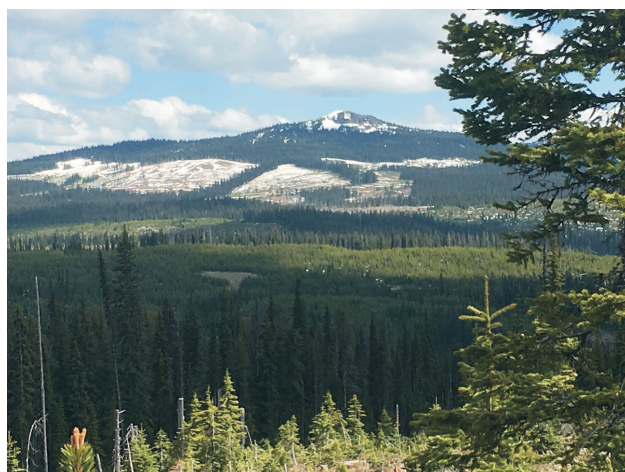


Figure 7: View to the southeast to Lightning Peak, which is capped by Miocene basalt of the Kallis formation that rests unconformably on Paleozoic basement.



Figure 8: Dump from workings of the AU silver-rich polymetallic veins (MINFILE 082ENE027) located approximately 3 km northwest of Lightning Peak and immediately northeast of the Waterloo deposit, shown on Figure 6.

than Early Cretaceous. The veins found further southeast along the northern margin of the Paleogene Okanagan batholith are very similar to the silver-rich sulphide veins in the Beaverdell camp; hence it is possible that they also represent a Paleocene mineralizing event.

Summary on the Lightning Peak camp

The Lightning Peak veins form a northwest-trending belt that extends from the northern margin of the Paleogene Okanagan batholith through a northwest-trending exposure of Paleozoic basement into the Early Cretaceous stock that hosts the main gold-rich veins. This mineralization may represent a zoned camp, marginal to the Paleogene Okanagan batholith, with more proximal silver-rich base-metal mineralization in the southeast and distal gold-vein mineralization in the northwest. Of note, examination of recent work undertaken in the area immediately northwest and northeast of Lightning Peak camp suggests the presence of a zoned mineral camp centred on porphyry-style molybdenite-copper mineralization in the vicinity of the TP mineral occurrence (MINFILE 082ENE049; Figure 6; Callaghan and York-Hardy, 1996). Furthermore, the same study identified prominent north-northeast- and northwest-trending linears, based on both ground topography and an airborne geophysical survey; these are inferred to be faults that parallel the northerly trend of the extensional graben faults and the northwest trends of controlling mineralizing structures, respectively, throughout the eastern half of the Penticton map area.

Midas Deposit Area

The Midas property (Figure 1) is located in the southern Monashee Mountains, southwest of Lower Arrow Lake (Figure 9). The area is included in the regional compilation maps of Tempelman-Kluit (1989) and Höy and Jackaman (2019), and the 1:50 000 scale Deer Park map (NTS 082E/08; Höy and Jackaman, 2010). Figure 9 shows the geology in the vicinity of the Midas molybdenum property and the Bulldog vein occurrence farther west.

The eastern part of the area is underlain by Eocene Coryell syenite dated at ca. 51 Ma (Carr and Parkinson, 1989). Granitic rocks of the Valhalla or Okanagan Complex, previously included as part of the Middle Jurassic Nelson Plutonic Suite, are exposed in the southwestern part of the map area. These are separated from the Proterozoic(?) Grand Forks Complex by the Kettle River extensional fault. Detailed mapping (Figure 9) shows that the Coryell and Okanagan batholiths are composite intrusions that can be separated into distinct intrusive phases. Late high-level stocks, essentially similar in age to the host batholiths, can be differentiated and these commonly localize mineralization.

The Midas porphyry-style molybdenum property (MINFILE 082ESE162) lies within a differentiated feldspar porphyry that is intruded by a swarm of northwest-trending feldspar porphyry dikes; this complex is cut by an east-trending breccia complex with stockwork quartz-magnetite mineralization and peripheral pyrite-argillic alteration. Mineralization, mainly within the breccia complex, includes molybdenite, minor chalcopyrite, and rare scheelite and sphalerite (summarized from MINFILE 082ESE162). Considerable work has been done on the property since its discovery in the early 1900s; the history of this exploration, including recent work, is summarized in recent assessment reports (e.g., Kennedy and Höy, 2010).

The Bulldog occurrence is a 2009 discovery 8 km west of the Midas property and is described in Kennedy and Höy (2010). A series of northwest-trending shears associated with intense propylitic alteration cut a small isolated body of Coryell syenite, dated at 51.99 Ma (Figure 9). Several parallel faults located to the northeast trend eastward toward the Midas property. Mineralization in the Bulldog area occurs as thin quartz veins and silicification, commonly with pyrite and jarosite alteration as well as elevated gold values.

Discussion on the Midas Deposit Area

The Midas property is a porphyry molybdenum prospect of Eocene age in a high-level quartz-feldspar porphyry complex within coarser grained Eocene Coryell syenite. Its location is structurally controlled along a series of northwest-trending faults; similar faults are also evident at the Bulldog gold occurrence to the west. Farther north, a zoned monzonite-monzodiorite intrusive complex cuts massive coarse-grained syenite. Megacrystic porphyritic granite surrounded by more massive granite is located southwest of the Coryell complex (Figure 9) and appears to correspond to an earlier phase than the syenite complex. The small syenite stock that hosts Bulldog mineralization is intrusive into the granite and a new U-Pb zircon date indicates a slightly younger age (Figure 9; R. Friedman, pers. comm. 2019).

Summary

This project was designed to demonstrate that large areas of the eastern half of the Penticton map area, underlain by largely undifferentiated and commonly poorly dated intrusive batholithic rocks, have the potential to include previously unrecognized stocks that may host mineralization. Several deposits and mineral camps were investigated, and all are shown to occur within or be related to isolated, generally high-level stocks that intrude Middle Jurassic, Paleocene or Eocene batholiths. These camps include dominantly polymetallic-vein mineralization in the Franklin camp, porphyry-style molybdenite deposits and high-grade silver base-metal-vein mineralization in the Beaverdell

area, gold and silver base-metal mineralization in the Lightning Peak area, and the Midas molybdenite porphyry deposit in the Deer Park map area. These camps illustrate the variety in both deposit types and ages of mineralization related to these small stocks.

An integral part of the project was to date the batholithic rocks and host stocks to better constrain the ages of associated mineralization. The results of U-Pb zircon and Ar-Ar mineral analyses have been summarized in Höy et al. (2019) and are included on the recently published compila-

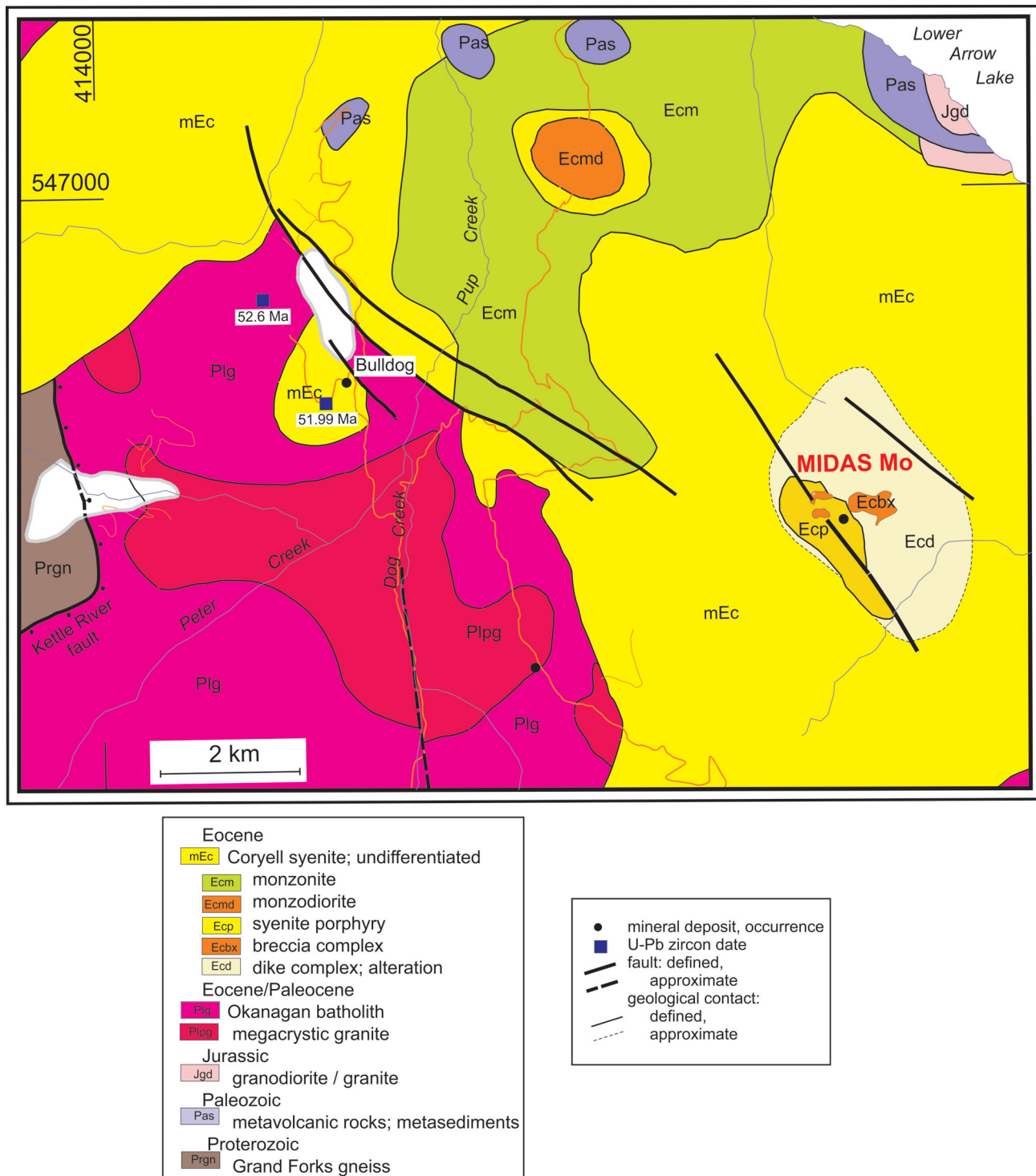


Figure 9: Geology of the Midas property and Bulldog mineral occurrence area. Geology modified from Tempelman-Kluit (1989) and Höy and Jackaman (2010); U-Pb zircon dates were obtained at The University of British Columbia (R. Friedman, unpublished data, 2019).

tion of the eastern half of the Pentiction map area (Höy and Jackaman, 2019). Unpublished U-Pb zircon dates that appear in this paper will be included in a separate paper to be released by Geoscience BC.

Several Ar-Ar mineral analyses of various phases of the mafic alkalic Averill Complex, host to much of the vein mineralization in the Franklin camp, confirm a Middle Jurassic age for the complex and, by inference, the age of Franklin camp mineralization.

Mineralization in the Lightning Peak camp is hosted by Jurassic granodiorite and a small, Early Cretaceous stock. The age of mineralization may be Cretaceous, or Paleocene, and related to the margins of the Paleogene Okanagan batholith that occurs immediately south of the camp.

The Beaverdell camp is located along the margins and within a granitic stock that was dated at ca. 59 Ma, a Paleocene age similar to that of many of the massive to porphyritic granites that occur to the east in the Almond Mountain (NTS 082E/07) map area. The Carmi and Tuzo Creek porphyry molybdenite deposits, located several kilometres north and south of the Beaverdell camp, respectively, are hosted within similar granitic stocks and are assumed to have a similar Paleocene age.

The Midas porphyry-style molybdenite deposit occurs in a small, late Coryell syenite porphyry that intrudes the central part of the Eocene Coryell batholith. A small Coryell stock several kilometres to the west contains minor gold-quartz vein mineralization.

Discussion

Large regions of the Pentiction map area are underlain by granitic terrane and their exploration can potentially lead to the discovery of new base- and precious-metal mineralization that is controlled by north- and northwest-trending structures. These structures are commonly the loci for late, high-level intrusions within similar-age batholithic bodies. Other than in existing mineral camps, the presence of these stocks often remains unrecognized and they do not appear on regional federal or provincial geological maps. Structures can also localize regional tectonic highs that expose contacts of batholithic rocks and country hostrocks, as well as being a favourable environment for mineralization. Features that help recognize these favourable areas within large terranes of dominantly granitic rock include:

- isolated exposures of basement rock
- marked changes in rock type as, for example, granodiorite to granite or syenite to monzonite
- textural changes, including porphyry or finer grained textures
- alteration zones, including typical K-feldspar, argillic or propylitic zones
- an increase in the density of dikes

- structures, including faults and shears, and possibly foliation within granitic rocks
- presence of mineralization.

Granitic and syenitic batholiths dominate the geology of the Pentiction area; these record repeated magmatic episodes during Triassic and Jurassic time, locally in the Cretaceous, and throughout the Paleocene and Eocene. The recent mapping undertaken, in conjunction with radiometric dating, has concentrated largely on Paleogene events and their relationship to mineralization. It has demonstrated that the Okanagan batholith, also referred to as the Valhalla Complex, is a composite batholith that includes massive to porphyritic megacrystic granite of Paleocene age (ca. 59–67 Ma) that was locally exposed in early Eocene time and unconformably overlain by graben-controlled Pentiction group conglomerate and volcanic rocks (ca. 52–57 Ma). Following burial, these were intruded by Eocene granite, also commonly included within the Okanagan batholith terrane, and similar-age syenite of the Coryell batholith (ca. 48–52 Ma). The large variety in igneous rock types, levels of exposure and ages is a direct function of vertical tectonics prevalent during regional extension in the central Okanagan in Paleogene time, and these have fundamentally controlled the distribution of base- and precious-metal mineralization.

Acknowledgments

Geoscience BC is gratefully acknowledged for financial support of this study. The authors also thank G.M. DeFields for his assistance in the field. The manuscript benefited considerably from reviews by G.E. Ray and G.M. DeFields.

References

- BC Geological Survey (2019): MINFILE BC mineral deposits database; BC Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey, URL <<http://minfile.ca/>> [September 2019].
- Cairnes, C.E. (1931): Lightning Peak area, Osoyoos District, B.C.; in Summary report, 1930, Part A, Geological Survey of Canada, p. 79–115.
- Cairnes, C.E. (1940): Kettle River, west half, Similkameen and Osoyoos districts, British Columbia; Geological Survey of Canada, Map 538A, scale 1:253 440.
- Callaghan, B. and York-Hardy, R.W. (1996): Airborne geophysical surveys, detailed interpretation report and related geological mapping on the Zalmac property; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 24 416, 73 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=24416> [September 2019]
- Caron, L. (2004): Assessment report on the Franklin property, Greenwood Mining Division: geology, geochemistry, trenching, diamond drilling; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 27 328, 47 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=27328> [November 2012].

- Caron, L. (2005): Assessment report on the 2004 exploration program: rock sampling, trenching, diamond drilling, Union property, Franklin camp, Greenwood Mining Division, British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 27 604, 37 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=27604> [November 2012].
- Carr, S.D. and Parkinson, D.L. (1989): Eocene stratigraphy, age of the Coryell batholith, and extensional faults in the Granby valley, southern British Columbia; *in* Current Research Part A, Geological Survey of Canada, Paper 89-1E, p. 79-87.
- Drysdale, C.W. (1915): Geology of the Franklin mining camp, southern British Columbia; Geological Survey of Canada, Memoir 15, 246 p.
- Höy, T. (2007): Geology and rock geochemistry, Chenier property, Kelly Creek area, southern British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 28 960, 32 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=28960> [September 2019].
- 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, URL <http://cdn.geosciencebc.com/project_data/GBC_Report2010-7/GBC_Map2010-7-1_Deer-Park.pdf> [November 2019].
- 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, URL <http://www.geosciencebc.com/i/project_data/GBC_Report2013-07/GBC_Map2013-07-1_Burrell.pdf> [November 2019].
- Höy, T. and Jackaman, W. (2016): Geology of the Almond Mountain map sheet (NTS 82E/07); Geoscience BC, Map 2016-08, scale 1:50 000, URL <http://cdn.geosciencebc.com/project_data/GBCReport2016-08/GBC_Map2016-08_Almond.pdf> [November 2019].
- Höy, T. and Jackaman, W. (2019): Geology of the Penticton map-sheet (east-half); Geoscience BC map 2019-04, scale 1:150 000, URL <http://cdn.geosciencebc.com/project_data/GBCR2019-04/GBCMap2019-04.pdf> [November 2019].
- Höy, T., Gabites, J. and Friedman, R. (2019): Summary report, U-Pb and Ar-Ar age dating, Penticton east-half (082E½); supplementary report to Geoscience BC Map 2019-04, Geoscience BC, 122 p., URL <http://cdn.geosciencebc.com/project_data/GBCR2019-04/GBCMap2019-04-Supp_Geochronology_PetrographyRpt.pdf> [November 2019].
- Keep, M. (1989): The geology and petrology of the Averill alkaline complex, near Grand Forks, British Columbia; M.Sc. thesis, The University of British Columbia, 110 p.
- Kennedy, T. (2006): Assessment report, prospecting program, Chenier property, Greenwood and Osoyoos Mining Divisions; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 28 578, 11 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=28578> [September 2019].
- Kennedy, T. and Höy, T. (2010): Geology and soil geochemistry, CP/Bully property, southern British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 31 485, 52 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=31485> [September 2019].
- Leary, G. (1970): Petrology and structure of the Tuzo Creek molybdenite deposit near Penticton, British Columbia; M.Sc. thesis, The University of British Columbia, 177 p.
- Leary, G. (1987): Report on high grade molybdenite potential of the Lake zone, Carmi Molybdenum deposit, Greenwood Mining Division, British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 16 102, 56 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=16102> [September 2019].
- Little, H.W. (1957): Kettle River, east half, Similkameen, Kootenay and Osoyoos districts, British Columbia; Geological Survey of Canada, Map 6-1957, scale 1:253 440, URL <<https://doi.org/10.4095/108451>> [November 2019].
- Little, H.W. (1961): Kettle River (west-half), British Columbia; Geological Survey of Canada, Preliminary map 15-1961, scale 1:253 440, URL <<https://doi.org/10.4095/108762>> [November 2019].
- Massey, N.W. and Duffy, A. (2008a): Boundary project: McKinney Creek (NTS 82E/03) and Beaverdell (NTS 82E/06, 07W, 10W, 11W) areas, south-central British Columbia; *in* Geological Fieldwork 2007, BC Ministry of Energy, Mines and Petroleum Resources, Paper 2008-1, p. 87-101, URL <http://cmscontent.nrs.gov.bc.ca/geoscience/PublicationCatalogue/Paper/BCGS_P2008-01-10_Massey.pdf> [November 2019].
- Massey, N.W.D. and Duffy, A. (2008b): Geology and mineral deposits of the area east of Beaverdell, British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, BC Geological Survey Branch, Open File 2008-9, scale 1:250 000, URL <http://cmscontent.nrs.gov.bc.ca/geoscience/PublicationCatalogue/OpenFile/BCGS_OF2008-09.pdf> [November 2019].
- Massey, N.W.D., Gabites, J.E., Mortenson, 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, Mines and Petroleum Resources, Paper 2010-1, p. 127-142, URL <http://cmscontent.nrs.gov.bc.ca/geoscience/PublicationCatalogue/Paper/BCGS_P2010-01-11_Massey.pdf> [November 2019].
- Peterson, N. (2013): 2012 drilling, geochemical, geological and geophysical report on the Waterloo property, southeast British Columbia, Vernon Mining Division, British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 33 907, 306 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=33907> [September 2019].
- Reynolds, P. (2009): Diamond drilling report on the Carmi molybdenum property, Kettle River project, British Columbia; BC Ministry of Energy, Mines and Petroleum Resources, Assessment Report 30 806, 211 p., URL <http://aris.empr.gov.bc.ca/search.asp?mode=repsum&rep_no=30806> [September 2019].
- 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, west of the sixth meridian, British Columbia; Geological Survey of Canada, Map 1736A, scale 1:250 000.
- 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.

