British Columbia Geological Survey annual program review 2016-2017

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1. Introduction

The British Columbia Geological Survey (BCGS), established in 1895, links government, the minerals industry, and British Columbians to the Province's geology and mineral resources. The BCGS produces geoscience data and knowledge that stimulate exploration activity and attract investment. The Survey strives to be a leader in public government geoscience, providing information to all stakeholders and communities through traditional reports, maps, and databases (Fig. 1), which can be freely accessed online. Headquartered in Victoria, the BCGS is part of the Mines and Mineral Resources Division of the Ministry of Energy and Mines. The Survey has a permanent staff of 29 people (Fig. 2) operating in three sections: 1) Cordilleran Geoscience; 2) Resource Information; and 3) the Mineral Development Office (MDO). The Cordilleran Geoscience Section is responsible for generating new geoscience knowledge, largely through field-based studies and surveys. The Resource Information Section is responsible for maintaining and developing the provincial geoscience databases and disseminating geoscience data online through MapPlace. This section is responsible for evaluating, approving, and archiving mineral and coal exploration assessment reports filed by the exploration and mining industry. The MDO links the province's mineral and coal resources to the investment community, distributes and promotes BCGS technical data, and coordinates the technical outputs of the Regional Geologists Program.

The BCGS is a collaborative agency and partners with federal, provincial, and territorial governments, other national and international organizations, and the mineral exploration industry to develop and deliver geoscience projects. Partnerships maximize effectiveness by optimizing resources and expertise. The Geological Survey of Canada (GSC) and the BCGS continue to benefit from strong partnerships delivering on two main programs, the Cordilleran Project in the second iteration of the Geo-mapping for Energy and Minerals (GEM 2) Program, and the fifth iteration of the Targeted Geoscience Initiative (TGI-5). The Survey has also entered in to a partnership agreement with the Geological Survey of Japan to advance studies on critical and strategic material. Several projects are being delivered through collaborations with the Department of Earth, Ocean, and Atmospheric Science at the University of British Columbia from TGI-5 grants from the GSC. Formal BCGS partnerships are also in place with the Mineral Deposits Research Unit at the University of British Columbia and Geoscience BC. Since 2003, the Ministry of Energy and Mines as maintained a formal partnership with the University of Victoria (MEM-UVic Partnership). This partnership supports joint research projects and student training that benefits School of Earth and Ocean Science, the Ministry of Energy and Mines, and mineral exploration sector.

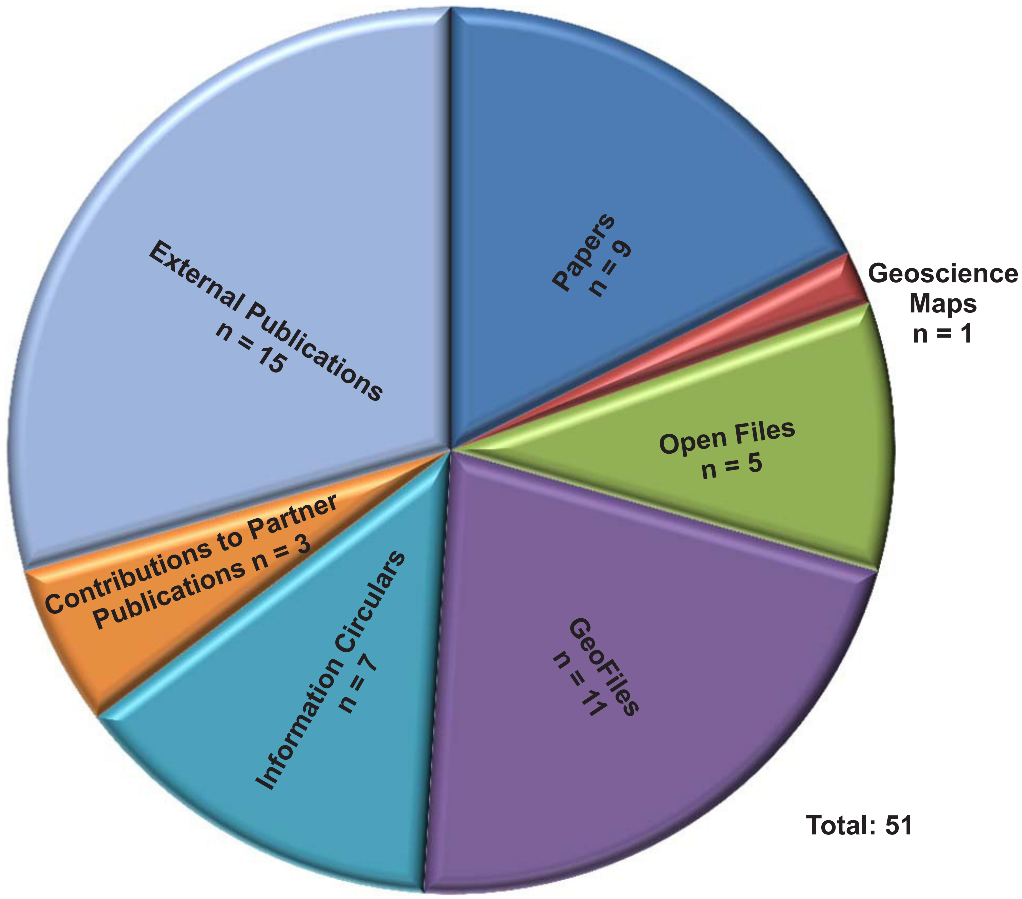
2. Cordilleran Geoscience Section

Geologists in the Cordilleran Geoscience Section have expertise in regional bedrock mapping, tectonics, mineral deposits, Quaternary and surficial geology, geochemistry, petrology, mineral exploration methods, metallogeny, and geoscience data management. British Columbia Geological Survey projects are based on short-term objectives and long-term goals. Many current projects are continuations of multi-year efforts, whereas others are new. Projects in 2016 focused on mapping, regional synthesis and map compilation; deposit studies; and exploration methods development (Fig. 3).

2.1. Mapping, regional synthesis and map compilations

2.1.1. Stikinia basement – northwest British Columbia

Major porphyry deposits in the Stikine terrane of northwest British Columbia, such as Red Chris and KSM (Clarke et al., 2017), are spatially associated with major, long-lived faults that probably originated as high-strain zones in pre-Devonian basement. Like transcrustal structures in other porphyry districts, they played a vital role in mineralization, serving as conduits for magmas and fluids. Although exposures are limited, this project targets the nature and structural history of deep basement to Stikinia in two ready accessible areas: along a transect from the Terrace area of western Stikinia into the Ecstall belt of the Coast Mountains; and west of the Anyox deposit, where Devonian to Middle Jurassic rocks are exposed (Nelson, 2017, this volume).



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 Mining and Exploration, **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 five 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 2016.

Fig. 2. Members of the British Columbia Geological Survey on Mount Finlayson, British Columbia.

2.1.2. Porphyry environment transitions – northwest British Columbia

The prolific belt of British Columbia's Intermontane porphyry deposits is difficult to track in the Stikine terrane of northwest British Columbia. The Porphyry Environment Transitions project, a collaboration with the GSC through the GEM 2 program, blends topical studies and focused mapping to address the continuity of this prospective Triassic-Jurassic magmatic belt and assess porphyry potential. In 2015, activities focused in the Sinwa Creek area (Mihalynuk et al., 2017a, this volume). In 2016, mapping was completed in the Turtle Lake map area, a region assumed to have been part of the Stuhini forearc (Late Triassic). Topical studies are also being directed at rationalizing the lithostratigraphic framework of prospective Upper Cretaceous rocks using new geochronologic and geochemical data (Zagorevski et al., 2017, this volume), documenting Middle to Late Triassic Alaskan-type ultramafic intrusions with Ni-Cu-PGE potential in northern Stikinia (Milidragovic et al., 2017, this volume), and establishing the boundary between Intermontane arc terranes and the Cache Creek terrane. Mihalynuk et al. (2017b, this volume) report on quartz-gold veins that cut calcareous black phyllite bedrock beneath placer deposits along Otter Creek in the Atlin camp. These veins indicate that lode gold may be genetically related to Late Cretaceous granitic intrusions such as the Surprise Lake batholith rather than to ultramafic rocks, significantly expanding targets for lode gold exploration.

2.1.3. Geological mapping, Skeena arch, west-central British Columbia

This project partners the Mineral Development Research Unit at The University of British Columbia, Geoscience BC, and the BCGS. Economically significant porphyry and related mineralization is genetically associated with the Bulkley (Late Cretaceous) and Babine and Nanika intrusive suites (Eocene) in central British Columbia. These intrusions and mineral occurrences are largely restricted to the Skeena arch, a northeast-trending structure that extends transverse to the general trend of Stikine terrane. Nonetheless, the structural history of the Skeena arch and, in particular, the significance of its arc-transverse orientation, has not been well established. Building on mapping in the Terrace area (Nelson et al., 2007, 2008a, 2008b) and aided by new high-resolution aeromagnetic data collected as part of Geoscience BC's SeArch project (Precision GeoSurveys Inc., 2016), 1:2,000-scale mapping documents arch-parallel stratigraphic relationships, structural features, and intrusive-mineralization trends of differing ages, collectively suggesting a long-lived underlying control (Angen et al., 2017, this volume).

2.1.4. Geological framework and metallogeny of the Tanzilla-McBride area – northwest British Columbia

This mapping project builds on recent studies in the Dease Lake area of northwestern British Columbia including BCGS mapping west of the study area (Logan et al., 2012) and reconnaissance studies in the Hotailuh batholith to the south

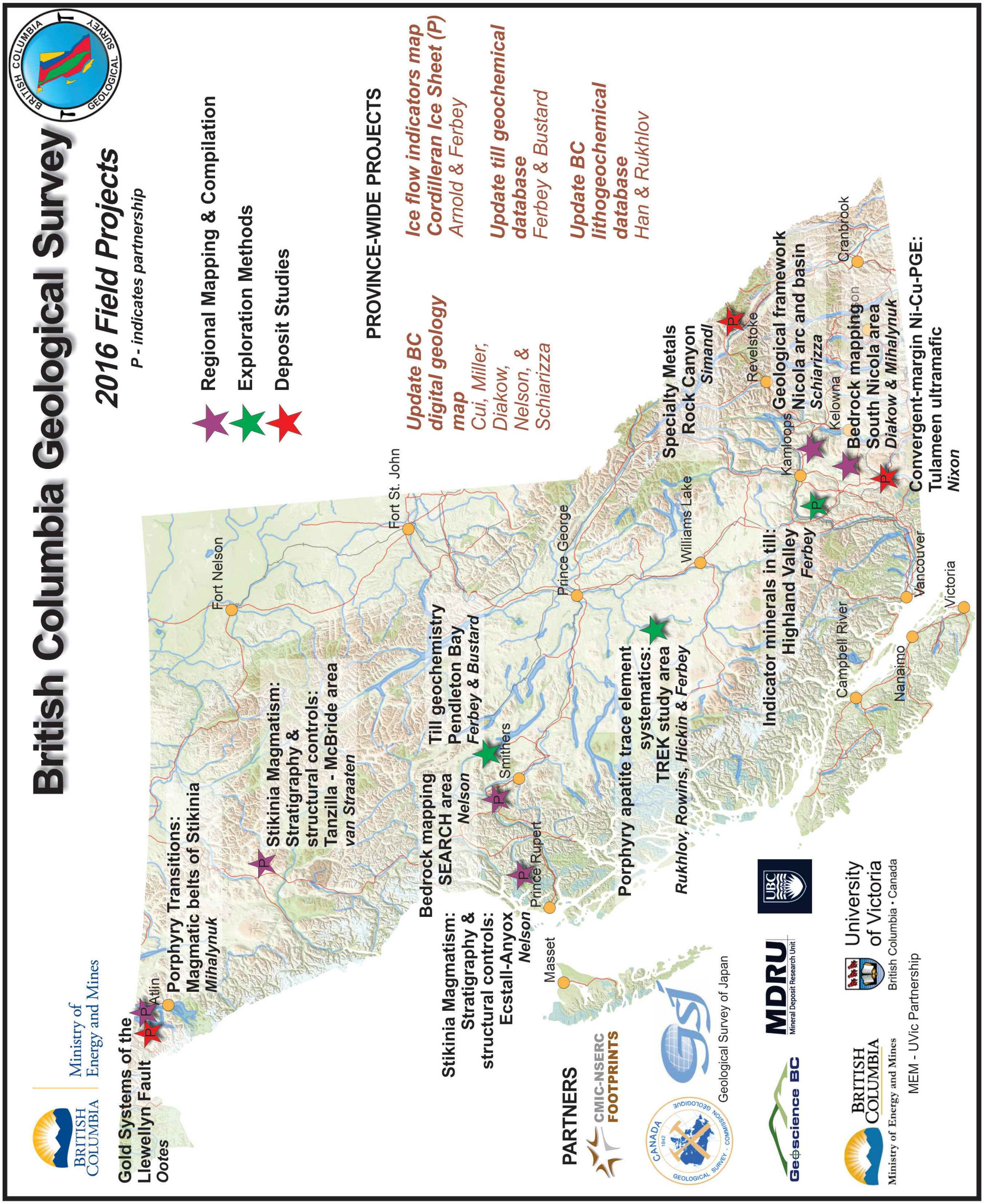


Fig. 3. British Columbia Geological Survey field projects in 2016.

(van Straaten et al., 2012). Volcano-sedimentary rocks north of the Hotailuh batholith previously mapped as Stuhini Group (Late Triassic) were reinterpreted as Hazelton Group (Jurassic) based on detrital zircon geochronology carried out as part of the BCGS program (Iverson et al., 2012). Detailed mapping of volcano-sedimentary units north of the Hotailuh batholith found them to be late Early to Middle Jurassic, essentially coeval with accretion of the Cache Creek and Stikine terranes (van Straaten and Nelson, 2016). Their study included an investigation of the Tanzilla prospect, an advanced argillic lithocap overlying a porphyry system at depth. The 2016 project provides a regional update of the geology east of Dease Lake and north of the Hotailuh batholith (van Straaten and Gibson, 2017, this volume). The project investigates late Early to early Late Jurassic alkaline and subalkaline magmatism and its relationship to porphyry copper potential. This late Early to early Late Jurassic alkaline to subalkaline magmatic episode may represent a new metallogenic epoch in the Canadian Cordillera.

2.1.5. Groundhog coalfield compilation – north-central British Columbia

The Groundhog coalfield compilation (British Columbia Geological Survey, 2016) is the latest in a series of posters that provide overviews of coalfield geology, coal products, annual and historic production, reserves and resource estimates, and past and current projects. Other regions in this series are the East Kootenay coalfields in southeast British Columbia (British Columbia Geological Survey, 2015a) and the Northern Rocky Mountain coalfields in northeast British Columbia (British Columbia Geological Survey, 2015b).

2.1.6. Nicola stratigraphy and geological framework – south-central British Columbia

The Nicola Group records a Mesozoic arc complex that includes Triassic to Jurassic volcanic and sedimentary rocks and related calcalkaline and alkaline intrusions. Originally named for exposures of volcanic rock and limestone on the south side of Nicola Lake (Dawson, 1879), the Nicola Group and coeval to slightly younger intrusions are the defining elements of the Quesnel arc terrane, an important Cu-Au-Mo metallotect that contains many porphyry and skarn deposits. Numerous informal subdivisions have been applied to the Nicola Group, but its regional stratigraphic architecture is not well understood. In 2015, BCGS started a multi-year field-based program to synthesize Nicola Group lithostratigraphy and establish a regional stratigraphic framework. This framework, combined with space-time-composition patterns of spatially associated plutons, will contribute to a better understanding of the evolution of the arc, and help establish the settings and controls of mineral occurrences. In 2016, work continued in the eastern part of the Nicola belt south of Kamloops in the Stump Lake – Salmon River area, (Schiarizza, 2017, this volume) tracking units identified about 150 km to the north in the Bridge Lake – Quesnel River area (Schiarizza, 2016).

2.1.7. Mapping ice-flow indicators for the Cordillera ice sheet through derived-stereo imagery

Understanding the extent, flow paths, and history of the most recent Cordilleran Ice Sheet (Late Wisconsinan; ~22-10 ka) comes from interpreting landforms, some of which were created by subglacial processes. Landforms, such as crag-and tails, drumlins, drumlinoids, and flutes are streamlined along ice-flow directions. As part of a GEM 2 collaboration with the GSC, the first part of this project (Arnold et al., 2016) resulted in a compilation map and an accompanying database of ice-flow controlled landforms that integrated independent databases from British Columbia (Ferbey et al., 2013) and the Yukon (Lipovsky and Bond, 2014). Given the cost of fieldwork in remote regions, data deficiencies remain. The second part of this project was directed at evaluating methods for using inexpensive derived-stereo imagery to remotely map landform features (Arnold and Hickin, 2017, this volume).

2.2. Deposit studies

2.2.1. Gold mineralization and the Llewellyn fault in northwest British Columbia

The Llewellyn fault is a north-northwest striking structure near the British Columbia-Yukon border, ~50 km west of the town of Atlin, British Columbia. A number of disparate gold prospects and past-producing mines (e.g., Engineer, Venus, Mt Skukum) occur near the fault. These deposits have a variety of geological characteristics ranging from shallow epithermal to deeper mesothermal orogenic systems. Some are spatially associated with felsic plutons and others have skarn-like features suggesting the presence of proximal intrusions. This project is aimed at assessing the genetic relationships, if any, between these deposits, the Llewellyn fault and spatially associated magmatism. Large transcrustal strike-slip faults, similar to the Llewellyn fault, host orogenic gold deposits in many Archean greenstone belts. These include the 'Golden Mile' (Kalgoorlie) in the Norseman-Wiluna belt of Western Australia, the Kirkland Lake-Larder Lake and Destor-Porcupine 'Breaks' in the Abitibi belt of Ontario, and the Con-Giant gold systems in the Yellowknife greenstone belt of the Northwest Territories. To characterize the various gold deposits along the Llewellyn fault, a reconnaissance study was undertaken in partnership with the GSC's TGI-5 Gold project. Preliminary structural and lithological data were collected from gold deposits in order to determine whether gold mineralization events could be attributed to long-lived deformation occurring along the entire length of the Llewellyn fault. Preliminary conclusions suggest a genetic relationship exists between gold mineralization, Eocene magmatism, and structures associated with the Llewellyn fault (Ootes et al., 2017, this volume).

2.2.2. Specialty metals

Specialty metals are part of the family of critical and strategic materials needed for technologically advanced devices and industrial processes. Also referred to as 'high technology metals' or 'rare metals', specialty metals include lithium (Li), zirconium

(Zr), yttrium (Y), beryllium (Be), scandium (Sc), tantalum (Ta), niobium (Nb), germanium (Ge), gallium (Ga), and the rare earth elements (REE). The GSC and BCGS are collaborating on a new four-year TGI-5 - Specialty Metals project, which builds on results from TGI-4. As part of this project, the BCGS is also partnering with the Geological Survey of Japan and the University of Victoria. The overarching objective of this project is to investigate the geological conditions responsible for generating mineralizing fluids and for depositing specialty metal ore. The project initially will target carbonatite-related Nb and REE deposits in British Columbia, but is expected to include Ge-, In-, and Ga-bearing deposits. Although much research will be focused in British Columbia, the project will be national in scope. In 2016, the project started at the Rock Canyon Creek REE-fluorite deposit in south central British Columbia. This work focused on better characterizing the deposit, especially its mineralogy (Hoshino et al., 2017, this volume), in order to address questions about the origin of ore-forming fluids and the temporal, structural, and stratigraphic relationship to Mississippi Valley-type and sparry magnesite deposits along the eastern flank of the Canadian Cordillera (Green et al., 2017, this volume).

2.2.3. Convergent-margin nickel-copper-platinum group element-chromium (Ni-Cu-PGE-Cr) deposits

This project is a collaboration between the University of British Columbia, the BCGS, and the GSC. It is a TGI-5 contribution that builds upon previous TGI-4 investigations of an emerging class of magmatic Ni-Cu-PGE sulphide deposits hosted by ultramafic-mafic intrusions in supra-subduction or convergent-margin tectonic settings. The principal objective is to determine the fundamental physicochemical controls of magmatic Ni-Cu-PGE-Cr mineralization associated with Alaskan-type ultramafic-mafic intrusions in the Canadian Cordillera. Field investigations and high-precision U-Pb CA-TIMS and $^{40}Ar/^{39}Ar$ geochronology will target two Alaskan-type intrusions in a Late Triassic-Early Jurassic Cordilleran magmatic arc of British Columbia: (1) the Turnagain ultramafic intrusion with its unusual endowment of world-class, low-grade Ni-Cu-PGE sulphides, and (2) the Tulameen ultramafic-mafic intrusion with its dunite-hosted chromitite-PGE alloy association that is more typical of Alaskan-type intrusions globally. The study also will address poorly known occurrences of magmatic Cu-rich sulphides (chalcopyrite, bornite) in late-stage ultramafic and mafic rocks of the Tulameen intrusion that appear to indicate delayed sulphide saturation in fractionated Ni-poor magma(s).

2.3. Exploration methods

2.3.1. Trace element systematics in apatite

Apatite ($Ca_5[PO_4]_3(F,OH,Cl)$), a widespread accessory phosphate mineral in many rocks, is the most abundant phosphate mineral in the world. The crystal structure and chemistry of apatite allow it to accommodate variable concentrations of many trace elements including Na, Mg, Si, S, V, Mn, Fe, As, Sr, Ba, rare earth elements (REE), Pb, Th and U. The trace-element composition of apatite is very sensitive to its environment of formation and it commonly crystallizes as an early-stage liquidus phase through to fluid saturation of the magma and associated metallic mineralization. Importantly, apatite resists chemical and physical weathering in glacial environments. These criteria make apatite a very good candidate for use as an indicator mineral. Over the last three years, BCGS, in collaboration with researchers from the School of Earth and Ocean Sciences at the University of Victoria have developed techniques that use the trace element chemistry in apatite for a variety of geological application, some of which are highlighted below.

2.3.1.1. Apatite trace-element compositions: A robust new tool for mineral exploration

The use of apatite as an exploration tool continues to be developed. Mao et al. (2016) demonstrated that differences in trace-element compositions between apatites from carbonatites, barren igneous rocks, and mineral deposits (e.g., orogenic Au, porphyry Cu-Au-Mo, IOCG) permit their discrimination using optimized discrimination diagrams. These diagrams were constructed using Discriminant Projection Analysis (DPA), a powerful multivariate statistical technique that uses an a priori knowledge of group members to calculate a set of linear discriminant functions or projections of variables (element concentrations) that maximize the differences between the predefined group. This allows samples to be plotted in the discriminant space so that group separation can be visualized and investigated. To test the discrimination technique, an orientation study using detrital apatite grains from till samples collected at four porphyry Cu±Au±Mo deposits in central BC (Gibraltar, Mt. Polley, Woodjam, and Highland Valley) was undertaken. Results were positive and the discrimination diagrams successfully identified apatites originating from the different types of porphyry deposits up ice-flow direction (Rukhlov et al., 2016). The next step in developing apatite as an indicator mineral using the Mao et al. (2016) discrimination technique is currently underway. Apatite grains recovered from regional till samples collected via Geoscience BC's Targeting Resources through Exploration and Knowledge (TREK) projects on the glaciated Nechako Plateau of central BC (Jackaman and Sacco, 2014; Jackaman et al., 2015) will be used to test areas containing both known and unknown mineral occurrences. This 'blind' test will effectively assess the apatite discrimination technique for grassroots exploration.

2.3.1.2. Redox conditions of porphyry Cu-Au-Mo deposits

Porphyry Cu-Mo-Au deposits form from magmatic-hydrothermal fluids that display a wide range of oxidation states. Most porphyry systems, especially the giant ones, form from fluids and magmas with high oxidation states, although a number form from intrinsically reduced fluids and magmas indicating that the role of oxygen fugacity in porphyry formation is complex. Previous studies have shown that concentrations of multivalent elements S, V, Cr, Mn, Fe, Ga, As, Ce, and Eu in apatite can be used as redox sensors in magmas and fluids. This project, in collaboration with researchers from the University of Victoria, is assessing the usefulness of apatite trace-element composition as a redox proxy using both new and published electron microprobe and laser-ablation inductively coupled plasma mass spectrometry data from 20 porphyry Cu-Mo-Au deposits exhibiting a wide range of oxidation states.

2.3.1.3. Apatite for discriminating tectonic settings

Using the apatite trace-element dataset of Mao et al. (2016), the DPA multivariate statistical technique has been applied to igneous apatites from different known tectonic settings. Results show that tectonic discrimination diagrams can be constructed in terms of six linear discriminant functions or projections using a variety of trace elements. It may be concluded that the trace-element chemistry of igneous apatite fingerprints tectonic environments, thus extending the utility of apatite as a petrogenetic tool.

2.3.2. Porphyry indicator minerals in tills of the Highland Valley Mine area, south-central British Columbia

Rocks of Quesnel terrane in the Intermontane Belt of south-central British Columbia host many large porphyry deposits, yet vast areas remain underexplored because much of the bedrock in the region is covered by glacial sediments. Nonetheless, geochemical and mineralogical data, particularly from locally derived tills, can help detect deposits buried under Quaternary sediments. The Highland Valley project, a joint investigation between the Canadian Mining Innovation Council (CMIC), the GSC, and BCGS, is a continuation of the collaborative TGI- 4 porphyry indicator mineral project (2011-2015) between the GSC and BCGS. The goal of this project is to develop a new surficial sediment exploration method for porphyry Cu-Mo-Au mineralization in drift-covered areas of British Columbia.

Till samples collected near the Highland Valley Copper mine were analyzed for geochemical, indicator mineral, and grain size determinations to test the utility of the method at a site where the configuration and tenor of ore-grade porphyry Cu mineralization are known. Furthermore, Quaternary geology mapping (Plouffe and Ferbey, 2015) indicates a relatively simple regional Late Wisconsinan ice-flow history. Sediment transport is generally southward, making provenance determinations on subglacial tills relatively straightforward. Results from this project were most recently published in Ferbey et al. (2016).

2.3.3. Indicator minerals in till and stream sediments of the Canadian Cordillera – A Geological Association of Canada (GAC) – Mineralogical Association of Canada (MAC) workshop, fieldtrip, and special volume

In the last five years, significant applied research efforts have been focused on using indicator minerals for exploration in the Canadian Cordillera. At the annual 2016 GAC-MAC meeting in Whitehorse, the BCGS partnered with the GSC and Yukon Geological Survey to deliver a workshop, a fieldtrip, and a special session dedicated to indicator mineral research. The geology, physiography, and glacial history of the Canadian Cordillera are intertwined and distinct from other less mountainous regions of Canada. Therefore, Cordilleran-specific mineral exploration techniques have evolved and interpretations need to consider the complexities of Cordilleran geology and physiography. The one-day workshop focused on characteristics unique to the Cordillera. In addition to a hands-on exploration exercise using real data from British Columbia, the workshop presented a number of successful indicator mineral case studies from British Columbia that exemplified recent advances. The workshop was followed by a fieldtrip that examined till and other glaciogenic sediments, highlighting features that distinguish subglacial basal tills from other diamicts (Fig. 4). The BCGS and GSC also convened a special session on indicator mineral research at the meeting. A collection of papers, edited by the BCGS and GSC, and devoted to recent developments in indicator mineral research and focused on the Cordillera will be released at the 2017 GAC-MAC meeting in Kingston, Ontario. The volume will be the inaugural publication in the new “Topics in Minerals Science” series by the MAC and the first joint publication of the GAC and MAC.

2.3.4. Till Geochemistry of the Pendleton Bay map area (93K/12), central British Columbia

Regional-scale-till geochemical surveys conducted by the BCGS, GSC, and other organizations have been effective at identifying covered mineralized bedrock sources, including both known and new mineral occurrences (Bustard and Ferbey, 2016). Data sets from these till geochemical surveys typically present determinations on silt-plus-clay size fraction for major, minor, and trace elements. The Pendleton Bay map area (93K/12) is relatively underexplored compared to other areas of the Interior Plateau with high potential for mineralization. Although samples were collected and analyzed in 1998 as part of the NATMAP Nechako Project, results from the Pendleton Bay map area were never released publicly and will be released in 2017.

2.3.5. New basal till potential maps for TREK Project study area

Drift prospecting exploration maps were first produced in British Columbia by the BCGS in 1994 (Giles and Levson, 1994). The purpose of these maps was to represent the value of different surficial sediments for designing geochemical, lithological, and heavy mineral exploration programs. Building on the success of these maps, a new generation of the drift prospecting exploration maps (now called basal till potential maps) has been developed. The new basal till potential maps applies a potential rating to a material type and retains the individual unit’s material classification to provide more information. In collaboration with Geoscience BC, six

Fig. 4. Overlooking the Yukon River, participants of the indicator mineral field trip at the GAC-MAC annual meeting held in Whitehorse, hear about the Late Wisconsinan glaciation in the region.

1:50,000-scale basal till potential maps were completed for the TREK project area of the Interior Plateau and will be released in early 2017.

2.3.6. Coking Chemistry

Coke strength after reaction (CSR) is a globally accepted measure of how well a coking coal will perform in the blast furnace of a steel mill. The ash chemistry of a coking coal can have an effect on its CSR, which is more pronounced in coalfields that form in freshwater and brackish environments such as the Canadian Rocky Mountain coalfields of the Kootenays and the Peace River. In the past, major oxide analyses of coal ash were routinely done to predict the slagging and fouling properties of the coal. Since the early 1980s, when the importance of ash chemistry to coking coal quality was recognized, comprehensive analyses became more common and detailed. The ash chemistry data in COALFILE and other public sources are being compiled into a database for incorporation into the greater BCGS coal geochemical database. The data, mainly from non-confidential reports, will serve to evaluate the ash chemistry characteristics of the Mist Mountain, Gates and Gething formations.

3. Resource Information Section

The British Columbia Geological Survey creates, delivers, and archives geoscience data to help the mineral industry, resource planners, public safety agencies, communities, First Nations, government, research organizations, and the general public make decisions related to the Earth sciences. In particular, the data and derived products increase exploration effectiveness by enabling users to efficiently gather regional information for property-scale evaluation, and help explorers advance projects without duplicating previous work.

3.1. MapPlace

Since 1995, MapPlace has provided web map services to help clients browse, visualize, and analyze geoscience and mineral resource data, such as geology, mineral occurrences, regional geochemical survey, assessment reports, surficial geology, geophysical survey, and mineral tenures. Building on its predecessor, MapPlace 2 beta is now available on the BCGS website. Relative to the original version, MapPlace 2 can be used on either a Mac or a PC, requires no plug-ins and works in most web browsers, has a simpler, more intuitive interface that is easy to use, accesses third-party base maps and imagery from sources such as Google, Bing Maps and OpenStreetMap, and displays province-level data at exceptional speeds. In contrast to other Canadian web map services, MapPlace 2 goes beyond simply displaying information. Databases are continuously updated and talk to each other, enabling users to conduct queries and generate custom results by connecting to current data from many sources. MapPlace 2 is designed for anyone who wants to reduce the costs of accessing and analyzing geoscience data in British Columbia, including the mineral industry, resource planners, public safety agencies, communities, First Nations groups, government, research organizations, and the general public. Based on Cui et al. (2017), BCGS will offer workshops on how to use MapPlace 2 throughout 2017 (Fig. 5). BCGS will continue to improve MapPlace 2 with advanced applications and access to more databases.

3.2. Databases

ARIS is the searchable database of over 35,400 assessment reports submitted to the Ministry of Energy and Mines, in compliance with Mineral Tenure Act (MTA) Regulations. These reports summarize results from exploration programs on mineral claims. After a one-year confidentiality period, the reports become an open resource for planning mineral exploration, investment, research, land use, and resource management. Between 1967 and 2014, ARIS stored work representing expenditures of about $2.8 billion (Fig. 6a). Digital data are available for download from 450 assessment reports through the ARIS search application and monthly tables.

COALFILE is a library of 990 Coal Assessment Reports submitted by exploration companies since 1900 (Fig. 6b). It includes data from about 15,400 boreholes, 550 bulk samples, 1000 maps, and 3600 trenches. MINFILE is an inventory documenting metallic mineral, industrial mineral, and coal occurrences in the province. With more than 14,600 entries (Fig. 6c), the database is being updated continuously. Users can query MINFILE by location, identification number, mineralogy, commodity, host rock, deposit type, geological setting, age, production, and references. Property File is a collection of more than 59,600 government, university, personal, and industry documents donated to the British Columbia Geological Survey during the last 150 years (Fig. 6d). Previously available only in hard copy, these documents can now be searched for, and downloaded from, the Property File database. Property File contains: unpublished reports; theses; field notes; company prospectuses; correspondence; hand-drawn maps; claim maps; mine plans; photographs; and geological, geochemical, geophysical, and drill data. The BCGS accepts donations to Property File.

The provincial geochemical databases hold field and geochemical data from multi-media surveys by the GSC, the BCGS, and Geoscience BC. The 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 (Fig. 6e); 2) till surveys; and 3) rock samples. The current version of the RGS database was completely recompiled from original sources in 2015 (Rukhlov and Naziri, 2015) and consists of five MS Access tables with locations, field observations, analytical results and laboratories, and geology underlying sample sites for about 65,000 stream-, lake- and moss-sediment and water samples (Fig. 7). The analytical determinations include up to 63 analytes from sediment samples and up to 78 analytes from water samples (Fig. 8). Han et al. (2016) published an update to the provincial lithogeochemical database, which includes a new data model and rigorous quality control (Fig. 9). This 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 in 21 laboratories.

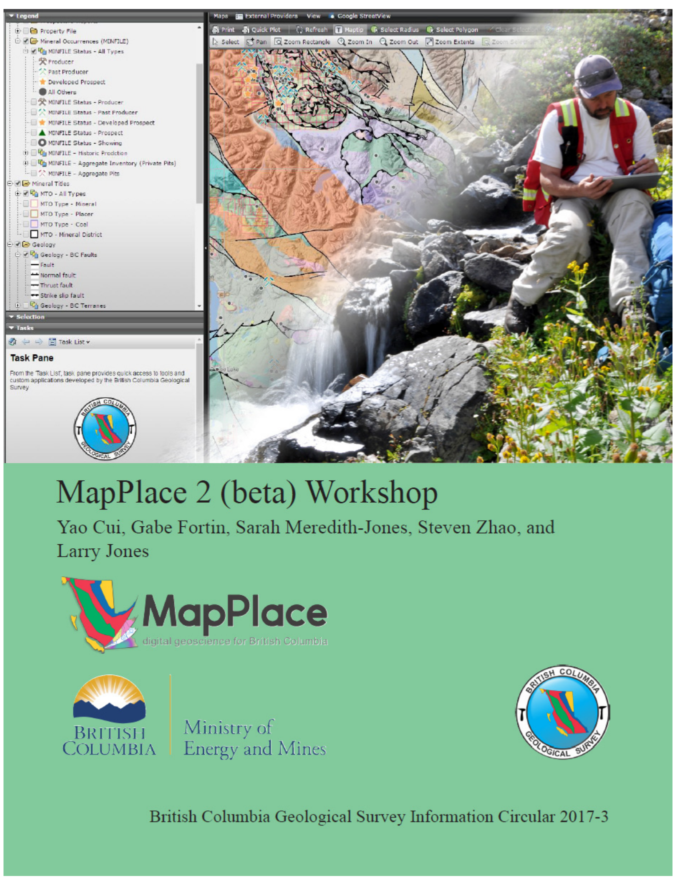


Fig. 5. Workshop notes for MapPlace 2 (Cui et al., 2017) can be downloaded at no charge from http://www.empr.gov.bc.ca/mining/geoscience/publicationscatalogue/informationcirculars/pages/IC2017-3.aspx.

3.3. British Columbia Digital Geology map

The BCGS has developed a ‘geospatial frame data’ (GFD) model to simplify compiling, updating, editing, and integrating geological maps into a province-wide spatial database for digital geology. Bedrock polygons are not part of the GFD but are generated from the GFD, which consists only of centroids (describing map units) and lines (defining geological boundaries). The GFD applications automate checking-out, anchoring, integrating, and creating bedrock polygons. These applications also streamline data quality checks, content standardization, and product delivery to web services. Integration of new compilations for the south Nicola, Chilcotin and Bonaparte, Atlin, Dease Lake, Iskut, and Bowser basin areas is currently underway (Fig. 10). The bedrock legend at the provincial scale also has a new colour scheme to highlight major geological units. The Digital Geology data download is updated regularly.

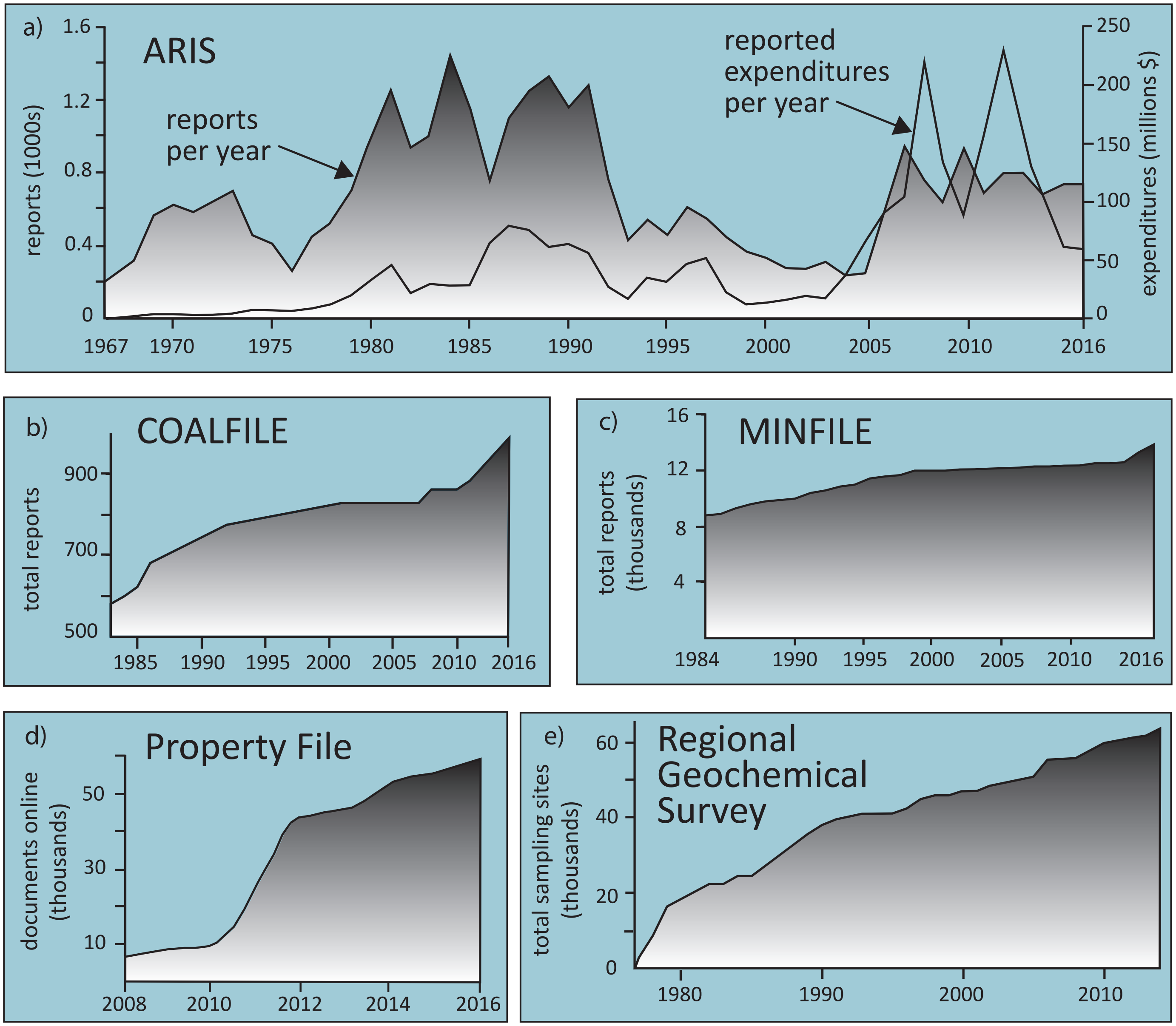


Fig. 6. Growth of key British Columbia Geological Survey databases.

3.4. Three-dimension geological modelling

The BCGS conducted a pilot project to test 3D modelling to generate a simple depth-to-bedrock predictive map for the Ootsa Lake porphyry Cu-Mo-Au district using datasets provided by Gold Reach Resources. The completed depth-to-bedrock model predicted overburden thicknesses based on extrapolation between drill holes, surface outcrops, and LiDAR data. Where combined with geophysical data and geochemical anomalies identified from Regional Geochemical Survey (RGS) data, the depth-to-bedrock map has proven helpful in ranking exploration targets. Geochemical anomalies in areas of shallow cover ranked higher than similar geochemical anomalies in areas of thicker overburden.

4. Mineral Development Office

The British Columbia Mineral Development Office (MDO) in Vancouver provides mineral and coal resource information and is a point of contact on issues affecting the exploration and mining industries. Through formal and informal activities including conferences, business meetings, investment missions, and over the counter contacts, the MDO promotes the province's mineral and coal industries both domestically and abroad.

A primary output is the delivery of a technical marketing campaign that highlights the province's mineral and coal potential, geoscience resources, global expertise, and attractive business climate. This includes developing publications aimed at audiences from large foreign investors through to

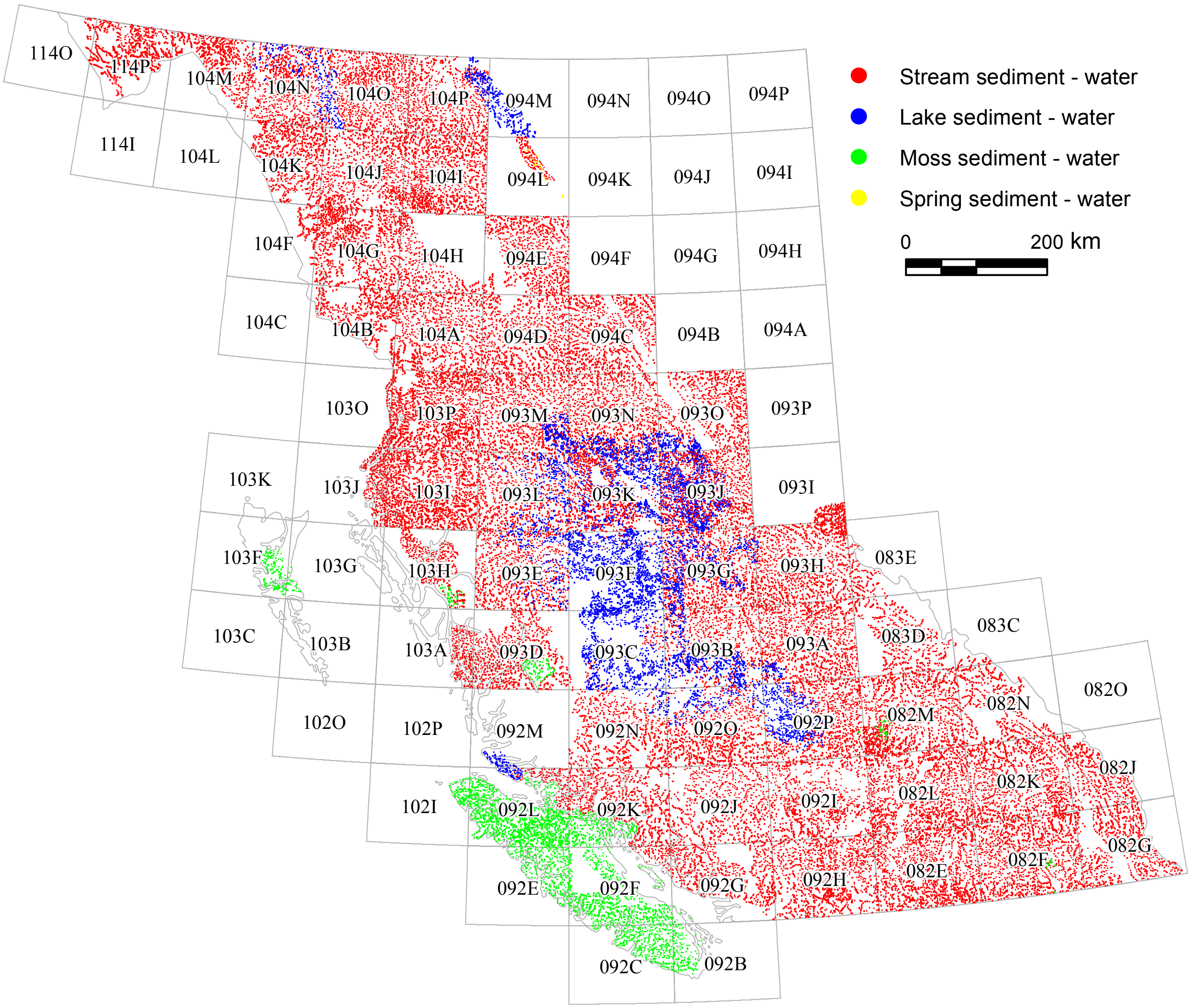


Fig. 7. Almost 65,000 regional geochemistry sites cover 80% of the province.

independent domestic entrepreneurs. These publications are distributed widely at conferences, business meetings, over the counter, and online.

In September of 2016, the MDO supported the Ministry of International Trade at a series of events in Asia. The MDO provided materials to raise British Columbia's profile at the China Mining Congress and Expo in Tianjin, the Canada Mineral Investment Forum in Beijing, the Canada Mineral Investment Forum in Seoul, and the Canada Mineral Investment Forum in Tokyo.

In October of 2016, the MDO was part of a British Columbia delegation that met with a visiting Qatari investment group at the Qatar Embassy in Ottawa. The Qatari government was interested in learning about investment opportunities in British Columbia's non-renewable resource sector. In early 2017, delegates from Qatar along with those from the United Arab Emirates, Saudi Arabia and Kuwait, plan to visit Victoria and Vancouver for further discussions about investment opportunities in British Columbia.

The MDO oversees publication of the "Provincial Overview of Exploration and Mining in British Columbia" a document containing an overview of mineral exploration and mining activities in the different regions of BC written by the Regional Geologists. The most recent annual summaries can be found in Clarke et al. (2017; Provincial overview of exploration and mining in British Columbia, 2016) and BCGS (2017; Coal industry overview, 2016).

Master ID: 092I091691

SUMMARY				Lake		Moss Mat	
NTS Map Sheet 092I		Physiography:	3				
Sample ID:	092I091691	Drainage Pattern:	1	Area (km^2):	-1	Height (m):	-1
UTM Zone:	10	Site Contamination:	8	Perimeter (km):	-1	Color:	-1
UTM East (NAD27):	643599	Stream Width (m):	1	Depth (m):	-1	Health:	-1
UTM North (NAD27):	5583407	Stream Depth (cm):	20	Relief:	-1	Host:	-1
UTM East (NAD83):	643505	Water Color:	0	Water Color:	-1	Thickness (m):	-1
UTM North (NAD83):	5583614	Bank Precipitation:	0	Sediment Colour:	-1		
Latitude:	50.38705	Sediment Composition:	310	Sediment Composition:	-1		
Longitude:	-120.98128	Sediment Colour:	8	Possible Site Contamination Source:	-1		
Elevation (m):	1590	Sediment Precipitation:	0	***Waters***			
Sample Type:	6	Channel Bed:	3	pH:	7.29		
Replicate Sample Status:	0	Channel Pattern:	1	U:	-1		
Stream source:	0			F:	33		
Stream Order:	2			SO_4:	-1		
Stream type:	1						

AAS Data

Element	Analysis	Unit
Cu	-1	ppm
Pb	-1	ppm
Ni	-1	ppm
Co	-1	ppm
Ag	-1	ppm
Mn	-1	ppm
Fe	-1	%
Mo	-1	ppm
Sn	-1	ppm
Hg	-1	ppb
As	-1	ppm
Sb	-1	ppm
Ba	-1	ppm
Cd	-1	ppm
V	-1	ppm
Bi	-1	ppm
Cr	-1	ppm
Se	-1	ppm
Zn	-1	ppm

ICPMS Data

Element	Analysis	Unit
Al	1.72	%
Sb	0.36	ppm
As	16.2	ppm
Ba	1060	ppm
Bi	0.24	ppm
Cd	0.6	ppm
Ca	1.44	%
Cr	13	ppm
Co	16.6	ppm
Cu	874.1	ppm
Ga	4.9	ppm
Au	2.1	ppb
Fe	6.21	%
La	44.5	ppm
Pb	13.47	ppm
Mg	0.33	%
Mn	8355	ppm
Hg	210	ppb
Mo	63.51	ppm
Ni	12.8	ppm
P	0.11	ppm
K	0.07	%

INAA Data

Element	Analysis	Unit
Au	2	ppb
First Duplicate of Au	-1	ppb
Second Duplicate of Au	-1	ppb
Sb	0.6	ppm
As	18	ppm
Ba	1500	ppm
Br	48	ppm
Ce	72	ppm
Cs	-1	ppm
Cr	51	ppm
Co	22	ppm
Eu	-1	ppm
Hf	6	ppm
Fe	7.3	%
La	55	ppm
Lu	0.6	ppm
Mo	65	ppm
Ni	10	ppm
Rb	39	ppm
Sm	10	ppm
Sc	13	ppm
Na	1.3	%

Fig. 8. Sample report from MapPlace for a regional geochemical survey data point.

5. 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
Paul Jago	Prince George	Northeast and North Central
Jim Britton	Kamloops	South Central
Fiona Katay	Cranbrook	Southeast
Bruce Northcote	Vancouver	Southwest

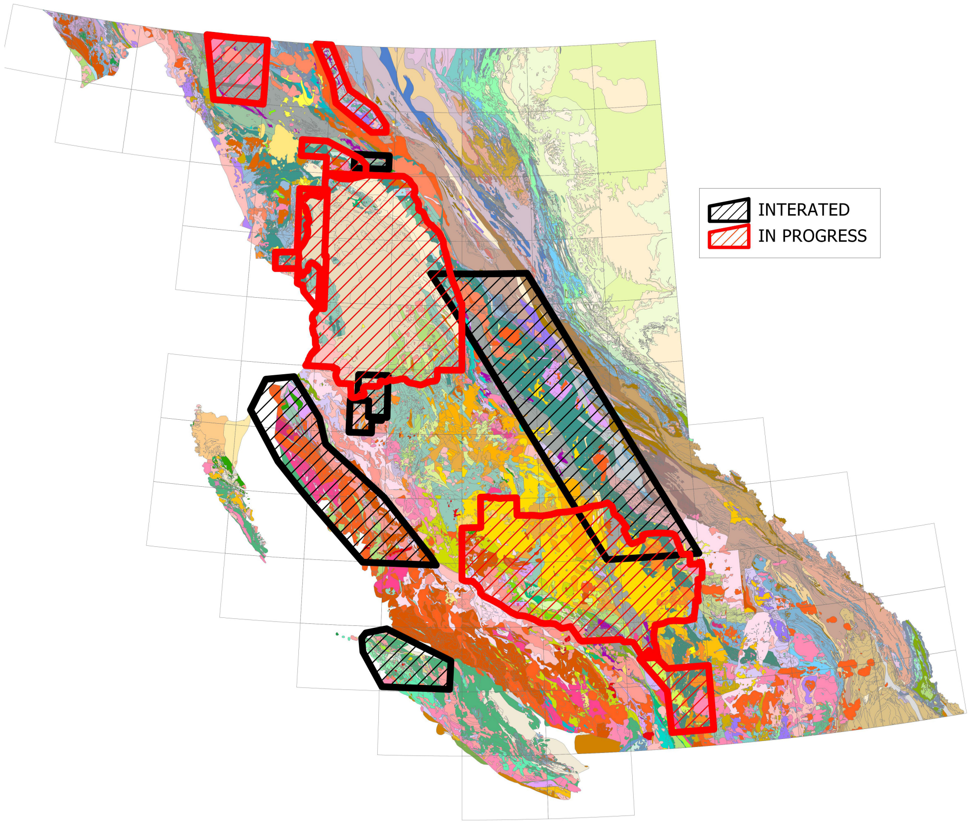


Fig. 9. Areas with recent and ongoing updates to the British Columbia digital geology map.

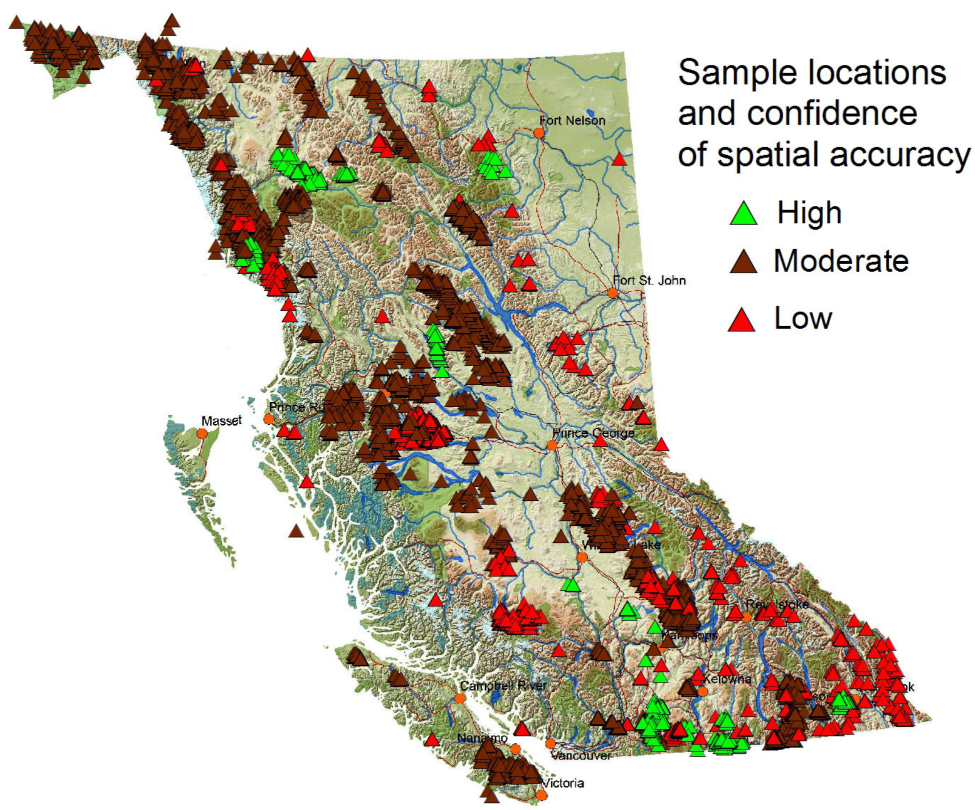


Fig. 10. Lithogeochemistry data distribution with location confidence.

6. Staffing announcements

The Survey was strengthened in 2016 by the addition of Gabe Fortin and Dejan Milidragovic (Fig. 11). Gabe joins us as a Geomatics Geologist focused on advancing MapPlace 2 and Dejan is a Senior Project Geologist specializing in Ni-Cu-PGE metallogeny and ultramafic-mafic rocks. Congratulations also goes out to JoAnne Nelson, a 30-year veteran of the BCGS and recipient of a Special Tribute by the Association for Mineral Exploration in recognition of her distinguished career in geoscience work focused on Cordilleran tectonics and metallogeny.

Laura de Groot, ARIS/MINFILE Database Manager will be retiring after 35 years with the Provincial Government, 31 of which were with the Survey. Laura played an important role in computerizing the MINFILE and ARIS and continues to work on enhancements to both systems and linking them to other datasets. We wish Laura a happy retirement.

Fig. 11. New staff at the British Columbia Geological Survey Victoria office. **a)** Dr. Dejan Milidragovic, Senior Minerals Geologist – Nickel metallogeny and igneous geology and **b)** Gabe Fortin Geomatics Geologist.

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In Memoriam

The Survey is saddened to report the passing of former Chief Geologist (1975-1984) Dr. Atholl Sutherland Brown in December, 2016.

Dr. Atholl Sutherland Brown, who served as British Columbia's 8th Chief Geologist from 1975 to 1984, died in Victoria at the age of 93. Atholl was born in Ottawa, but grew up mainly in Victoria. He joined the Royal Canadian Air Force in 1941 and, as a member of the Royal Air Force in Burma, flew 48 missions and was awarded the Distinguished Flying Cross. After the war, Atholl attended the University of British Columbia and subsequently earned a Ph.D. in geology at Princeton. He joined the British Geological Survey in 1951 and was involved in early mapping of the Cariboo and the Queen Charlotte Islands (Haida Gwaii). Atholl was an excellent scientist and wrote numerous papers on the geology and mineral deposits of British Columbia, especially porphyry copper and molybdenum deposits. This expertise lead to his editorship of the Canadian Institute of Mining and Metallurgy Special Volume No. 15 on "Porphyry Deposits of the Canadian Cordillera". Atholl also authored several books including two published by the Geological Association of Canada. The first was "British Columbia's Geological Surveys 1895-1995: A Century of Science and Dedication", which was a lively history of the British Geological Survey and its gyrations published in 1998 to mark its 100th year anniversary. His most recent book "Searching for the Origins of Haida Gwaii - Adventures While Mapping the Geology of the Islands 1958-1962" was published in 2013 and is a testament to his incredible energy and fine intellect right to the end of his life. Atholl was a natural leader always looking for ways to give back to the geological community. He served as President of the Geological Association of Canada in 1980 and was a charter member of the Committee of Provincial and Territorial Geologists. The Committee remains instrumental in establishing closer relationships amongst the provincial, territorial and federal geological surveys.

Atholl was an active member of the Victoria geological community and could be counted on to show up at the Survey's alumni golf tournament, Open House, and various social events. He was held in very high regard by the Canadian geological community and will be greatly missed.