British Columbia Geological Survey annual program review 2018-2019

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1. Introduction

Founded in 1895, the British Columbia Geological Survey (BCGS) is the oldest scientific agency in the province. The Survey conducts research to establish the geological evolution and mineral resources of the province. Drawing on continuously advancing concepts and technologies, the Survey creates knowledge to guide societal decisions centred on the Earth sciences, connecting government, the minerals industry, and communities to the province's geology and mineral resources. The information provided by the Survey is used for effective mineral exploration, sound land use management, and responsible governance. This information benefits decisions that balance the economy, the environment, and community interests. Survey activities serve government, the general public, First Nations, local communities, the minerals industry, public safety agencies, environmental scientists, and other research organizations. The Survey strives to be a leader in public government geoscience, providing geological and geomorphological information through reports, maps, and databases (Fig. 1), which can be freely accessed online. This paper highlights the activities of the Survey in 2018.

The BCGS is part of the Mines and Minerals Resource Division in the British Columbia Ministry of Energy, Mines and Petroleum Resources. Headquartered in Victoria, the Survey also operates a satellite office in Vancouver focussed on the exploration and mining industry (Mineral Development Office or MDO). Staffed by 28 people, the BCGS consists of three sections: 1) Cordilleran Geoscience; 2) Resource Information and 3) the Mineral Development Office (Fig. 2). The Cordilleran Geoscience Section delivers new geoscience, primarily through field-based bedrock and surficial geology mapping projects, regional geochemical surveys, and targeted mineral deposit studies. It also manages the Survey's laboratory and curates the provincial sample archive. The Resource Information Section is responsible for maintaining and developing geoscience databases and disseminating these data online through MapPlace 2, our geospatial web service. The Resource Information Section is also responsible for collecting, evaluating, approving, and archiving assessment reports submitted by the exploration and mining industry in order to maintain titles in good standing. As the steward of mineral and coal resources in the province, the Survey has an important role in stimulating activity, attracting investment, and providing continuous research based on a corporate memory that extends back more than 125 years. The Mineral Development Office provides investment intelligence to government and global business, connecting the national and international investment community to the Survey and to the province's mineral resources. It also produces the annual Provincial Overview of Exploration and Mining in British Columbia (e.g., British Columbia Geological Survey, 2019; Clarke et al., 2019).

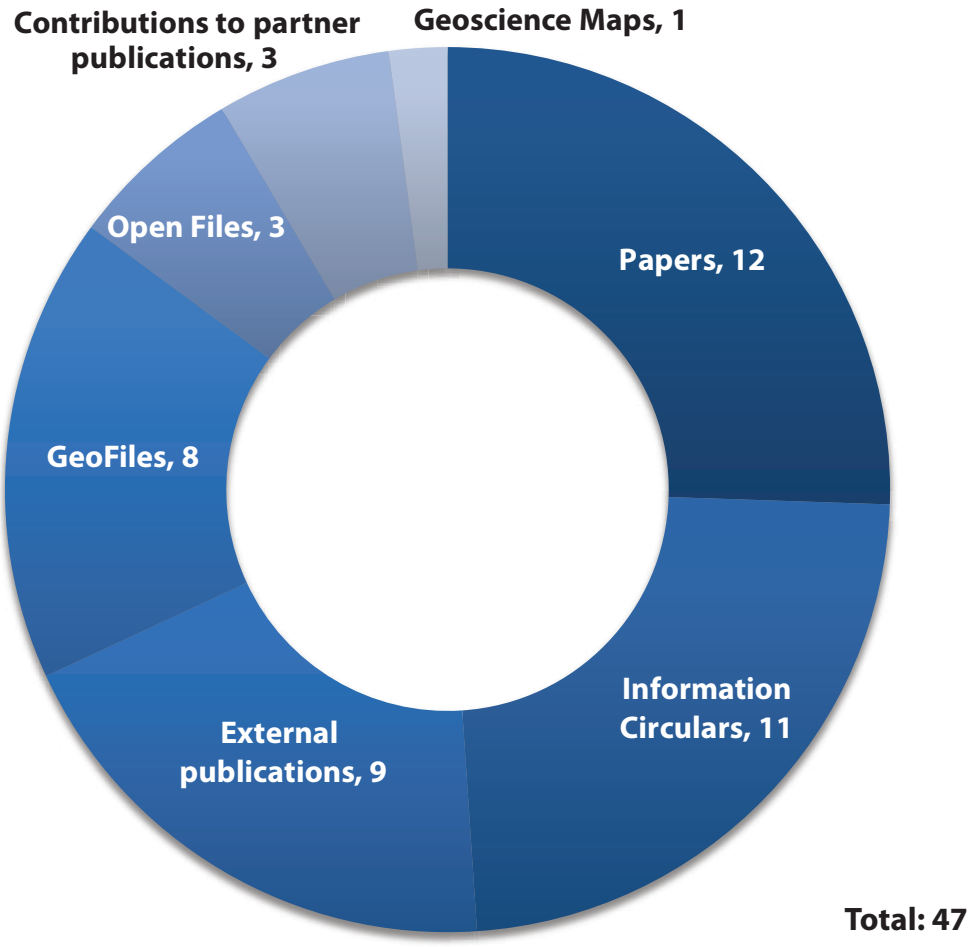
The BCGS continues to evolve with several staff changes. Chief Geologist and Executive Director Dr. Stephen Rowins departed from the Survey to pursue an opportunity as director and professor at the Centre for Exploration Targeting at University of Western Australia. Dr. Adrian Hickin, former Director of the Cordilleran Geoscience Section, was selected as Steve's replacement and has been appointed Chief Geologist. With the filling of several vacancies in the last five years, the Survey is seeing significant renewal, and is working to fill other key geoscience roles in 2019. The Survey continues to invest in the next generation of geoscientists by hiring and training student assistants, supporting graduate students, and mentoring student research (Fig. 3).

2. Partnerships

The BCGS is small and works to make best use of limited resources. Thus, partnerships are important. BCGS and the Geological Survey of Canada (GSC) continue to deliver projects through the second iteration of the Geo-mapping for Energy and Minerals (GEM 2) program and through three Targeted Geoscience Initiative 5 (TGI 5) projects.

In 2013, the Government of Canada renewed support for the second phase of the GEM program (2013-2020) aimed at advancing geological knowledge and further developing modern geological maps and data sets. The BCGS collaborated with the GSC and the Yukon Geological Survey with a project examining Cache Creek and Stikine terranes near Atlin.

The TGI 5 program is directed at building knowledge and developing methods to better target buried mineral deposits.



Types of Publications by the British Columbia Geological Survey

Papers*: This series is reserved for reviews and final thematic or regional works. Geological Fieldwork, our annual review of field activities and current research, is released as the first Paper of each year.

Geoscience Maps: This series is the BCGS vehicle for publishing final maps.

Open Files: These maps and reports present the interim results of ongoing research, particularly mapping projects.

GeoFiles: These publications enable rapid release of extensive data tables from ongoing geochemical, geochronologic, and geophysical work. As such, they serve the same function as data repositories provided by many journals, providing immediate access to raw data from specific projects.

Information Circulars: These publications provide accessible geoscience information to a broad audience in government, industry, and the general public. Included in the Information Circular series are the annual Provincial Overview of Exploration and Mining in British Columbia**, and the Coal Industry Overview.

Contributions to partner publications: This category includes reports, maps, and other products published by another agency such as the Geological Survey of Canada or Geoscience BC, but have received contributions from British Columbia Geological Survey staff.

External publications: These are contributions to the peer reviewed literature and published in a recognized national or international scientific journal.

*The count refers to the total number of articles authored by BCGS personnel in a volume.

**Although six articles are included in Exploration and Mining in British Columbia, it is counted as a single volume.

Fig. 1. British Columbia Geological Survey publications in 2018.

Fig. 2. Members of the British Columbia Geological Survey at Johnson Street Bridge, Victoria.

The program aims to understand the geological processes responsible for deriving, transporting, and depositing ore metals. One BCGS-TGI 5 project, in northwest British Columbia and southern Yukon, is assessing gold occurrences spatially related to the Llewellyn fault and Tally Ho shear zone. BCGS leads another TGI 5 project focused on specialty metal deposits in the province that contain rare earth elements, lithium, tantalum, and niobium. This project includes a partnership with the Geological Survey of Japan. The third TGI 5 project, also led by BCGS, is in collaboration with the University of British Columbia and is working towards a mineral deposit model for orogenic Ni-Cu-PGE mineralization. The current iteration of the TGI program is expected to conclude in 2020.

In 2018, the Survey partnered informally with the Saanich Inlet Protection Society, a Vancouver Island community group, to develop a proposal to the UNESCO Global Geoparks Network for creating a geopark dedicated to Saanich Inlet (British Columbia Geological Survey, 2018a). It also continues to work with the Tumbler Ridge Geopark Society to enhance the Tumbler Ridge Global Geopark, which UNESCO added to the Network in 2014.

3. Cordilleran Geoscience Section

Geologists with the Cordilleran Geoscience Section undertake single- and multi-year field-based projects that include regional mapping, mineral deposit studies, and developing

Fig. 3. Training the next generation of field geologists.

new exploration methods (Fig. 4). Collectively, the section provides a range of expertise that includes, regional mapping, metallogeny, coal, tectonics, surficial and Quaternary geology, geochemistry, petrology, and mineral exploration methods.

In addition to the main projects undertaken in 2018, and itemized in more detail below, Cordilleran Section geologists provided new information from previous studies. Mihalynuk et al. (2019) report U-Pb zircon data from the Granduc and Rock and Roll volcanic massive sulphide deposits in northwestern British Columbia that are consistent with previous work indicating that mineralization took place in the Late Triassic. Building on work in the Decar area of central British Columbia (Milidragovic et al., 2018), Milidragovic and Grundy (2019) provide new geochemical and petrographic data from Cache Creek terrane, concluding that volcano-sedimentary rocks of the Sowchea succession are likely oceanic plateau deposits whereas the Trembleur ultramafite (host to the Decar nickel-iron awaurite prospect) and overlying rocks of the Rubyrock igneous complex formed in a suprasubduction zone setting. Representing two fundamentally different tectonic settings, these two tectonostratigraphic packages were interleaved during Cache Creek terrane-Stikine terrane collision in the Late Jurassic. Coal geology compilation work continued, with updated releases for the East Kootenay coalfields (British Columbia Geological Survey, 2018b) and the Peace River coalfields (British Columbia Geological Survey, 2018c).

3.1. Mapping, regional synthesis, and compilation

3.1.1. Porphyry transitions; magmatic belts of Stikinia (BCGS-GSC)

Although fieldwork on this project finished in 2016, further work is planned towards synthesizing data and updating the provincial geology compilation. This project, initiated as a collaboration with the Geological Survey of Canada through the Geo-mapping for Energy and Minerals (GEM 2), addresses the continuity of the prospective Triassic-Jurassic magmatic belt in northern Stikinia, assesses the porphyry potential of this belt, and evaluates the potential of deposits in adjacent terranes.

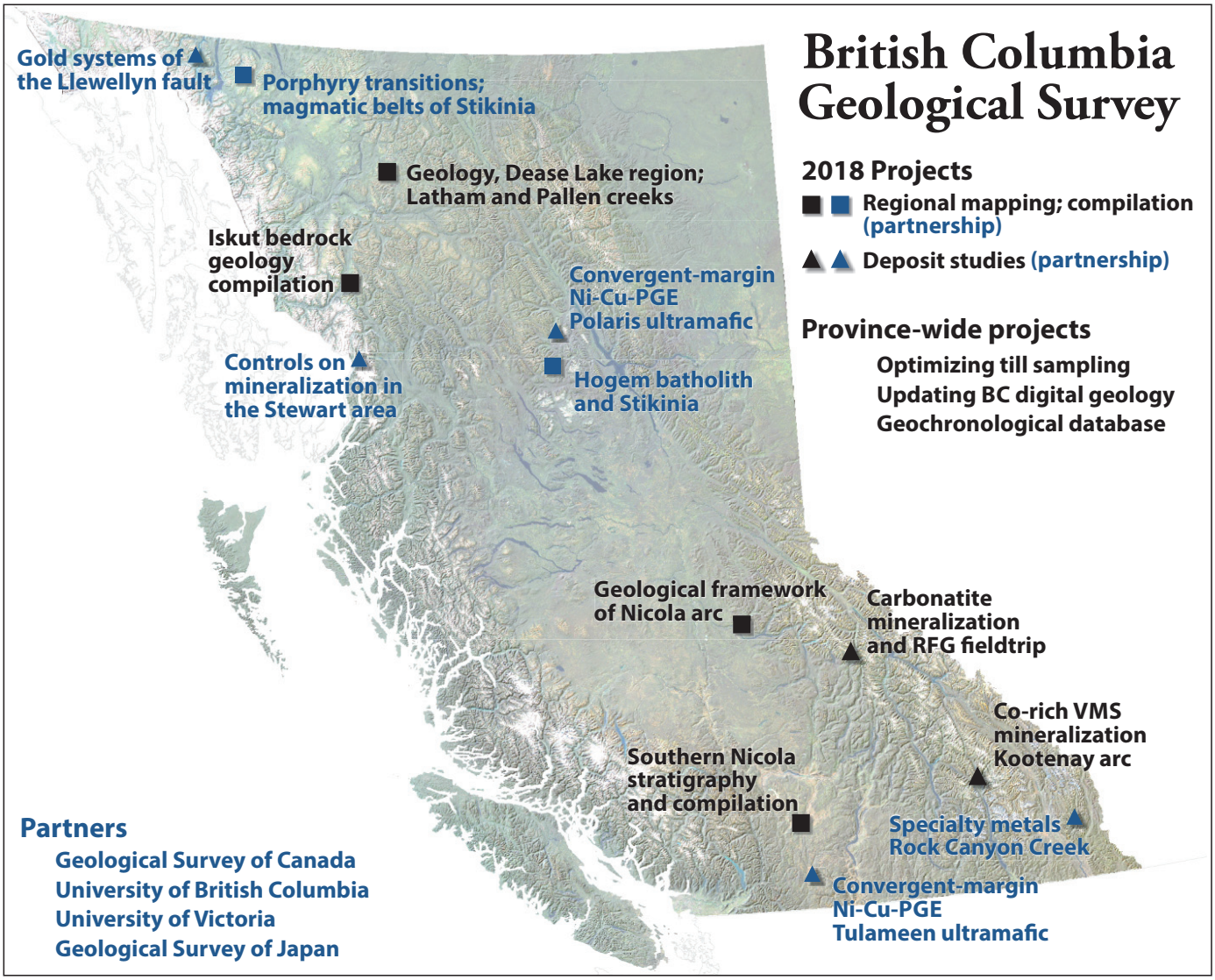


Fig. 4. British Columbia Geological Survey projects in 2018.

3.1.2. Regional mapping in the Dease Lake region

This was the third and final field season of a mapping project in the Dease Lake region that examined Upper Triassic to Middle Jurassic arc-related volcanic and sedimentary rocks and allied intrusive rocks to better understand the tectonic and metallogenic history of northern Stikinia and bounding terranes (Fig. 5). Mapping in 2018 (van Straaten and Wearmouth, 2019) focused on the Latham and Pallen Creek areas southwest of Dease Lake and distinguished three volcano-sedimentary units sitting above upper Paleozoic rocks of the Stikine assemblage: 1) the Tsaybahe group (Lower to Middle Triassic); 2) the Stuhini Group (Upper Triassic) and 3) the Hazelton Group (Lower to Middle Jurassic). The Tsaybahe group is an informal name assigned to fine-grained siliciclastic and overlying plagioclase and augite-phyric basalts that are texturally similar to the overlying Stuhini Group. They are distinguished from the Stuhini Group based on age, stratigraphic position and distinctive low magnetic susceptibility. Stuhini Group volcanic rocks are unconformably overlain by the Hazelton Group, which includes a lower sedimentary unit (Spatsizi Formation) and overlying volcanic rocks (Horn Mountain Formation). The Tsaybahe group likely represents nascent Stuhini arc magmatism. Developed within or adjacent to Upper Triassic and Middle Jurassic plutons that cut the supracrustal units are zones with locally elevated copper, gold, silver and/or molybdenum in fractures, veins, skarns, and gossans. This project will now begin a synthesizing year, and the recent mapping will be incorporated into the provincial geology compilation.

Fig. 5. Middle part of Horn Mountain Formation, west of Tanzilla, Dease Lake mapping project.

3.1.3. Iskut bedrock compilation

Part of the Golden Triangle of northwestern British Columbia (e.g., British Columbia Geological Survey 2018d), the Iskut River region hosts many significant porphyry, precious-metal and volcanogenic massive sulphide deposits that are related to the Hazelton Group and allied intrusions (latest Triassic to Middle Jurassic). Nelson et al. (2018) set out new nomenclature and definitions for the Hazelton Group, providing a unified stratigraphic framework that will assist exploration in this highly prospective region. Digital data and working files supporting the Iskut region compilation are in Nelson (2019), and new U-Pb zircon geochronologic data from the Mitchell deposit are in Febbo et al. (2019).

3.1.4. Hogem batholith and Stikinia

In 2018, a multi-year 1:50,000-scale mapping project was initiated in north-central British Columbia targeting northern Hogem batholith and adjacent volcanic and sedimentary rocks of Stikinia (Fig. 6). The main objectives of this project are to update the bedrock and surficial maps of northern Hogem batholith and adjacent Quesnel, Stikine, and Cache Creek terranes and to generate new geochronological data to better understand the timing of intrusive events and their relationship to mineralization. This project will provide the first detailed maps of northern Hogem batholith and update reconnaissance-level maps of adjacent terranes that date from the 1940s. Based mainly on crosscutting relationships and the presence or absence of tectonic fabrics, Ootes et al., (2019 a,b) identify four main plutonic suites (from oldest to youngest): Thane Creek (ca. 200 Ma), Duckling Creek (ca. 180 Ma), Mesilinka (ca. 135 Ma), and Osilinka (ca. 135 Ma). To the ca. 34 mineral occurrences previously known from the area, and additional 17 were discovered this summer. Most are in the Thane Creek and Osilinka suites and consist mainly of disseminated chalcopyrite and malachite staining. New gold and copper-bearing quartz veins were also discovered, and crosscut Thane Creek diorite and Osilinka granite. Work in 2019 will map the more northerly part of Hogem batholith and Cache Creek terrane to the west.

Fig. 6. Fly camp, Hogem batholith project.

3.1.5. Stratigraphic architecture of the Nicola arc

The large number of operating porphyry Cu-Au-Mo mines in Quesnel terrane marks it as the most important metallotect in the Canadian Cordillera. Despite its economic importance, the regional stratigraphic framework of the main Triassic to Jurassic arc sequences has not been well-defined. The BCGS

currently has two projects that, together, will provide a coherent stratigraphic architecture for the Nicola arc: the Nicola Group stratigraphic framework project between Bonaparte Lake and Likely; and the southern Nicola arc project in the Merritt and Princeton areas (Fig. 4).

3.1.5.1. Nicola Group stratigraphic framework

This project was initiated in 2015 with the primary objective of establishing a regional stratigraphic framework for Triassic rocks of the Nicola arc in the central part of the Quesnel terrane. Based on new work in the Bridge Lake-Quesnel River area in 2018, Schiarizza (2019) refines his earlier four-fold subdivision of the Nicola Group. Assemblage one is represented mainly by the Spanish Mountain unit (new informal name), which consists of Middle Triassic sedimentary rocks and local pillowed basalt with N-MORB and E-MORB geochemical characteristics. Undated, but possibly correlative rocks in the south-central part of the Nicola belt include volcaniclastic sandstone, chert, and pyroxene-phryic basalts of the Wavey Lake unit (new informal name), which is locally overlain by early Carnian siltstone of the Meridian Lake unit (new informal name). Assemblage two (Carnian and early Norian), the most widespread subunit of the Nicola Group, contains volcanic sandstone and conglomerate, locally intercalated with pyroxene-phyric basaltic rocks. Assemblage three (Norian) consists of pyroxene-phyric basalt flows and related breccias. Assemblage four (late Norian and Rhaetian) may be separated from older Nicola rocks by an unconformity or disconformity. It consists of red and maroon polymictic conglomerate with abundant hypabyssal and plutonic rock fragments, feldspathic sandstone, and distinctive analcime basalt and coarse, crowded plagioclase-phyric andesite. The Nicola Group is flanked to the east by Middle and Upper Triassic slate, siltstone and quartz sandstone of the Slocan Group (Fig. 7), part of a siliciclastic basin that formed east of, and coeval with, the Nicola arc; Middle Triassic carbonaceous shales previously included in the Nicola Group are re-assigned to the Slocan Group. Upper Triassic to Lower Jurassic calcalkaline and alkaline plutonic rocks that cut the Nicola Group are equivalent to regional plutonic suites in Quesnel terrane, and include a latest Triassic monzodiorite suite that is coeval with assemblage four and hosts significant porphyry Cu-Au deposits. Work in 2019 will entail formalizing nomenclature, generating detrital zircon geochronologic data, and correlating results with the southern Nicola arc project.

Fig. 7. Steeply dipping sandstone with thin interbeds of slaty siltstone, Slocan Group, southeast of Spanish Lake. Beds are overturned.

3.1.5.2. Southern Nicola arc

The Southern Nicola Arc project began in 2012 as a regional mapping program along the western part of the Nicola arc between Merritt and Princeton with an aim of re-examining the three stratigraphic belts first proposed for the Nicola Group (Preto, 1979; Mihalynuk et al., 2016). This mapping, together with new biostratigraphy and geochronology has redefined the original belts and their relationships. A brief field study in 2018 measured a key section representing the lower of two major subdivisions proposed for the Nicola Group and re-examined an area containing a representative section of the upper part of the lower stratigraphic subdivision. These data will be incorporated into a new 1:50,000 scale map that will detail Nicola Group geology between Merritt and Princeton, integrated with Nicola Group studies to the north, and entered into the provincial digital geology compilation.

3.1.6. Surficial geology mapping and till sampling

Plouffe and Ferbey (2018) published a new 1:50,000-scale surficial geology map of the Highland Valley copper mine area, and Ferbey et al. (2018) described the geochemistry and mineralogy of 14 subsurface till samples recovered from a diamond drill hole on the Rateria porphyry Cu±Mo property. An updated index of British Columbia surficial geology maps (Arnold and Ferbey, 2016) was released in January, 2018.

3.2. Deposit studies

3.2.1. Gold and Llewellyn fault (BCGS-GSC-YGS-TGI 5)

This project is examining the nature and timing of gold mineralization spatially related to the Llewellyn fault zone. This structure is a brittle, steeply dipping, southeast-striking dextral strike-slip fault that overprints earlier ductile deformation with similar orientation and kinematics. This early ductile shear zone is similar to the Tally Ho shear zone in Yukon. Ootes et al. (2018) concluded that the early ductile fabrics formed between 120 and 75 Ma, considerably older than the brittle deformation that is bracketed between 56 and 50 Ma, and that the various styles of gold mineralization developed at distinctly different periods. Geochronologic samples collected in 2018 from southern Yukon and northern British Columbia will better establish the age of early ductile strain.

3.2.2. Specialty metals (BCGS-GSC-TGI 5)

Specialty metals are elements such as rare earth elements (REE), Li, Ta, Nb, Ga, Ge, In, Co, W, Mg, Cs, Rb, Rh, Be,

Zr, Hf, V, Sb and Sc that are not only essential to the growth of the electronics and green-energy sector, but also critical or strategic for technologically advanced devices and industrial processes. Work in 2018 emphasized laboratory analyses of British Columbia carbonatite samples collected during the last six years, focussing on quantifying radiogenic and stable isotope levels.

Simandl et al. (2019) report on an occurrence of fersmite from the Mount Brussilof magnesite deposit in southeastern British Columbia. Fersmite is a Nb- Ta-bearing mineral commonly found as an alteration product of pre-exiting niobium-bearing minerals in carbonatites, alkaline and peralkaline intrusions, and rare earth element pegmatites. In contrast, fersmite at Mount Brussilof appears to be primary. It forms crystals on sparry dolomite, which is commonly found in Mississippi Valley-type Zn-Pb deposits, crosscutting and lining cavities in sparry magnesite. This fersmite is rich in Nb, Th and heavy rare earth elements, but poor in Ta. Chemical mapping of individual crystals shows strong zonation suggesting that the hydrothermal fluids from which fersmite precipitated evolved with time.

3.2.3. Tulameen-Polaris: Towards a new mineral deposit model for convergent margin Ni-Cu-PGE (BCGS-TGI 5)

This project builds on our current understanding of high-tenor Ni-Cu-PGE deposits formed at convergent margins that are found in Alaskan-type ultramafic-mafic intrusions and that are possibly genetically linked to Cu-Au porphyry systems (e.g., Nixon et al., 2017; Manor et al., 2017, Nixon 2018). One objective is to develop a new mineral deposit model encompassing the temporal evolution and ore system processes involved in the genesis of Cu-PGE recently found in the Tulameen Alaskan-type ultramafic complex (Nixon, 2018). The project continues with a study of the Polaris Alaskan-type ultramafic intrusion to better establish its age and character, to place its Ni-Cu-PGE mineralization in a geological context, and to test for possible relationships to the Hogem batholith immediately to the south (Fig. 4) and its Cu-Au mineral systems. In 2018, previously collected samples from the Tulameen body were analyzed and several weeks of fieldwork spent at the Polaris complex (Fig. 8) to examine geological relationships and collect samples for geochemical, isotopic, and geochronologic analysis.

3.2.4. Blue River carbonatites

Carbonatites are igneous rocks containing abundant primary carbonate minerals. These rare rocks generally form in intracratonic settings as part of crustal-scale dome and rift systems. In the Canadian Cordillera, carbonatites were emplaced episodically, at ca. 810-700, 500, and 360-330 Ma, forming part of the British Columbia alkaline province, which defines a long (at least 1000 km), narrow (ca. 200 km) orogen-parallel belt. The ca. 810-700 Ma and 500 Ma carbonatites were injected during protracted breakup of the supercontinent Rodinia and passive margin development on the western flank of Laurentia.

Fig. 8. In the distance, rust brown-weathering dunite, Polaris ultramafic complex.

In contrast to these and to most carbonatites globally, the 360-330 Ma carbonatites, such as the Blue River area examples, are unusual. They were emplaced near the continental margin during subduction rather than in the cratonic interior during continent breakup. The Blue River carbonatites include at least 18 carbonatite and 2 alkaline, silica-undersaturated-rock occurrences. As part of the Resources for Future Generations conference and sponsored by the Mineralogical Association of Canada, Ruhklov et al., (2018a) led a field trip that examined the characteristics, magmatic evolution, and mineralization of the Blue River carbonatites as represented by the Upper Fir complex, which hosts one of the largest and best studied Nb-Ta deposits in the Canadian Cordillera (Fig. 9). New isotopic and elemental compositions of minerals from Blue River carbonatites and related rocks (Ruhklov et al., 2018a, b) are indistinguishable from worldwide carbonatites generated by deep-mantle plumes. The 360-330 Ma Cordilleran examples formed along the western margin of Laurentia while subduction was taking place immediately to the west. Lithospheric extension related to this Late Paleozoic subduction is considered responsible for rifting the continental margin and initiating the Slide Mountain ocean as a back-arc basin. Ruhklov et al. (2018a) conclude that this same back-arc extension triggered the most prolific pulse of alkaline magmatism in the Cordillera, including emplacement of the Blue River carbonatites, which were derived from a long-lived, deep-level mantle plume that was tapped episodically since the Neoproterozoic. Further fieldwork in 2018 collected samples from the Blue River and from the Ice River complex to test this model.

3.2.5. Co-rich VMS mineralization, Kootenay arc

In 2018, a reconnaissance program was initiated in the Kootenay arc examining the potential for Cu-Co-Ni Beshi-type volcanogenic massive sulphide deposits in the Lardeau Group that may hold similarities to Outokupu-style polymetallic massive sulphides in Finland described by Peltonen et al. (2008).

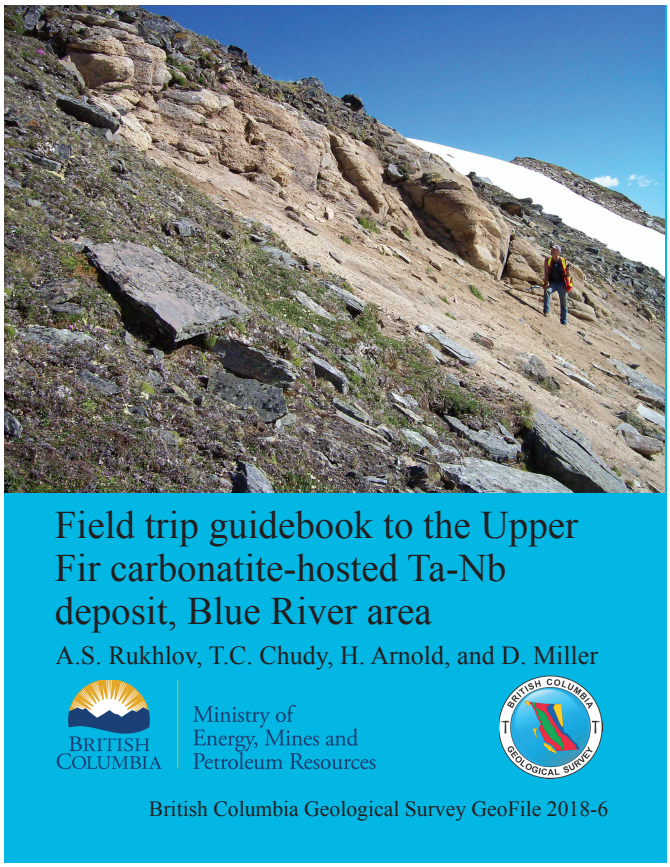


Fig. 9. Field trip guidebook to the Upper Fir-carbonatite-hosted Ta-Nb deposit (Rukhlov et al., 2018a). The cover photo shows a sill-like body of calcite carbonatite in the Howard Creek area.

3.3. Geochemical databases

Fieldwork generates vast amounts of rock, till, stream-sediment, and coal geochemical data. In the past, the British Columbia Geological Survey has modelled geochemical data sets individually. Han et al. (2019) developed a skeleton data model capable of capturing and representing the commonalities of individual sets by focusing on common entities, attributes, and relationships. They use this skeleton data model to update existing models for four province-wide data sets (lithogeochemical, regional drainage, till, and coal ash), capturing the unique characteristics of each. Applying the skeleton data model streamlines data handling steps, from data compilation to product generation, and establishes a reliable flow for managing geochemical data at the Survey.

3.4. BCGS Emeritus Scientists

Emeritus Scientist Ray Lett continued in his role as mentor to Survey geologists and serving as a peer reviewer. He also continued to be productive, releasing unpublished geochemical data from between Lillooet and French Bar Creek, south-central British Columbia (Lett, 2018a), the Porcher Island, Grenville Channel, and Dundas Island area, central British Columbia coast (Lett, 2018b), and the McLeod Lake area, central British Columbia (Lett, 2018c).

Shortly after her retirement in early 2018, JoAnne Nelson, the Survey's most recent Emeritus, launched a cross-country lecture tour as recipient of the 2017 Canadian Provincial and Territorial Geologists Medal and devoted to her work on the tectonic evolution of the Canadian Cordillera. JoAnne will be releasing a GeoFile digital data release (Nelson, 2019) to accompany her most recent work in the Iskut River region (Nelson et al., 2018).

4. Resource Information Section highlights

As custodian of all provincial public geoscience data, the Survey preserves and archives more than a century's worth of information, including geological maps and reports, thematic studies, and mineral occurrence, geochemical, and geophysical data. Survey activities are traditionally aimed at enhancing British Columbia's mineral exploration competitiveness, and delivering geoscience is a priority in making the province an attractive investment destination. The Survey continues to upgrade databases and to make geoscience information more accessible through MapPlace 2, our geospatial web service. These activities help explorers advance projects without duplicating previous work. They also help government, First Nations, and communities make decisions about mineral exploration, resource development, environmental protection, natural hazards, and land use.

4.1. MapPlace 2

MapPlace 2 is the BCGS geospatial web service that enables people to easily visualize, search, report, and generate custom results and maps from all province-wide geoscience databases (Cui et al., 2018a). Through MapPlace 2, multiple layers of geospatial data, such as mineral titles, assessment reports, powerlines, aquifers, topography and satellite imagery, can be accessed. Recent enhancements include the addition of OpenStreetMap as a base map, and KML downloads for selected bedrock units and other data.

4.2. Databases

4.2.1. ARIS

ARIS (Assessment Report Index System) is an index database linking to a collection of mineral exploration assessment reports submitted in compliance with Mineral Tenure Act Regulations. The ARIS library of more than 36,700 PDF reports, dating from 1947, describes exploration work valued at more than $2.8 billion. After a one-year confidentiality period, the reports become an open resource that can be used for planning mineral exploration, investment, research, land use, and resource management. Currently, digital data are available for download from 480 assessment reports through the ARIS search application. The BCGS welcomes the submission of assessment report digital data. Data can be submitted when a report is filed or e-mailed to ARIS.digital@gov.bc.ca.

Norris and Fortin (2019) conducted a pilot project to extract geochemical data from assessment reports in the Interior Plateau region and incorporate them into a new database.

Data harvested from about 125 assessment reports submitted between 2000 and 2015 (Fig. 10) include about 1.5 million determinations from about 35,000 samples. Future assessment report-sourced databases will include information from drill holes and geophysical surveys. The BCGS is also implementing recommendations from the Exploration Assessment Data Digital Formats Proposal by PDAC to ensure that the structure of the databases will meet future national standards.

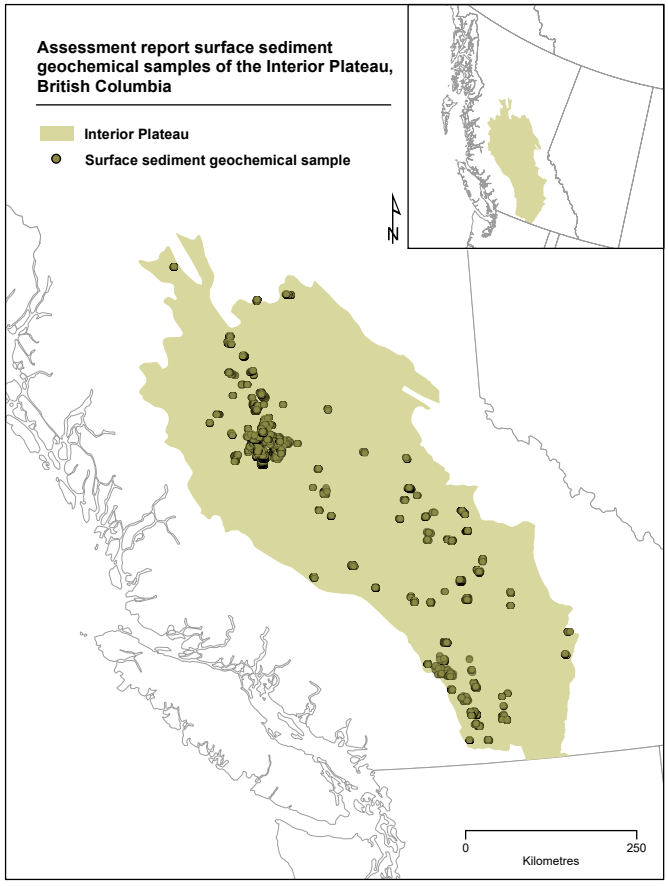


Fig. 10. Surface sediment geochemistry data harvested from assessment reports.

4.2.2. COALFILE

COALFILE includes a collection of 1010 coal assessment reports, dating from 1900. It includes data from about 15,700 boreholes, 550 bulk samples, 5600 maps, 3650 trenches, 480 coal ash chemistry analyses and links to MINFILE.

4.2.3. MINFILE

MINFILE is a database of more than 14,800 mineral, coal, and industrial mineral occurrences. It is widely used by the mineral industry to develop exploration strategies, plan investments, evaluate or estimate resource potential, and carry out metallogenic studies. It also serves government agencies and other organizations concerned with natural resources and land use. The MINFILE database can be queried via an online application that interacts with MapPlace 2, ARIS, and Property File.

4.2.4. Property File

Property File is a collection of more than 73,500 reports, maps, photos, and technical notes donated to the Survey since the late 1800s. These documents can be accessed from the Property File database using a full-text, search tool. The BCGS accepts donations to Property File.

4.2.5. Geochemical databases

The provincial geochemical databases hold field and geochemical data from multi-media surveys by the Geological Survey of Canada, the BCGS, and Geoscience BC. These databases are updated regularly and contain results from: 1) the Regional Geochemical Survey program (RGS) including analyses from stream-sediment, lake-sediment, moss, and water samples; 2) till surveys; and 3) rock samples. The current version of the RGS database of about 65,000 samples is compiled from 111 original sources (Han and Rukhlov, 2017) and is delivered in flat tabular XLS format for ease of use and consistency with previously published data. The till database is an XLS format compilation from about 40 reports released between 1992 and 2017 and includes geochemical data for about 10,500 samples (Bustard and Ferbey, 2017; Bustard et al., 2017). The lithogeochemical database includes data from about 2000 papers and reports published by the BCGS, GSC and universities between 1986 and 2015. The data set consists of about 11,000 samples, including a quarter million determinations analyzed by 26 different methods at 21 laboratories (Han et al., 2016). The skeleton data model developed by Han et al. (2019) is being used to update existing models for the province-wide data sets.

4.3. British Columbia digital geology map

BCGS offers province-wide digital coverage of bedrock geology, including details from field mapping at scales from 1:50,000 to 1:250,000 (Cui et al., 2018b). The BC digital geology continuously integrates new regional compilations as the data become available (Fig. 11). The digital geology (in GeoPackage and Esri shapefile formats) and Truetype font for

Fig. 11. Digital data capture in the field.

stratigraphic age symbols are freely available for download under the British Columbia Open Government License. Customized bedrock geological maps and legends can be visualized and data downloaded in KML format by spatial and non-spatial queries via MapPlace 2. The BCGS is introducing new lithology codes in the digital geology database that will capture distinguishing features on the geological processes and environments of bedrock units. The digital geology is maintained by a geospatial frame data model with techniques to simplify the integration process and shorten the time from field mapping, compilation, and integration to data delivery.

4.4. Website update

The BCGS has a newly designed, easier to use website (Fig. 12). The site has better navigation links and search capabilities. The search results link to over 8300 publication assets (PDF, ZIP, XLS, and various map formats). Search capabilities have been enhanced allowing one to search the content of documents for specific text strings.

4.5. EarthResourceML

EarthResourceML is an XML-based standard for the exchange of digital information. The BCGS is reviewing EarthResourceML and developing interoperable (data exchange capable) web services. These web services would enable access to geological data on the OneGeology portal, and allow interoperable connections of the Survey's databases. Data components have been mapped to the vocabularies adopted by the Commission for the Management and Application of Geoscience Information (CGI). The implementation of EarthResourceML would help to enhance usability of the various databases by adopting the open standard in the data models, contents, and vocabularies.

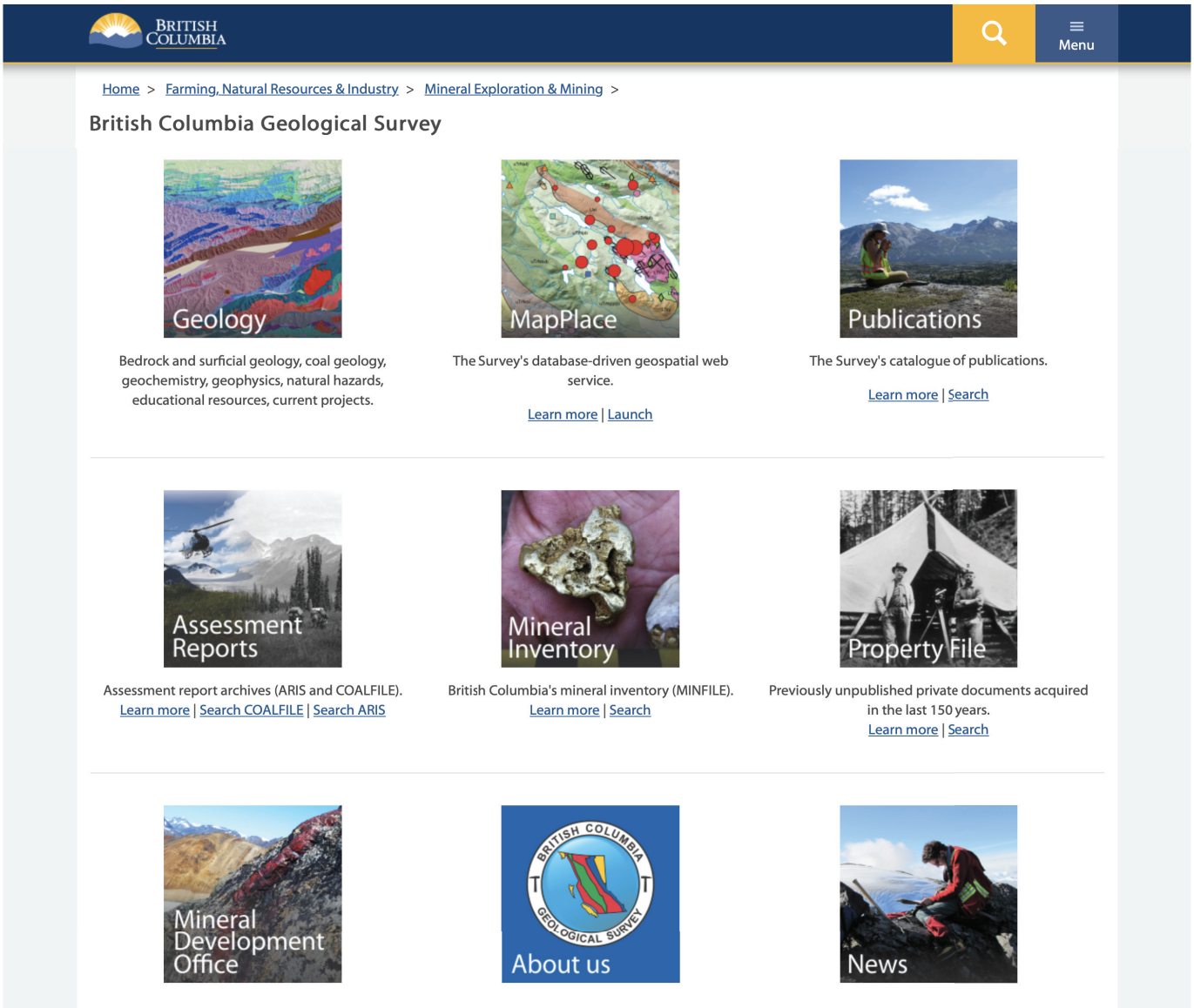


Fig. 12. Newly designed British Columbia Geological Survey website.

4.6. Three dimensional geological modelling

The British Columbia Geological Survey used 3D modelling to help analyze the Upper Fir carbonatite-hosted Ta-Nb deposit (see section 3.2.4. above, and Rukhlov et al., 2018), generating a series of cross sections to illustrate the spatial variation of rock compositions in the deposit (Fig. 13).

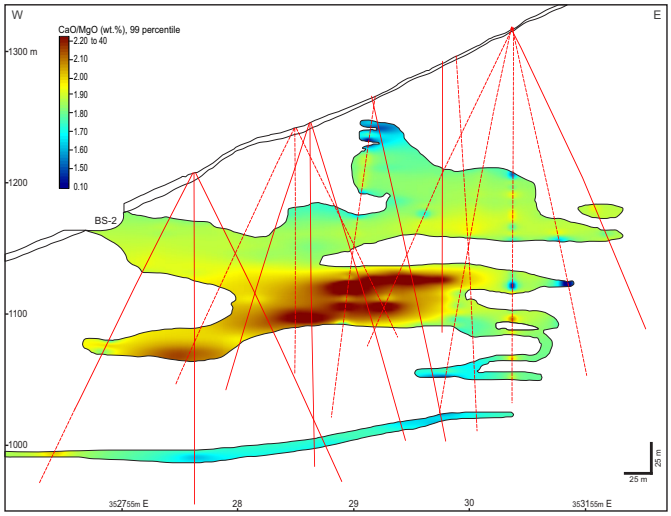


Fig. 13. Cross section showing the 99th percentile for CaO/MgO (wt.%) from drill-core samples (1 m intervals), gridded by the inverse-distance 3D interpolation method using GOCAD® software.

5. British Columbia Geological Survey Mineral Development Office (MDO)

The Mineral Development Office is the Vancouver base of the British Columbia Geological Survey. It links the more than 800 exploration and mining companies headquartered in Vancouver to provincial mineral and coal information. The MDO distributes Survey data and provides technical information and expertise about mineral opportunities to the domestic and international investment community.

The MDO monitors the activities of the mining and exploration sectors and co-ordinates production of the 'Provincial Overview of Exploration and Mining in British Columbia', an annual volume that summarizes activities in the different regions of the province and written by the Regional Geologists and the MDO (see British Columbia Geological Survey, 2019; Clarke et al., 2019). In 2018, the MDO led production of a brochure devoted to the Golden Triangle of northwestern British Columbia, which hosts most of the major gold, silver, and copper deposits in west-central Stikinia (British Columbia Geological Survey, 2018d). More than 150 mines have operated in the region since prospectors first arrived near the end of the 19th century and it currently hosts the Brucejack and Red Chris mines. The MDO also led developing a brochure about low-carbon emission energy technologies and metals mining in the province (British Columbia Geological Survey, 2018e).

Exploration expenditures in the province increased from last year and will be highlighted in the 2018 British Columbia Mineral and Coal Exploration Survey, a joint initiative amongst EY (formerly Ernst & Young), the Ministry of Energy, Mines and Petroleum Resources, and the Association for Mineral Exploration (AME). Conducted in the fall of 2018, the survey is based on data collected directly from prospectors and exploration companies. Expenditure trends suggest that exploration in British Columbia continues to undergo an exploration lifecycle 'reset' that began with an upturn in outlays in 2017.

6. Regional geologists

The British Columbia Regional Geologists (Table 1) represent the provincial government on geological matters at a regional level and capture information on industry activity in their jurisdictions. Within their communities, they provide information on exploration trends, possible investment opportunities, land use processes, First Nation capacity building, and public outreach.

Table 1. British Columbia's regional geologists.

Regional Geologist	Office	Region
Vacant	Smithers	Northwest
John DeGrace	Prince George	Northeast and North Central
Vacant	Kamloops	South Central
Fiona Katay	Cranbrook	Southeast
Bruce Northcote	Vancouver	Southwest

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References cited

Arnold, H., and Ferbey, T, 2016. British Columbia surficial geology map index. British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Open File 2016-3.

British Columbia Geological Survey, 2018a. Saanich Inlet, southern Vancouver Island: Geology of an Aspiring Global Geopark. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Information Circular 2018-3, 8 p.

British Columbia Geological Survey, 2018b. The East Kootenay coalfields. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Information Circular 2018-6.

British Columbia Geological Survey, 2018c. The Peace River coalfields. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Information Circular 2018-7.

British Columbia Geological Survey, 2018d. The Golden Triangle of northwestern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Information Circular 2018-5, 8 p.

British Columbia Geological Survey, 2018e. Low-carbon energy technologies and metals mining in British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Information Circular 2018-11, 8 p.

British Columbia Geological Survey, 2019. Provincial Overview of Exploration and Mining in British Columbia, 2018. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Information Circular 2019-01, 133 p.

Bustard, A.L., and Ferbey, T., 2017. An index of base and precious metal regional- to property-scale subglacial till geochemical and mineralogical surveys in British Columbia, British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Open File 2016-2 (updated August 2017).

Bustard, A.L., Han, T., and Ferbey, T., 2017. Compiled till geochemical data for British Columbia, British Columbia British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2017-9.

Clarke, G., Northcote, B., Katay, F., and DeGrace, J.R., 2019. Exploration and Mining in British Columbia, 2018: A summary. In: Provincial Overview of Exploration and Mining in British Columbia, 2018. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Information Circular 2019-01, pp. 1-37.

Cui, Y., Zhao, S., Fortin, G., Meredith-Jones, S., and Jones, L.D., 2018a. Development of MapPlace 2 geospatial web service to disseminate geoscience in British Columbia. In: Geological Fieldwork 2017, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2018-1, pp. 183-195.

Cui, Y., Hickin, A.S., Schiarizza, P., Miller, D., Nixon, G.T., Nelson, J.L., and Ferri, F, 2018b. Methods to update the digital geology of British Columbia and synopses of recently integrated mapping programs. In: Geological Fieldwork 2017, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2018-1, pp. 197-215.

Febbo, G.E., Friedman, R.M., Kennedy, L.A., and Nelson, J.L., 2019. U-Pb geochronology of the Mitchell deposit, northwestern British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2019-03, 8 p.

Ferbey, T., Plouffe, A., and Hickin, A.S., 2018. Geochemistry and mineralogy of subsurface till samples recovered from diamond drill hole R17-01, Rateria property (porphyry Cu±Mo), south-central British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2018-8, 15 p.

Han, T., and Rukhlov, A.S., 2017. Regional Geochemical Survey (RGS) data update and release using the newly developed RGS database, British Columbia British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2017-11, 7 p.

Han, T., Rukhlov, A.S., Naziri, M., and Moy, A., 2016. New British Columbia lithogeochemical database: Development and preliminary data release. British Columbia Ministry of Energy and Mines, British Columbia Geological Survey, GeoFile 2016-4, 6 p.

Han, T., Rukhlov, A.S., Riddell, J.M., and Ferbey, T., 2019. A skeleton data model for geochemical databases at the British Columbia Geological Survey. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2019-01, pp. 125-135.

Lett, R.E., 2018a. Compilation of geochemical data between Lillooet and French Bar Creek, south-central British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2018- 4, 42 p.

Lett, R.E., 2018b. Regional moss mat-sediment geochemical survey in the Porcher Island, Grenville Channel, and Dundas Island area, central British Columbia coast. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2018-5, 32 p.

Lett, R.E., 2018c. Digital data release for a multimedia geochemical survey in the McLeod Lake map area (NTS 093J/5, 6, 12) central British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2018-7, 2 p.

Manor, J.M., Scoates, J.S., Wall, C.J., Nixon, G.T., Friedman, R.M., Amini, M., and Ames, D.E., 2017. Age of the Late Cretaceous ultramafic-hosted Giant Mascot Ni-Cu-PGE deposit, southern Canadian Cordillera: Integrating CA-ID-TIMS and LA-ICP-MS U-Pb geochronology and trace element geochemistry of zircon. Economic Geology, 112, 1395-1418.

Mihalynuk, M.G., Zagorevski, A., Logan, J.M., Friedman, R.M., and Johnston, S.T., 2019. Age constraints for rocks hosting massive sulphide mineralization at Rock and Roll and Granduc deposits between Iskut and Stewart, British Columbia. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2019-01, pp. 97-111.

Mihalynuk, M.G., Diakow, L.J., Friedman, R.M., and Logan, J.M., 2016. Chronology of southern Nicola arc stratigraphy and deformation. In: Geological Fieldwork 2015, British Columbia Ministry of Energy and Mines, British Columbia Geological Survey Paper 2016-1, pp. 31-63.

Milidragovic, D., and Grundy, R., 2019. Geochemistry and petrology of rocks in the Decar area, central British Columbia: Petrologically constrained subdivision of the Cache Creek complex. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2019-01, pp. 55-77.

Milidragovic, D., Grundy, R., and Schiarizza, P., 2018. Geology of the Decar area north of Trembleur Lake, NTS 93K/14. In: Geological Fieldwork 2017, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2018-1, pp. 129-142.

Nelson, J.L., 2019. Iskut region geological compilation: Supporting data and working files. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2019-02, 2 p.

Nelson, J.L., Waldron, J., van Straaten, B., Zagorevski, A., and Rees, C., 2018. Revised stratigraphy of the Hazelton Group in the Iskut River region, northwestern British Columbia. In: Geological Fieldwork 2017, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2018-1, pp. 15-38.

Nixon, G.T., 2018. Geology of the Tulameen Alaskan-type ultramafic-mafic intrusion, British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2018-2, 1:20,000 scale.

Nixon, G.T., Scheel, J.E., Friedman, R.M., Wall, C.J., Gabites, J., Jackson-Brown, S., and Scoates, J.S., 2017. Staged emplacement of the Turnagain Alaskan-type ultramafic-mafic intrusion, British Columbia, Canada: implications for Ni-Cu-PGE mineralization and the origin of zoned complexes. Society for Geology Applied to Mineral Deposits, 14th Biennial Meeting, v. 2, 555-558.

Norris, J., and Fortin, G., 2019. Assessment report-sourced surface sediment geochemical database: Development and initial data release from the Interior Plateau. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2019-04, 10 p.

Ootes, L., Castonguay, S., Friedman, R., Devine, F., and Simmonds, R., 2018. Testing the relationship between the Llewellyn fault, Tally-Ho shear zone, and gold mineralization in northwest British Columbia. In: Geological Fieldwork 2017, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2018-1, pp. 67-81.

Ootes, L., Bergen, A.L., Milidragovic, D., Graham, B., Simmonds, R., 2019a. Preliminary geology of northern Hogem batholith,

Quesnel terrane, north-central British Columbia. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources British Columbia Geological Survey Paper 2019-01, pp. 31-53.

Ootes, L., Bergen, A.L., Milidragovic, D., and Graham, B., 2019b. Preliminary geology of Notch Peak and Ogden Creek (parts of NTS 094C/04 and 093N/13), northern Hogem batholith, Quesnel terrane, north-central British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Open File 2019-02, 1:50,000 scale.

Peltonen, P, Kontinen, A., Huhma, H., and Kuronen, U., 2008. Outokumpu revisited: New mineral deposit model for the mantle peridotite-associated Cu-Co-Zn-Ni-Ag-Au sulphide deposits, Ore Geology Reviews, 33, 559-617.

Plouffe, A., and Ferbey, T., 2018. Surficial geology of the Highland Valley Copper mine area (Parts of NTS 092I/06, 7, 10 and 11), British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey, Geoscience Map 2018-01, 1:50,000 scale.

Preto, V.A., 1979. Geology of the Nicola Group between Merritt and Princeton. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Bulletin 69, 90 p.

Rukhlov, A.S., Chudy, T.C., Arnold, H., and Miller, D., 2018a. Field trip guidebook to the Upper Fir carbonatite-hosted Ta-Nb deposit, Blue River area, east-central British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2018-6, 72 p.

Rukhlov, A.S., Mao, M., Spence, J., Creaser, R.A., Czech, E., and Gabites, J., 2018b. Mineral chemistry and isotopic systematics of carbonatites and related rocks from the Blue River area. Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey GeoFile 2018-1.

Schiarizza, P., 2019. Geology of the Nicola Group in the Bridge Lake-Quesnel River area, south-central British Columbia. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2019-01, pp. 15-30.

Simandl, G.J., Petrus, J.A., Matthew I., Leybourne, M.I., Paradis, S., and Akam, C., 2019. Characterization of primary fersmite from the Mount Brussilof magnesite deposit, southeastern British Columbia. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2019-01, pp. 113-123.

van Straaten, B.I., and Wearmouth, C., 2019. Geology of the Latham and Pallen Creek area, northwestern British Columbia: Distinguishing the Tsaybahe group, Stuhini Group, and Hazelton Group, and the onset of Triassic arc volcanism in northern Stikinia. In: Geological Fieldwork 2018, British Columbia Ministry of Energy, Mines and Petroleum Resources, British Columbia Geological Survey Paper 2019-01, pp. 79-96.

In Memoriam

On November 20, 2018 Brian Grant, a former long-time member of the British Columbia Geological Survey, passed away peacefully surrounded by family. Brian first joined the Survey in 1986 as part the MINFILE group. He was later appointed head of the Scientific Review Office and then became Director of Regional Mapping and Economic Geology before leaving in 2008 to pursue interests in the private sector. Brian made an enormous contribution to the Survey during his time as editor by ensuring that all publications were of a high standard. He made the Survey and its employees look great! Brian's career in the mineral exploration and mining community spanned more than 50 years. After starting a degree in aerospace engineering at St. Francis Xavier University, Brian changed gears and entered the geology program at Memorial University in Newfoundland, where he completed his degree in 1974. He worked on many projects in North America, Africa, and South America, exploring for massive sulphides, gold, diamonds, tin, nickel, porphyries, uranium, coal, and industrial minerals. Between 2008 and 2012, Brian was President and Director of Goldbrook Ventures Inc. where he oversaw the exploration for Ni-Cu-PGE-bearing sulphides in the Raglan Belt of the Ungava Peninsula. Brian then took on advisory and consulting roles, serving on the board of several companies (Rockland Minerals Corp., Tasu Global Resources Inc., Masuparia Gold, Quadra Mining Corp.) and undertaking general contracting in the exploration community. Brian will be missed by his family, members of the British Columbia Geological Survey, and the exploration community.