British Columbia Geological Survey annual program review 2015-2016

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1. Introduction

Providing a summary of projects, events, and accomplishments over the past year, this review highlights activities of the British Columbia Geological Survey (BCGS). Established in 1895, the Survey links government, the minerals industry, and British Columbians to the Province's geology and mineral resources. The key roles of the Survey are to

- create, maintain, and deliver geoscience knowledge to lead informed decision making
- attract companies and individuals to explore British Columbia for new mineral and coal resources
- act as the public steward of mineral and coal resources
- guide public policy by providing assessments on mineral exploration and mining activities.

The BCGS remains committed to producing 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 a branch in the Mines and Mineral Resources Division of the Ministry of Energy and Mines. The Survey has a permanent staff of 28 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.

2. Cordilleran Geoscience Section

The Cordilleran Geoscience Section consists of resident geologists with expertise in regional bedrock mapping, tectonics, mineral deposits, Quaternary and surficial geology, geochemistry, petrology, mineral exploration methods, copper and gold metallogeny, and geoscience data management. The Survey is happy to announce the hiring of two new project geologists, Dr. Bram van Straaten and Luke Ootes, who joined the Cordilleran Section in 2015, bring expertise in regional mapping and copper and gold metallogeny.

2.1. Projects

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 2015 focused on porphyry initiatives, deposit studies, exploration methods development, and regional synthesis and map compilation (Fig. 3).

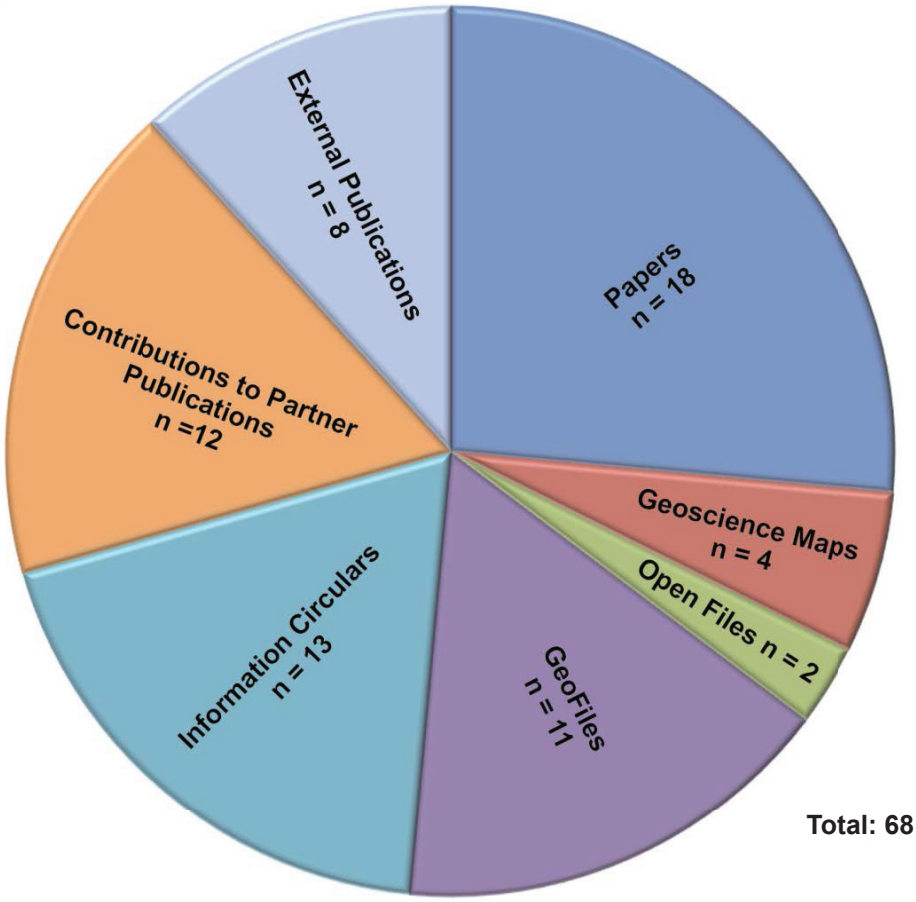
2.1.1. Porphyry initiatives

2.1.1.1. Porphyry environment transitions (GEM 2)

The prolific belt of British Columbia's porphyry deposits is difficult to track in the Stikine terrane of northwestern British Columbia. The Porphyry Environment Transition project, a collaboration with the Geological Survey of Canada (through the Geomapping for Energy and Minerals program; GEM 2), completed its second year of fieldwork in 2015. Through mapping and topical work, the project is targeting regional controls on porphyry mineralization by addressing questions of Late Triassic arc productivity, polarity, and paleogeography, and evaluating indicators of arc prospectivity near its apparent northern termination (see Martin et al., and Mihalynuk et al., this volume).

2.1.1.2. Stikinia magmatism: Stratigraphic and structural controls: Red Mountain to Kitsault (GEM 2)

Mesozoic Stikinia is largely known for its Cu-Au porphyry and related mineral endowment. Significant deposits of this type are found throughout the northwestern part of the terrane, from Dease Lake in the north to Stewart in the south. Farther south however, major coeval deposits show epithermal vein and volcanogenic character. This project is designed to increase



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 2015.

Fig. 2. Members of British Columbia Geological Survey.

understanding of both porphyry and non-porphyry mineral occurrences, targeting stratigraphic, structural, and tectonic controls, which will aid in reconstructing the overall tectonic and metallogenetic environment of Stikinia. This project also contributes to the BCGS-Geological Survey of Canada GEM 2 partnership.

2.1.1.3. Stikinia magmatism: Stratigraphic and structural controls: Tanzilla (GEM 2)

An enigmatic Jurassic volcanic succession on the northeastern margin of Stikinia hosts several early-stage mineral exploration projects, including the Tanzilla porphyry system. The Tanzilla alteration zone is large, but poorly explored and with little detailed mapping. As part of the GEM 2 program, the Tanzilla alteration zone was evaluated using ideas generated from previous work in the KSM-Brucejack and emerging KSP (Bronson corridor) regions. Based on new field mapping and preliminary lithogeochemical and geochronological data, these rocks are now considered part of the Hazelton Group and have been formally defined as the Horn Mountain Formation (see van Straaten and Nelson, this volume).

2.1.1.4. Porphyry indicator minerals in till, central British Columbia (TGI-4)

Quesnel, Cache Creek, and Stikine terranes are prospective for porphyry-style mineralization. However, in the Interior Plateau of British Columbia, bedrock is commonly covered by glacigenic sediments. Historically, these sediments have been regarded as a hindrance to mineral exploration. Nonetheless, regional-scale and detailed geochemical surveys by the British Columbia Geological Survey, Geological Survey of Canada, and university researchers have demonstrated that tills can be used to explore for mineralized bedrock. Major, minor, and trace element determinations on the silt-plus-clay fraction of basal tills have successfully detected known sources of mineralization (e.g., Prosperity, Bell, Granisle, Equity Silver, Huckleberry, Mount Milligan) and identified new mineral occurrences (e.g. 3Ts, Huckleberry Mine, Red Sky).

Heavy minerals in basal till have been used extensively to identify buried diamondiferous kimberlite pipes. Recent work by the Mineral Deposits Research Unit (MDRU) at the University of British Columbia has demonstrated that similarly diagnostic minerals occur in ore and alteration zones of alkaline and calcalkaline porphyry deposits in British Columbia. Work by the British Columbia Geological Survey and the Geological Survey of Canada has demonstrated that mineral assemblages considered to be porphyry indicator minerals (PIMs) can be recovered from till samples. The primary objective of this project is to assess the use of these mineral assemblages in basal till samples to explore for concealed base and precious metal deposits in the Province. This three-year project, funded largely by the Geological Survey of Canada's Targeted Geoscience Initiative 4 (TGI-4) program, focuses on characterizing the mineral assemblage of basal tills derived from known porphyry Cu-Mo-Au deposits in central British Columbia.

2.1.1.5. Highland Valley Copper porphyry indicator minerals survey (TGI-4 and CMIC)

A one-year project, funded jointly by the Canadian Mining Innovation Council (CMIC) and the British Columbia Geological Survey, this project focuses on till geochemistry and porphyry indicator minerals at the Highland Valley Mine site. By comparing data from tills and the Highland Valley deposits (and the other deposits studied in the TGI-4 program), the objective of the project is to establish which minerals survive glacial erosion, transport, and deposition, and near-surface oxidation to serve as tools for porphyry deposit exploration.

2.1.1.6. South Nicola arc project (SNAP) compilation

Southern Nicola belt is a Triassic to Early Jurassic intra-

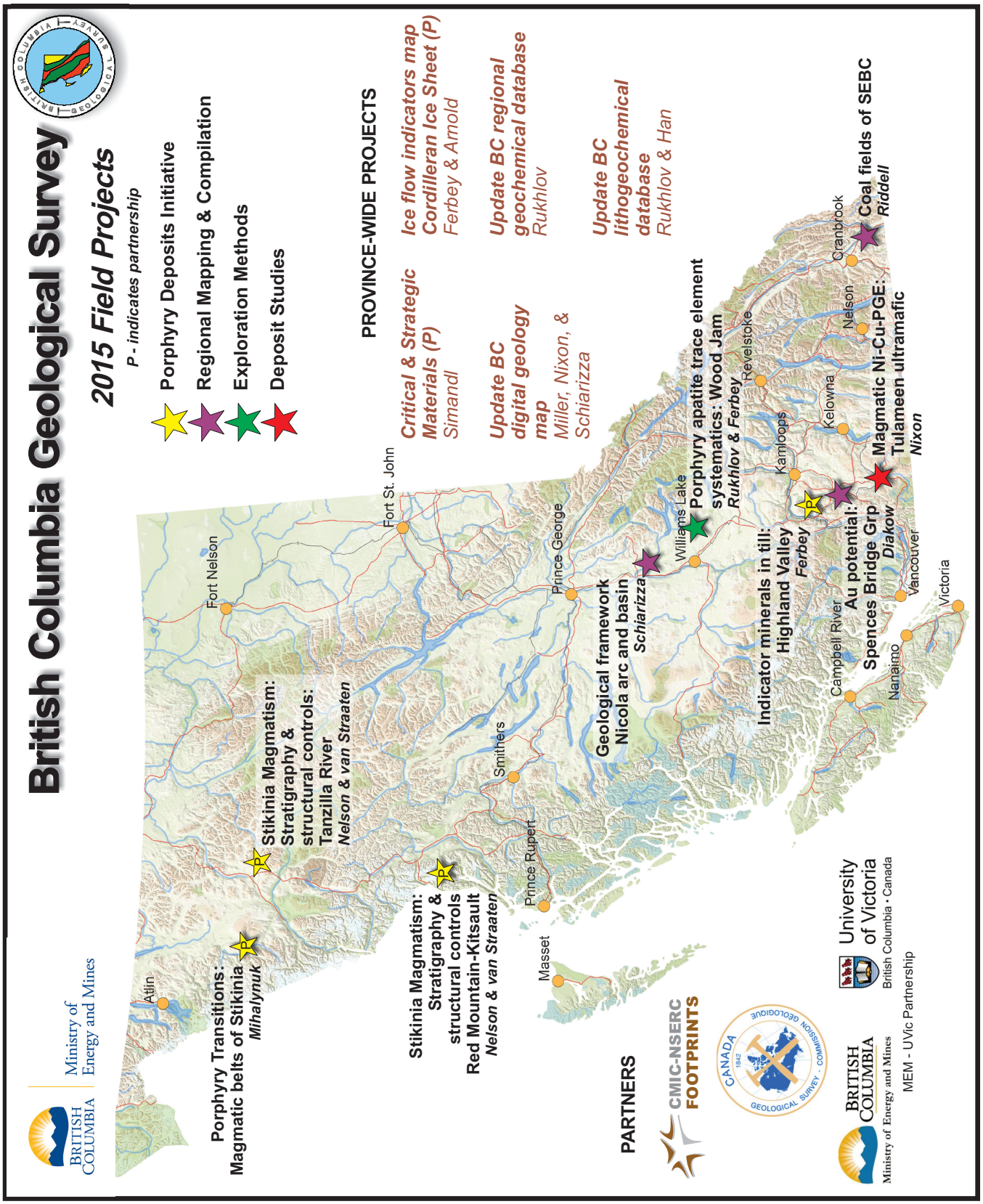


Fig. 3. British Columbia Geological Survey field projects in 2015.

oceanic arc succession that was probably deposited in a setting much like the Fiji-Vanuatu-Solomon-Papuan arc complex of today. It is prolifically mineralized, with most past and present mineral production from porphyry-style mineralization, which commonly contains appreciable Au, Ag and Mo. Mineralization occurs in plutons and their adjacent volcanic and sedimentary country rocks. The British Columbia Geological Survey completed a two-year field mapping program in 2014. In 2015, the project focused on completing 1:50,000 scale maps (from Princeton to the Aspen Grove) and compiling these maps for integration into the British Columbia Digital Geology map.

2.1.2. Deposit studies

2.1.2.1. Epithermal potential of Spences Bridge Group

The Spences Bridge Group is an undeformed and little metamorphosed subaerial volcano-sedimentary succession occupying a northwest-trending belt, up to 25 kilometres wide and 165 kilometres long, between Princeton and Lillooet. It records short-lived Early Cretaceous, continent-margin arc magmatism that developed on an older basement including oceanic rocks of Cache Creek terrane (Carboniferous to Jurassic) and island arc rocks of Quesnel terrane (Late Triassic). Epithermal mineralization was only recently discovered in 2001, a consequence of prospecting following a British Columbia Regional Geochemical survey. These discoveries, and the known epithermal occurrences are in rocks of the Pimainus Formation at the base of the Spences Bridge Group. To test the potential for epithermal mineralization elsewhere in the Spences Bridge Group, a regional mapping project was initiated in selected segments of the belt underlain exclusively by Pimainus Formation rocks.

2.1.2.2. Orogenic Ni-Cu-PGE

This project builds on the now completed TGI-4 ‘orogenic Ni’ deposits studies, conducted as a collaboration between the British Columbia Geological Survey, the Geological Survey of Canada, and the University of British Columbia. New activities by the British Columbia Geological Survey focus on establishing a deposit model for orthomagmatic Ni-Cu±PGE deposits in convergent-margin tectonic settings, such as in British Columbia. With the aim of isolating key ore-forming characteristics of the sulphide-rich intrusions, the most recent activities are directed at completing a geochemical, mineralogical, and geochronological comparison of the Giant Mascot and Turnagain Ni-sulphide deposits with the well-known sulphide-poor intrusion of the Tulameen Alaskan-type complex.

2.1.3. Exploration methods

2.1.3.1. Critical and strategic materials

The demand for strategic and critical materials has grown rapidly in recent years, as ever more technologically advanced devices and industrial processes make use of their unique properties. Interest in specialty metals peaked in 2010 owing to growing global demand, their high value, declining exports from China, and challenges of finding new deposits. These factors created a window of opportunity for Canada to establish itself as a world leader in specialty metal exploration and, potentially, exploitation given the favourable geology in parts of Canada. In November 2015, the British Columbia Geological Survey, with sponsorship from the Pacific Section of the Geological Association of Canada and the Geological Survey of Canada, hosted the Critical and Strategic Materials Symposium, which considered materials of high economic or trade importance (hence ‘critical’) and those of importance to a nation’s security (hence ‘strategic’). The Symposium coincided with the end of the ‘Specialty Metals Project’, a five-year collaborative effort between the British Columbia Geological Survey, the Geological Survey of Canada, and several academic and industry partners. ‘Specialty metals’, also known as ‘rare metals’ are uncommon, nonferrous metals used in quantities of typically less than 150,000 tonnes/year or derived from geographically restricted areas. The Specialty Metals Project ran from 2010 to 2015 and was supported by the TGI-4 program.

To accompany the Symposium, the British Columbia Geological Survey produced a volume titled “Symposium on Critical and Strategic Materials Proceedings, November 13-14, 2015, Victoria, British Columbia” (Fig. 4). This volume is a record of the Symposium proceedings, with papers on: the uses, markets, and resources for select critical materials; carbonatites and related mineralization; peralkaline intrusion-related mineralization; rare earth elements; graphite; recent developments in exploration and analytical methods; and a regional geological study.

2.1.3.2. Detrital apatite trace-element compositions: A robust new tool for mineral exploration

Apatite is the most abundant phosphate mineral, occurring as an accessory or rock-forming mineral in many rocks. The crystal structure and chemistry of apatite permit elemental substitution that is sensitive to the environment in which it forms. These properties make apatite a promising indicator for mineral exploration. In this project, a collaboration between the British Columbia Geological Survey and the University of Victoria, apatite grains from the major types of magmatic-hydrothermal mineral deposits (30 localities, mostly in British Columbia) together with apatites from carbonatites (29 intrusive complexes) and unmineralized rocks (11 localities) were analyzed by electron microprobe and laser ablation-inductively coupled plasma mass spectrometry. Discriminant analysis of several elements reveals that apatite grains from mineral deposits can be distinguished from apatite grains in carbonatites and unmineralized rocks. Apatites from the different deposit types also have distinctive trace-element compositions that are readily distinguished by the discriminant functions.

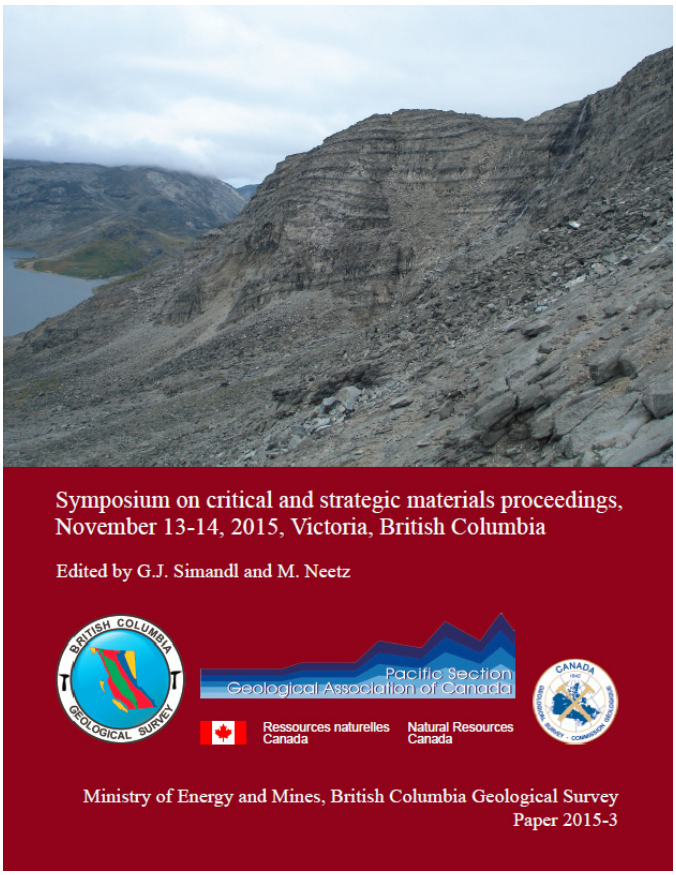


Fig. 4. British Columbia Geological Survey Paper 2015-3, Symposium on Critical and Strategic Materials Proceedings, November 13-14, 2015, Victoria, British Columbia.

2.1.3.3. Application of trace element composition of detrital apatite from till as a porphyry indicator mineral

Building on work demonstrating that apatite can be used as an indicator mineral to effectively discriminate mineralized systems from barren rocks, and to distinguish different deposit types (see above), this project provides a test by examining detrital apatite grains from TGI-4 till samples collected at the Gibraltar, Mt. Polley, Woodjam, and Highland Valley porphyry deposits. Apatite grains were analyzed by electron microprobe and laser ablation-inductively coupled plasma mass spectrometry. Classification of the examined apatite grains using discriminant functions correctly identified the porphyry deposits in all four study areas. Results show that apatite trace-element chemistry is diagnostic of specific porphyry deposits and their relative oxidation states and thus can be used as an exploration tool for these deposits (see Rukhlov et al., this volume).

2.1.3.4. Application of lead isotopes in till for mineral exploration

The objective of the project was to determine if elemental abundances and Pb isotopic ratios from Chehalis valley basal till samples collected in 2014 could cost effectively highlight the down-ice glacial dispersion of volcanogenic massive sulphide (VMS) occurrences. Despite the relatively young age of the Seneca VMS deposit and surrounding volcanic rocks (Middle Jurassic), the contrast in Pb isotopic ratios between tills derived from country rocks and tills containing ore material is 3-7%. This contrast is 2-3 orders of magnitude above the analytical uncertainties of state-of-the-art multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS). In this study, a simplified method, in which Pb isotopic ratios are measured by high-resolution inductively coupled plasma mass spectrometry (HR-ICP-MS), is consistent with the MC-ICP-MS results. The relatively inexpensive method of determining Pb isotopic ratios in tills by using HR-ICP-MS constitutes a robust exploration tool for a broad range of concealed Pb-rich deposits including relatively young deposits. This study was published as British Columbia Geological Survey Paper 2015-2 (Fig. 5).

2.1.4. Regional synthesis and map compilation

2.1.4.1. Nicola Arc Stratigraphic Framework

The Nicola Group comprises a diverse assemblage of mainly Upper Triassic volcanic, volcaniclastic, and sedimentary rocks that outcrop over a broad area in southern and central British Columbia. It, and coeval to slightly younger intrusions, are the

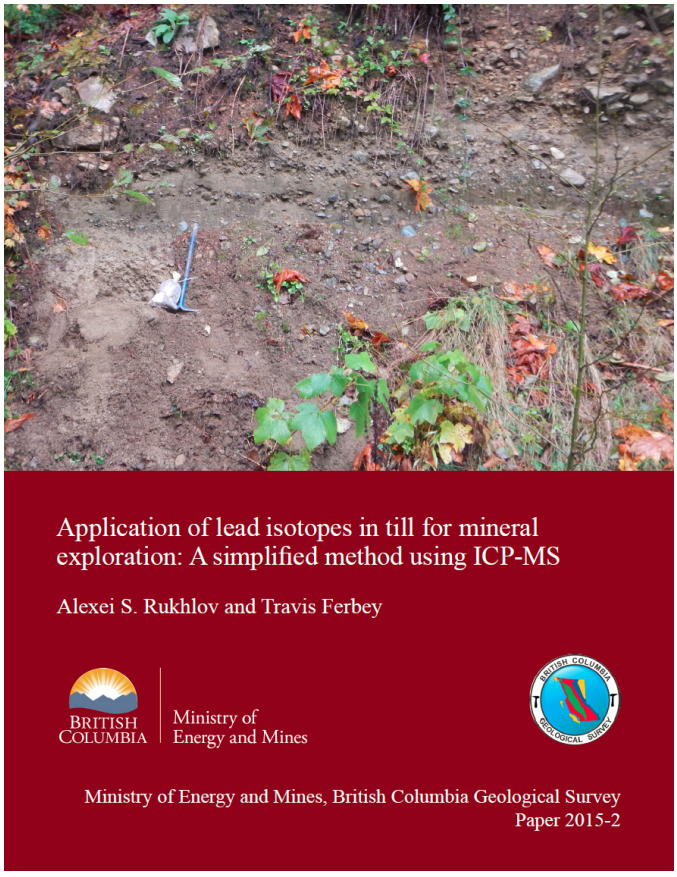


Fig. 5. British Columbia Geological Survey Paper 2015-2, Application of lead isotopes in till for mineral exploration: A simplified method using ICP-MS.

defining elements of the Quesnel arc terrane, an important Cu-Au-Mo metallogenic province that contains numerous porphyry and skarn deposits. However, the stratigraphic architecture of the Nicola group is not well understood. Building on the South Nicola Arc Project (SNAP), this multi-year project initiated in 2015, aims to establish a stratigraphic framework for the group that can be applied at regional and local scales (see Schiarizza, this volume).

2.1.4.2. Ice-flow indicators for the Cordilleran Ice Sheet (GEM 2)

In 2013, the British Columbia Geological Survey compiled a Province-wide ice-flow indicator map. The motivation was to provide the mineral exploration community with a spatial database of ice-flow indicators to assist interpreting till, stream, and soil geochemical surveys. This product was well received by the exploration community and it was decided that, in collaboration the federal GEM 2 program, the database would be expanded to incorporate all mapped ice-flow features for the entire Cordilleran Ice Sheet.

The first phase of the project is now complete, with the integration of ice-flow indicator databases from the British Columbia Geological Survey, Yukon Geological Survey, Geological Survey of Canada, and United States Geological Survey. The second phase is generating new data in northern British Columbia where data are sparse. The compilation will incorporate data captured from digital stereo airphotos, pseudo-stereo orthophoto mosaics, and other imagery. These data will also be used to assess, where possible, the quality of the existing ice-flow data.

2.1.4.3. Coal Fields of British Columbia

The British Columbia Geological Survey has completed coalfield compilation posters for the East Kootenay Coalfields of southern British Columbia and coalfields in the northeastern part of the Province. These posters provide overviews of coalfield geology, coal products, annual and historical production, reserves and resource estimates, and past and current projects.

3. Resource Information Section

The British Columbia Geological Survey serves as the custodian of geoscience data from across the province. These data include bedrock geology, surficial geology, mineral occurrences, and multi-element geochemistry from rock, till, stream-sediment, and water samples. The information resides in databases that are integrated with MapPlace, the free BCGS online service that allows clients to browse, visualize, and analyze multidisciplinary geoscience data and create custom maps. The data and derived products provide baseline geoscience information for mineral exploration, resource assessment, and land use planning. In particular, they increase exploration effectiveness by enabling users to efficiently gather regional information for property-scale evaluation, and help explorers advance projects without duplicating previous work.

Since 1995, MapPlace, has provided open geoscience data and custom map-making tools to help assess the mineral potential of British Columbia, assist exploration, and guide investment decisions. Through MapPlace, BCGS databases talk to each other. ARIS, MINFILE, COALFILE, Property File, geochemical surveys, mineral titles, geological and topographic maps, and the British Columbia Geological Survey publication catalogue can be queried simultaneously, and the output projected onto base imagery of choice (Fig. 6). The next generation of MapPlace, (MapPlace 2), scheduled for release in 2016, is capable of accessing queried BCGS databases to display province-wide maps within seconds.

ARIS is the searchable database of over 34,700 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. 7a). Between 1996 and 2014 most expenditures are a result of drilling (Fig. 8). COALFILE is a library of Coal Assessment Reports submitted by exploration companies since 1900 (Fig. 7b). It includes data from 15,092 boreholes, 541 bulk samples, 995 maps, and 3580 trenches. MINFILE is an inventory documenting metallic mineral, industrial mineral, and coal occurrences in the province. With over 14,000 entries (Fig. 7c), 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 over 55,000 government, university, personal, and industry documents donated to the British Columbia Geological Survey over the last 150 years (Fig. 7d). 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 BC Geological Survey accepts donations to Property File.

The provincial geochemical databases hold field and geochemical data from multi-media surveys by the Geological Survey of Canada, the British Columbia Geological Survey, and Geoscience BC (GBC). 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. 7e); 2) till surveys; and 3) rock samples. The 2015 version of the RGS database consists of five MS Access tables with locations, field observations, analytical results, and geologic descriptions of sample sites. The determinations include up to 63 analytes from sediment samples and up to 78 analytes from water samples. The provincial rock geochemical database, last released in

Fig. 6. MapPlace 2 screen capture.

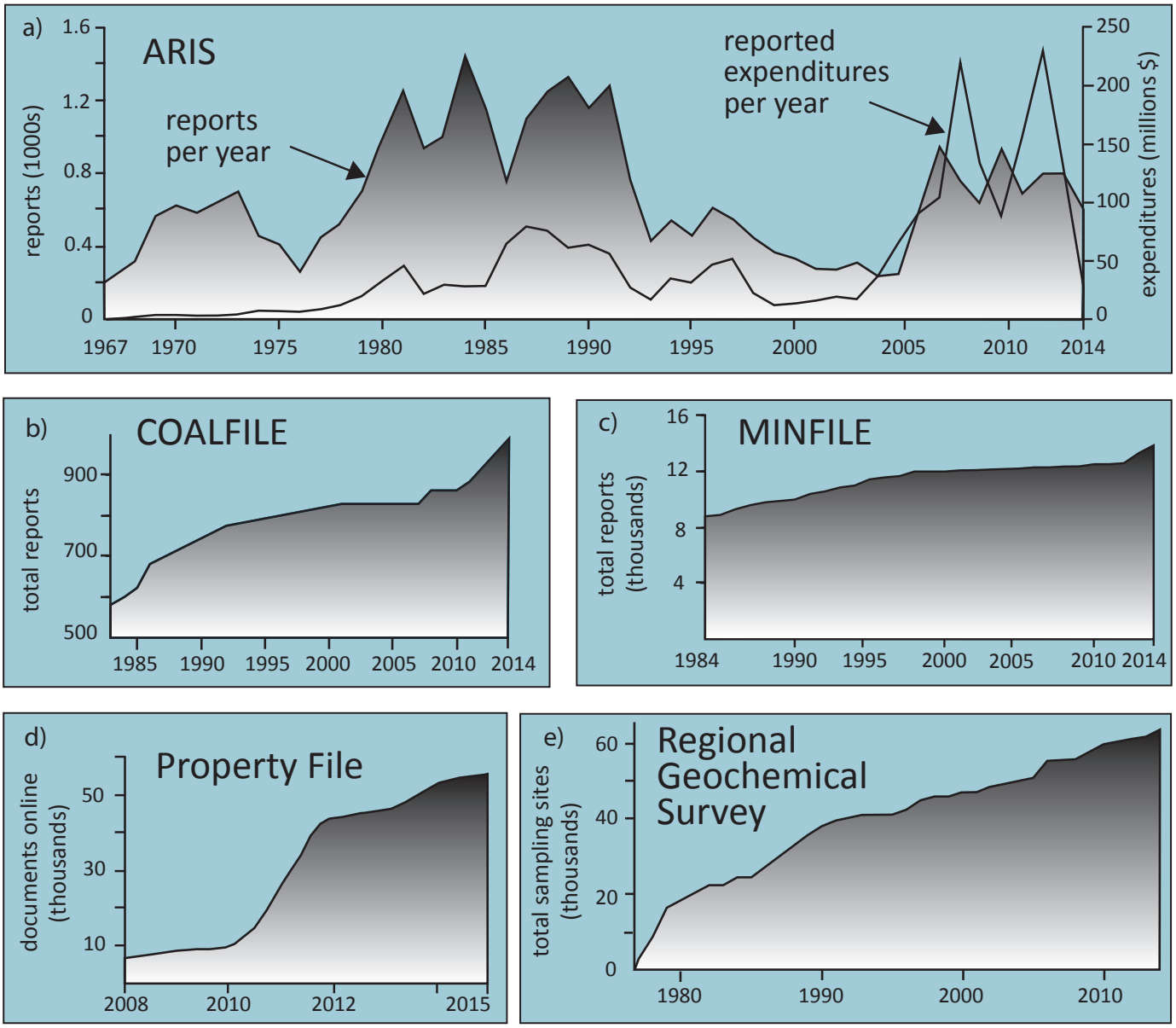


Fig. 7. Growth of some British Columbia Geological Survey databases.

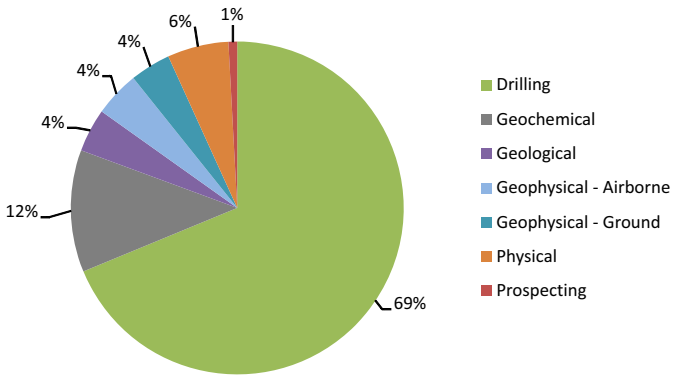


Fig. 8. Assessment report expenditures by type of work from 1996-2014.

2005, was updated and released in January 2016 to include over 10,000 records.

British Columbia Digital Geology is the data source used to create the digital Geological Map of British Columbia (Fig. 9). The October 2015 release integrates five geological maps for northern Vancouver Island.

4. Mineral Development Office

The Mineral Development Office (MDO) is the technical marketing arm of the British Columbia Geological Survey and the Ministry of Energy and Mines. The MDO promotes the mineral and coal industries, domestically and abroad, at conferences, business meetings, investment missions, and over-the-counter contacts. Its location in downtown Vancouver

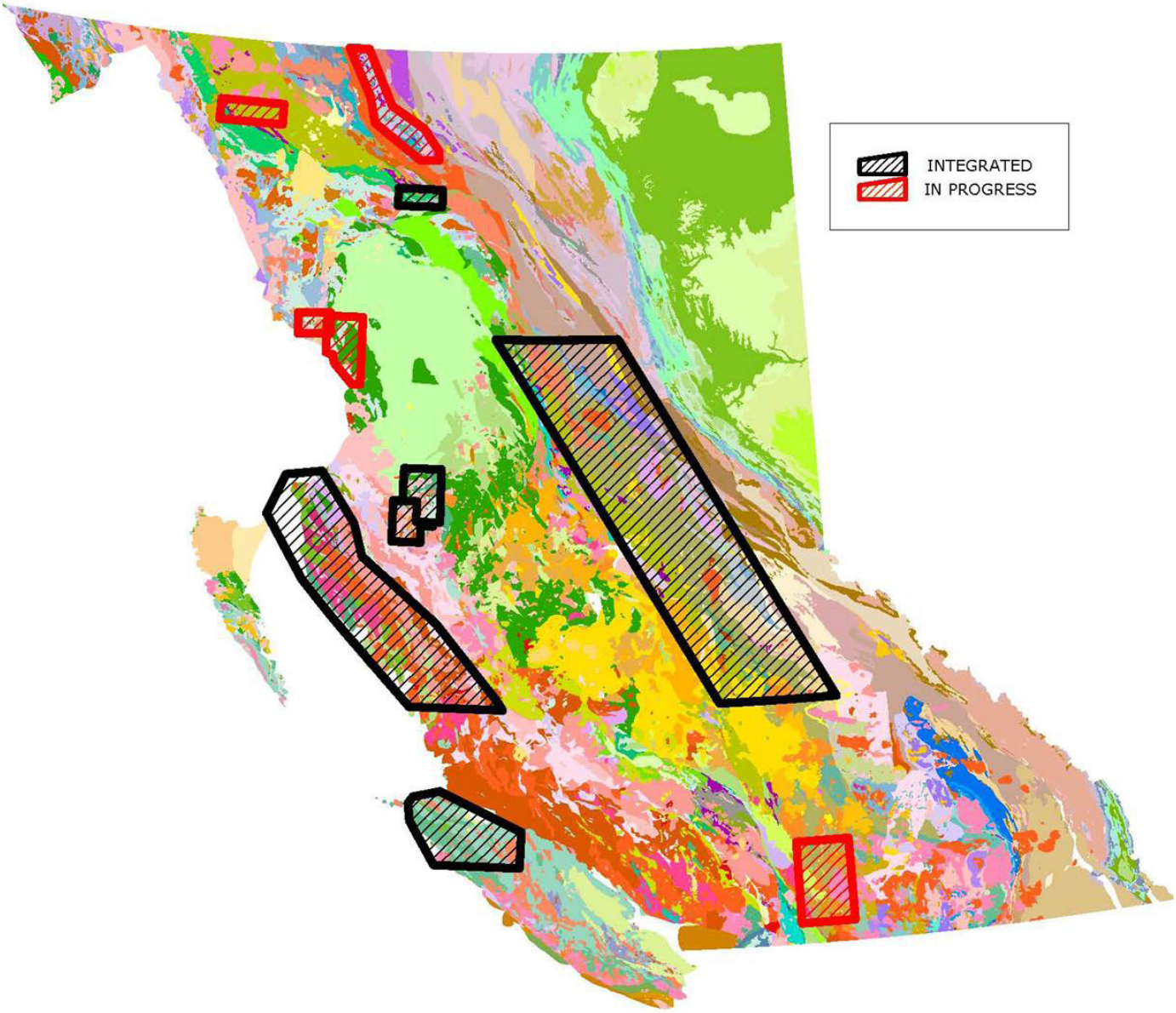


Fig. 9. Areas of British Columbia with recent (black boxes) or ongoing (red boxes) updates to the British Columbia digital geology map (www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/DigitalGeologyMaps/Pages/default.aspx).

provides the minerals industry with a point of contact for Survey activities, access to government geoscience products, and advice on mineral and coal opportunities in the Province.

Technical marketing by the MDO targets an audience ranging from large foreign investment groups to independent domestic entrepreneurs, highlighting the Province's mineral and coal potential, geoscience resources, global expertise, and attractive business climate. In 2015 a number of promotional publications were revised, including brochures for copper, gold, molybdenum, coal, nickel, zinc, and jade, which was also produced in Chinese. The MDO office website was redesigned and updated with new publications and revised links to government and industry associations. Website revisions included a Google Earth interactive map showing all British Columbia porphyry deposits with defined resources and comprehensive information about the deposits through a link to MINFILE. In the fall of 2015, the MDO supported the Ministry of International Trade by participating in the China Mining Congress and Expo in Tianjin and the Canada Mineral Investment Forum in Beijing.

The MDO oversees delivering provincial and regional level exploration and mining summary documents from the Regional Geologist Program, maintaining a legacy that dates back to 1874 with the Annual Reports of the Minister of Mines.

5. Regional Geologists Program

The Regional Geologists Program was created in the early 1970s to facilitate economic development in the mineral

exploration and mining sector. The British Columbia Regional Geologists 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.

Acknowledgment

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