Atlas of Gold Compositions for British Columbia: Developing a New Tool for the Exploration Community

R.J. Murphy, School of Earth and Environment, University of Leeds, Leeds, United Kingdom, r.j.murphy@leeds.ac.uk

R.J. Chapman, School of Earth and Environment, University of Leeds, Leeds, United Kingdom

J.K. Mortensen, MDN Geosciences Ltd, Salt Spring Island, British Columbia

B. Bluemel, Bonanza Geosciences, Squamish, British Columbia

D.A. Banks, School of Earth and Environment, University of Leeds, Leeds, United Kingdom

Murphy, R.J., Chapman, R.J., Mortensen, J.K., Bluemel, B. and Banks, D.A. (2020): Atlas of gold composition for British Columbia: developing a new tool for the exploration community; *in* Geoscience BC Summary of Activities 2019: Minerals, Geoscience BC, Report 2020-01, p. 77–82.

Introduction

Detrital gold grains can be of great help to mineral exploration campaigns because they are broadly dispersed and create a larger footprint around lode-gold deposits. Erosional products of orebodies provide vectors to mineralization, but these can be obscured by surficial deposits (Averill, 2011). In British Columbia (BC), recent indicator-mineral research has been primarily focused on porphyry-epithermal systems and methodologies based on resistant minerals such as magnetite (Celis et al., 2014; Pisiak et al., 2015), apatite (Bouzari et al., 2010, 2016; Mao et al., 2016) and tourmaline (Chapman et al., 2015). Detrital gold grains are ideal for use as indicator minerals because of their mechanical durability and chemical stability. However, the potential for gold grains recycling into successive fluvial environments diminishes the clear spatial relationship to lode source. In BC, the complex Cordilleran geology provides multiple plausible sources of gold particles; consequently, the discovery of gold particles during routine stream-sampling programs may not be sufficient to confirm a specific mineralization. A methodology has been developed to differentiate gold particles sourced from various styles of mineralization (porphyry, epithermal, skarn and orogenic).

Development of a gold indicator-mineral methodology is advantageous in BC because it benefits both greenfield and brownfield exploration activities. Exploration for porphyry copper-gold deposits in southern and central BC accounts for the majority of greenfield exploration spending, so any new sources of information would be valuable; brownfield exploration in areas of current mining are also important, both in the context of potential expansion and to establish exploration templates related to a known deposit for application elsewhere. In addition to ongoing exploration for porphyry copper-gold deposits in BC, there is also extensive exploration activity targeting orogenic-gold systems. Licence areas may contain detrital gold, but the location and nature of the source may be unclear because of geological and geographic complexity, remoteness of the location or lack of bedrock exposure. In these cases, the ability to establish the geological context of the source mineralization would be of great benefit to explorers.

The compositional variation between gold from different economic placer-locality populations is well known, principally because the silver content of the gold alloy influences the revenue to the miners. Gold-alloy composition is a function of the conditions of metal precipitation (Gammons and Williams-Jones, 1995), which vary according to the style of mineralization. In addition, minerals coeval with gold occur as micro-inclusions in the gold grains and are revealed in polished section. In conjunction, the alloy composition and mineral-inclusion suite of detrital gold particles define a 'microchemical signature' that is consistent with their hypogene source. Therefore, the source mineralogy can be reconstructed even when undiscovered.

Whilst gold may form in several geological environments, the associated mineralogy may provide a strong marker for the nature of the hypogene source. Generic elemental associations have been established for inclusion suites of gold from both alkalic and calcalkalic porphyry environments (e.g., Chapman et al., 2017, 2018) and recent studies have explored the potential to develop trace-element signatures for gold from different environments using laser-ablation inductively coupled plasma–mass spectrometry (Banks et al., 2018; Liu et al., 2019).

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

The current project will develop a new, publicly available reference database of gold microchemistry, specifically for mineralization styles encountered in BC, to encourage and assist mineral exploration efforts. The reference database will draw on results of recent projects (3868 gold particles from 68 localities), historic unpublished data and new data from analysis of material in collections at The University of British Columbia (6756 gold particles from 17 placer districts). Gold from porphyry, epithermal, skarn and orogenic systems is represented. The database will be compatible for interrogation using machine-learning techniques and will provide a new targeting tool for exploration companies in BC.

Previous Studies of Gold Composition in the Canadian Cordillera

Previous research has sought to characterize hypogene gold and its associated detrital expression for a variety of deposit styles across the Cordillera. The inclusion suites of gold from calcalkalic porphyry systems in Yukon exhibit a generic Bi-Pb-Te-S signature (Chapman et al., 2018), which is also present but less pronounced in associated epithermal systems. In contrast, detrital gold samples from alkalic porphyry copper-gold deposits in BC exhibit a strong Pd-Hg signature, matching the distinctive Pd-Hg mineralogy reported in late-stage veins (Chapman et al., 2017). Both studies highlighted the variation of gold mineralogy between the main ore stage (generally associated with potassic alteration and present as 5–20 µm blebs, which have exsolved from chalcopyrite or bornite) and later vein mineralization, which commonly contains gold sufficiently massive to be concentrated in placer lags. Thus, the mineralization of the most economically important phase (potassic) may be mineralogically distinct from that which forms the best detrital indicator.

Metamorphic fluids responsible for orogenic mineralization tend to be less chemically complex than their magmatic hydrothermal counterparts and this is reflected in the mineralogy of the inclusion suites observed in gold from orogenic systems (e.g., Chapman and Mortensen, 2016). Nevertheless, the inclusion signature from different episodes of orogenic mineralization may differ substantially even in the same area (e.g., Chapman et al., 2010, 2016), characterized by the relative abundance of base-metal sulphides, and sulpharsenide and telluride minerals. On the other hand, gold-silver alloys from magmatic hydrothermal systems typically contain higher levels of copper than gold from orogenic systems (Morrison et al., 1991, Chapman et al., 2017, 2018), which may be a function of mineralization temperature controlling substitution of copper into the gold-silver lattice (Chudnenko and Palyanova, 2016).

Sample Acquisition

Existing collections of detrital gold particles and hypogene-ore material collected by researchers at The University of British Columbia Mineral Deposit Research Unit (UBC-MDRU) and the University of Leeds are used for this project. The UBC-MDRU collection, curated by J. Knight, provides a key resource; this collection consists of detrital gold particles, polished sections and rock chips collected or donated from 352 localities across BC. Gold samples are also available from published studies describing two previous Geoscience BC funded projects at the University of Leeds relating to the Cariboo gold district (Chapman and Mortensen, 2016) and a regional study of alkalic porphyry copper-gold deposits (Chapman et al., 2017). The sample coverage of the UBC and University of Leeds collections is shown in Figure 1.

Additionally, relevant samples from existing UBC research collections have been made available, consisting of polished blocks of ore material from mines in the Hedley, Rossland, Sheep Creek, Zeballos, and Portland Canal mining districts. Detrital particles collected from drainages of the Kerr-Sulphurets-Mitchell deposit, acquired during recent fieldwork as part of other University of Leeds research, will also be analyzed. The project also benefits from the donation of detrital gold particles and ore-material hand specimens from the CLY prospect on the site of the historic Bunker Hill mine.

In total, samples from 495 localities will be utilized for this project. A summary of the samples available and the current extent of their analysis is presented in Table 1.

Sample Preparation

Gold particles collected from detrital sources or liberated from the crushing and sluicing of hypogene material were mounted in 25 mm diameter resin blocks according to particle size and polished to expose their interiors (Figure 2). Exposing the cores of the particles provides the best opportunity to analyze the primary phase of mineralization and is necessary to identify mineral inclusions.

Analytical Techniques

Scanning Electron Microscope (SEM)

The SEM will be used to locate and identify mineral inclusions, which are identified using both the secondary electron and back-scattered electron functions. The elemental composition of individual inclusions can be determined using the energy dispersive X-ray spectroscopy facility.

Electron Probe Microanalyzer (EPMA)

The EPMA (Figure 3) is used to analyze the alloy composition of each individual gold particle according to the Ag,

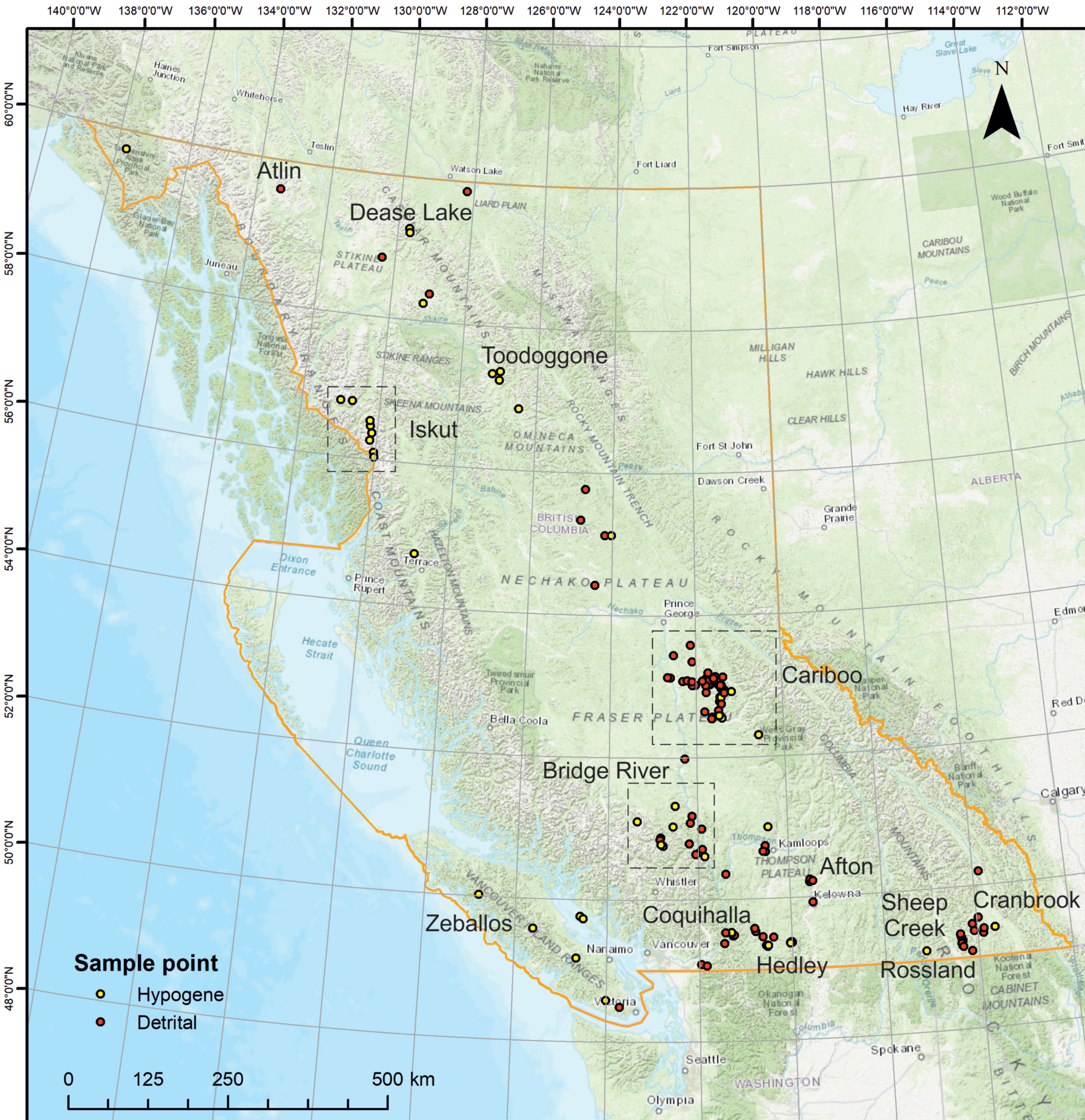

Figure 1. Location of samples from The University of British Columbia and the University of Leeds collections. Key camps and areas have been identified. Base map was created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under licence. Copyright © Esri. All rights reserved. For more information about Esri® software, visit https://www.esri.com/en-us/home.

Cu, Hg and Pd contents. Analysis is undertaken using a fully focused beam with a voltage of 20 kV and an intensity of 50 nA. Count times for primary alloy elements (Au and Ag) are 30 s on-peak, and 15 s at high and low off-peak; for trace alloy elements (Cu, Hg and Pd), count times are doubled to improve precision. These settings provide the most efficient compromise between accuracy and analysis time to characterize large numbers of gold particles.

Laser-Ablation Inductively Coupled Plasma–Mass Spectrometry (LA-ICP-MS)

Lastly, LA-ICP-MS is a precise analytical technique that determines elemental concentrations at a parts per billion scale, thus improving the ability to distinguish the minor alloying elements in gold (Banks et al., 2018). However, as it involves the ablation of the sample, it can only be under-

Table 1. Samples analyzed for the project, separated by district; additional usable material, such as hand specimens, polished sections and additional gold grains yet to be mounted, is also detailed.

District	Sample localities	Mounted grains	Analyzed for alloy composition	Analyzed for inclusions	Additional usable material
Alberni	7	1	0	0	17 polished sections
Atlin	3	20	0	0	Unmounted grains; 1 polished section
Cariboo	106	4137	3162	1548	Unmounted grains
Clinton	10	338	213	0	Unmounted grains
Fort Steele	10	34	0	0	None
Golden	2	3	0	0	None
Kamloops	13	363	358	172	3 polished sections; unmounted grains
Lillooet	59	1239	1140	0	4 polished sections; unmounted grains
Nelson	11	17	0	0	26 polished sections; unmounted grains
New Westminster	35	1372	785	0	6 polished sections; unmounted grains
Omineca	8	337	85	65	2 polished sections; unmounted grains
Osoyoos	8	0	0	0	9 polished sections
Portland Canal	12	509	50	0	21 polished sections; unmounted grains
Quesnel	10	349	62	19	Unmounted grains
Similkameen	14	783	681	82	Unmounted grains
Slocan	2	17	17	0	1 polished section
Stikine	75	1320	759	0	12 polished sections; unmounted grains
Trail Creek	3	26	0	0	33 hand specimens
Vancouver	3	147	41	0	Unmounted grains
Vernon	11	31	29	0	Unmounted grains
Victoria	1	48	0	0	Unmounted grains

taken following full characterization by EPMA and SEM. Analysis via LA-ICP-MS will therefore be undertaken on samples where the compositional information collected is insufficient to ascribe a microchemical signature, for example, where minor alloying elements such as Cu, Hg and Pd are below the detection limit of the EPMA.

Integration of Existing Data

Full datasets acquired by Chapman and Mortensen (2016) and Chapman et al. (2017) were made available for the project. These datasets include alloy-composition data using target elements Au, Ag, Cu, Hg and Pd, and recorded mineral inclusions for 3868 gold grains. Furthermore, these datasets are formatted to be compatible with machine-learning techniques and therefore provide the template for the database generated for this project.

Compositional data relating to the UBC gold collection were provided as scanned copies of dot-matrix printouts and required digitizing using optical character-recognition

Figure 2. Gold particles are mounted in circular blocks of resin, which are then polished to reveal the particle interiors for analysis.

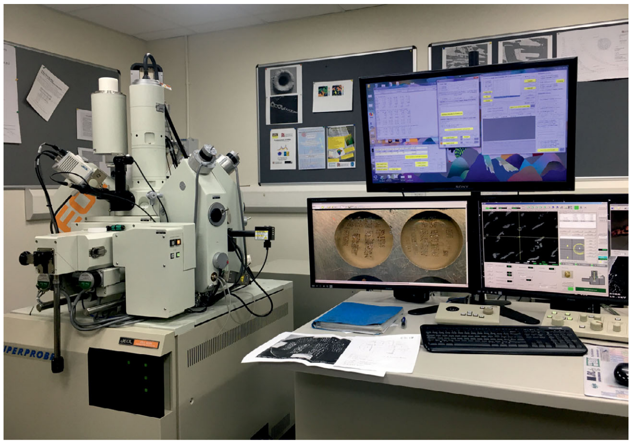

Figure 3. The JEOL Ltd. JXA-8230 electron probe microanalyzer at the University of Leeds.

software. The datasets were then reformatted to be consistent with the existing dataset from the University of Leeds, which describes 5364 gold particles from a total of 148 localities.

Future Work

With the majority of samples now received, analytical work using the SEM and EPMA is underway. Newly generated data will be integrated with the database as it is acquired. Samples that are not yet prepared for use with the instruments will be mounted and polished. Thin sections will be prepared from relevant hand specimens and inspected by reflected-light microscopy; those containing visible gold will be scheduled for analysis.

Conclusion

This project will develop a large, microchemical and mineralogical database of gold grains from a variety of deposit styles encountered in BC. Newly generated data for alloy composition and inclusion mineralogy from a range of locations will be amalgamated with existing datasets. The database will provide a comprehensive reference for exploration companies, allowing the likely source-mineralization styles in their licence area to be determined and therefore being of great help to exploration campaigns at an early stage. The database will be compatible for interrogation using machine-learning techniques and will provide a new targeting tool for exploration companies in BC.

Acknowledgments

This project was funded by Geoscience BC. The authors would like to thank The University of British Columbia and its Mineral Deposit Research Unit for access to relevant sample collections. They also thank W. Howard for the donation of samples and information relating to the CLY prospect at Bunker Hill mine. Lastly, T. Torvela is thanked for her helpful review of this paper.

References

Averill, S.A., (2011): Viable indicator minerals in surficial sediments for two major base metal deposit types: Ni-Cu-PGE and porphyry Cu; Geochemistry, Exploration, Environment, Analysis, v. 11, p. 279–291, URL <https://pubs.geoscienceworld.org/geea/article-abstract/11/4/279/128954> [November 2019].

Banks, D.A., Chapman, R.J. and Spence-Jones, C. (2018): Detrital gold as a deposit-specific indicator mineral by LA-IPS-MS analysis; *in* Geoscience BC Report 2018-21, 49 p., URL <http://cdn.geosciencebc.com/project_data/GBCReport2018-21.pdf> [October 2019].

Bouzari, F., Hart, C.J.R., Barker, S. and Bissig, T. (2010): Porphyry indicator minerals (PIMs): exploration for concealed deposits in south central British Columbia(NTS 092I/06, 093A/12, 093N/01, /14); *in* Geoscience BC Summary of Activities 2009, Geoscience BC, Report 2010-1, p. 25–32, URL <http://cdn.geosciencebc.com/pdf/SummaryofActivities2009/SoA2009_Bouzari.pdf> [October 2019].

Bouzari, F., Hart, C.J.R, Bissig, T. and Barker, S. (2016): Hydrothermal alteration revealed by apatite luminescence and chemistry: a potential indicator mineral for exploring covered porphyry copper deposits; Economic Geology, v. 111, p. 1397–1410, URL <https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/111/6/1397/152471> [October 2019].

Celis, M.A., Bouzari, F., Bissig, T., Hart, C.J.R. and Ferbey, T. (2014): Petrographic characteristics of porphyry indicator minerals from alkalic porphyry copper-gold deposits in south-central British Columbia (NTS 092, 093); *in* Geoscience BC Summary of Activities 2013, Geoscience BC, Report 2014-1, p. 53–62, URL <http://www.llbc.leg.bc.ca/public/PubDocs/bcdocs/454425/2013/07_Celis.pdf> [November 2019].

Chapman, R.J. and Mortensen, J.K. (2016) Characterization of gold mineralization in the northern Cariboo Gold District, British Columbia, Canada, through integration of compositional studies of lode and detrital gold with historical placer production: a template for evaluation of orogenic gold districts; Economic Geology, v. 111, no. 6, p. 1321–1345, URL <https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/111/6/1321/152454> [October 2019].

Chapman, R.J., Allan, M.M., Mortensen, J.K., Wrighton, T.M. and Grimshaw, M.R. (2018): A new indicator mineral methodology based on a generic Bi-Pb-Te-S mineral inclusion signature in detrital gold from porphyry and low/intermediate sulfidation epithermal environments in Yukon Territory, Canada; Mineralium Deposita, v. 53, no. 6, p. 815–834, URL <https://link.springer.com/article/10.1007/s00126-017-0782-0> [October 2019].

Chapman, R., Mileham, T., Allan, M. and Mortensen, J. (2017) A distinctive Pd-Hg signature in detrital gold derived from alkalic Cu-Au porphyry systems; Ore Geology Reviews, v. 83, p. 84–102, URL <https://www.sciencedirect.com/science/article/pii/S0169136816305005> [October 2019].

Chapman, R.J., Mortensen, J.K., Crawford, E.C. and LeBarge, W., 2010. Microchemical studies of placer and lode gold in the Klondike District, Yukon, Canada: 1. Evidence for a small, gold-rich, orogenic hydrothermal system in the Bonanza and Eldorado Creek area; Economic Geology, v. 105, no. 8, p. 1369–1392, URL <https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/105/8/1369/128235> [October 2019].

Chapman, J.B., Plouffe, A., Jackson, S.E., Ryan, J.J. and Ferbey, T. (2015): Mineral markers of porphyry processes: regional and local signatures of porphyry prospectively; *in* TGI 4 – Intrusion Related Mineralisation Project: New Vectors to Buried Porphyry-Style Mineralisation, N. Rogers (ed.), Geological Survey of Canada, Open File 7843, p. 521–534.

Chudnenko, K.V. and Palyanova, G.A. (2016): Thermodynamic modeling of native formation of Au-Ag-Cu-Hg solid solutions; Applied Geochemistry, v. 66, p. 88–100, URL <https://www.sciencedirect.com/science/article/pii/S0883292715300780> [October 2019].

Gammons, C.H. and Williams-Jones, A.E. (1995): Hydrothermal geochemistry of electrum: thermodynamic constraints; Economic Geology, v. 90, p. 420–432, URL <https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/90/2/420/21472> [October 2019].

Lui, H., Beaudoin, G., Makvandi, S. and Jackson, S. (2019): Geochemical signature of native gold from various Au-bearing deposits – implications for mineral exploration; Society for Geology Applied to Mineral Deposits, 15th SGA Biennial Meeting, Glasgow, Scotland, August 27–30, 2019, extended abstract, p. 675–678.

Mao, M., Rukhlov, A.S., Rowins, S.M., Spence, J. and Coogan, L.A. (2016): Apatite trace element compositions: a robust new tool for mineral exploration; Economic Geology, v. 111, p. 1187–1222, URL <https://pubs.geoscienceworld.org/segweb/economicgeology/article-abstract/111/5/1187/152473> [October 2019].

Morrison, G.W., Rose, W.J. and Jaireth, S. (1991): Geological and geochemical controls on the silver content (fineness) of gold in gold-silver deposits; Ore Geology Reviews, v. 6, p. 333–364, URL <http://dx.doi.org/10.1016/0169-1368(91)90009-V> [October 2019].

Pisiak, L.K., Canil, D., Grondahl, C., Plouffe, A., Ferbey, T. and Anderson, R.G. (2015): Magnetite as a porphyry copper indicator mineral in till: a test using the Mount Polley porphyry copper-gold deposit, south-central British Columbia (NTS 093A); in Geoscience BC Summary of Activities 2014, Geoscience BC, Report 2015-1, p. 141–150, URL <http://www.geosciencebc.com/i/pdf/SummaryofActivities2014/SoA2014_Pisiak.pdf> [October 2019].