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New TGI-4 till geochemistry and mineralogy results near the Highland Valley, Gibraltar, and Mount Polley mines, and Woodjam District: An aid to search for buried porphyry deposits

A. Plouffe, T. Ferbey, R.G. Anderson, S. Hashmi, and B.C. Ward

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New TGI-4 till geochemistry and mineralogy results near the Highland Valley, Gibraltar, and Mount Polley mines, and Woodjam District: An aid to search for buried porphyry deposits

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SUMMARY

Surficial geological research, with the objective of developing innovative techniques for the detection of buried porphyry mineral deposits, was conducted near four porphyry mineralized systems in south central British Columbia (Highland Valley, Gibraltar and Mount Polley mines and the Woodjam district). This project is part of the Targeted Geoscience Initiative 4 Program of the Geological Survey of Canada (Natural Resources Canada). Interpretation of the results takes into account the bedrock geology, known mineralization (MINFILE occurrences from the British Columbia Geological Survey database (http://www.empr.gov.bc.ca/Mining/Geoscience/MINFILE/Pages/default.aspx) and the reconstruction of ice-flow history.

This data, consisting of 282 till samples that were analyzed for geochemical compositions and indicator minerals, indicates that at the four study sites, Cu content of the clay-sized fraction of till is more elevated near known mineralization compared to surrounding regions. The number of chalcopyrite grains in the heavy mineral concentrates (0.25 – 0.5 mm; s.g. >3.2) are elevated near mineralization at Highland Valley and Gibraltar mines and known mineralized zones at Woodjam. Epidote content in the heavy mineral concentrates at Woodjam are similarly enhanced in samples collected closest to interpreted propyllitically-altered source rocks. The distribution of all these indicators in till are the net effect of glacial erosion of the source bedrock, entrainment and dispersal processes.

These results reveal that till geochemistry combined with till mineralogy are effective at detecting porphyry mineralization buried by glacial deposits. This first data set will be supplemented by tree bark geochemistry, which will be completed in 2013.

INTRODUCTION

The Kamloops Exploration Group (KEG) Conference and Trade Show is an annual meeting which gathers the Cordilleran mineral exploration community for enlightened discussions around technical presentations and poster displays on all aspects of mineral exploration in British Columbia. In 2013, the conference was in its 26th year with over 500 registrants.

This open file contains the slides and brief descriptive notes of an invited talk on the recent results of the collaborative activities of the Geological Survey of Canada (GSC; Natural Resources Canada) and the British Columbia Geological Survey (BCGS; British Columbia Ministry of Energy and Mines) under the intrusion-related ore system Targeted Geoscience Initiative - 4 (TGI-4) project. The notes include minor updates to that presentation, based on field work conducted in May 2013 following the KEG Conference. The open file seeks to provide an annotated archive of the presentation that can be distributed to a wide audience. It also marks the progress of the research activity from 2012 (cf., Anderson et al., 2012a, b). The slides are included at the end of this document after the references.

Slide 1

Title of the presentation, authors and their affiliations.

Slide 2

The TGI-4 Program of the GSC is a five year program (2010-2015) comprising research on seven ore-systems: volcanogenic massive sulfide (VMS), lode gold, Ni-Cu-PGE-Cr, specialty metals, sedimentary exhalative (SEDEX), uranium and intrusion-related.

This presentation includes results from activities of the intrusion-related ore system project at four study sites in south central British Columbia: Gibraltar, Highland Valley, Mount Polley mines and Woodjam district.

Slide 3

The activities of this project include till geochemistry and mineralogy, biogeochemistry (Engelmann spruce and lodgepole pine bark), ice-flow history reconstruction, and detailed structural studies at Gibraltar Mine (M.Sc. thesis project to start in 2013 at the University of British Columbia under the supervision of Lori Kennedy). This presentation focused on the first set of results related to till geochemistry and mineralogy.

Slide 4

A typical setting for surficial sedimentary deposits in the Interior Plateau of British Columbia or any glaciated landscape with moderate relief generally consists of bedrock overlain by glacial sediments on which a dense forest canopy has developed since deglaciation. One of the objectives of this project is to identify: 1) elements and minerals in glacial sediments (till) indicative of buried mineralization and 2) the vectors (ice-flow movements) required to trace their bedrock source. Furthermore, a complementary and integrated objective is to identify the elemental composition of tree bark (biogeochemistry) that is indicative of buried mineralization. The white arrow identifies location of the tree bark sample at this locality.

Slide 5

None of the work reported in this presentation would have been possible without the interaction, interest and support of the mining and exploration companies and their personnel listed on the slide.

They have provided access to properties and drill core, provided property tours, discussed the geology of the deposits, and provided safety briefing and training for all aspects of a safe work environment at their mine site or exploration camp.

Slide 6

Capable field assistance in 2012 was provided by N. Evanoff and K.-L. Robillard. D. Sacco, in his role of senior assistant, provided outstanding support as the third member of the surficial mapping and sampling team.

METHODOLOGY

Slide 7

At each till sampling site, large (ca. 10 kg) and small (ca. 2 kg) samples of bulk till material were collected at an average depth of 80 cm below the depth of visible soil weathering. Sample site spacing was about 1-2 km. Pick is 90 cm long.

Slide 8

The small samples (ca. 2 kg) were submitted for grain size separation at the Sedimentology Laboratory of the GSC. The clay-sized fraction (<0.002 mm) was separated by decantation and centrifuge and the silt and clay-sized fraction (<0.063 m, -230 mesh) by dry sieving. Both fractions were sent for geochemical analyses in a commercial laboratory (Acme Analytical Laboratories Ltd. in Vancouver); digestion and analytical methods indicated on the slide. This presentation includes only the analytical results on the clay-sized fraction leached by lithium borate / tetraborate, nitric acid, and fusion followed by inductively coupled plasma emission spectrometry (ICP-ES); later publications will provide results from inductively coupled plasma mass spectrometry (ICP-MS) analyses.

The large samples (ca. 10 kg) were sent for separation of heavy minerals. The samples were first sieved to < 2mm and then weighted. This weight is used to normalized the mineral grain counts. The number of indicator mineral grains need to be normalized because there is variability (+/- 2 kg) in the weight of the samples collected in the field. Heavy mineral were separated using a two-step procedure including a shaking table and heavy liquids at a commercial laboratory (Overburden Drilling Management, Ottawa (ODM)). Magnetic minerals were separated and archived using a hand magnet. Indicator minerals were identified in two density fractions (specific gravity (s.g.) 2.8 – 3.2 and >3.2) and in each of the following size fractions: 0.25 – 0.5 mm, 0.5 – 1 mm, and 1 – 2 mm.

Strict quality assurance and quality control measures were followed as part of those analyses including blank, duplicate and primary standards for geochemical analyses (Spirito et al., 2011), and blank, duplicate and spiked samples for indicator mineral processing and identification (Plouffe et al., in press).

ICE-FLOW HISTORY

Slide 9

The reconstruction of ice-flow movements is fundamental to interpret till composition and glacial dispersal and thus to provide vectors to buried mineralization. The ice-flow history is reconstructed from the mapping of glacial landforms observed on aerial photographs and other small scale images (e.g., digital elevation model) and by measuring glacial erosional indicators on bedrock outcrop surfaces.

Examples of glacial striations at the four study sites are depicted on this slide. In rare instances, two ice-flow movements, with cross-cutting relationships indicating their relative age, can be identified on a striated outcrop. In the example from Woodjam, older grooves oriented 055 – 235° contain younger striations oriented 125 – 305°. Although there are no sense indicators on this outcrop for both sets of striations, (hence the double headed arrows on the striation symbols) once placed in a regional context, these striations are interpreted to reflect an early ice-flow to the southwest from the Cariboo Mountains followed by a later ice movement to the northwest from an ice divide located to the south in the Woodjam district region (see Plouffe et al., 2011). Compass is 22 cm and knife 24 cm long. View direction is to the west in Woodjam photograph.

Slide 10

The regional ice-flow history for a sector of the Interior Plateau of British Columbia can be presented based on previous studies (Tipper, 1971a,b; Plouffe et al., 2011; Anderson et al., 2012b) augmented with new data obtained from our most recent field work completed in 2012 and 2013.

Slide 11

The following generalized ice-flow history relates to three of the four study sites (Gibraltar Mine, Mount Polley Mine and Woodjam district) located west of the Cariboo Mountains (A).

At the onset of the Late Wisconsinan glaciation (Fraser Glaciation), valley and piedmont glaciers that formed in the Cariboo Mountains advanced in a general westward direction over the Interior Plateau (B). As glaciation intensified, glaciers advanced westerly at least as far as the Gibraltar Mine area (C). At glacial maximum, an ice divide formed around the 52° latitude, from which ice was flowing to the north and south (D).

HIGHLAND VALLEY DISTRICT

Slide 12

Generalized geology of some key bedrock units in southern Interior Plateau and location of Highland Valley Mine study site.

Porphyry Cu-Mo mineralization at Highland Valley district is hosted in the Late Triassic Guichon Creek Batholith which has intruded the Mississippian to Upper Triassic Cache Creek Complex (not shown on this map) and the Upper Triassic Nicola Group (McMillan, 1985; McMillan et al., 2009; Anderson et al., 2012b).

Slide 13

Till and biogeochemical sample locations are depicted on a shaded digital elevation model produced from the Shuttle Remote Topographic Mission (SRTM) data (http://eros.usgs.gov/). Samples were collected north and southeast from the principal pits: Valley, Bethlehem, Lornex and Highmont. Sampling in May 2012 was hampered south of the pits because of the snow cover at high elevation (> 1200 m above sea level).

Only one ice movement, generally to the south (red arrows) has been identified in the Highland Valley Mine region as reported in Fulton (1975), Ryder (1976), and Bobrowsky et al. (1993; 2002) and confirmed from striations measured as part of our field study.

Part of the mineralization at Highland Valley was exposed to glacial erosion because it is directly overlain by till of the last glaciation. However, part of the mineralization was protected from glacial erosion because it is covered by pre-glacial sediments (Bobrowsky et al., 1993; Anderson et al., 2012a; Plouffe et al., 2012).

Slide 14

Chalcopyrite is one key porphyry indicator mineral identified in the 0.25 – 0.5 mm and s.g. >3.2 fraction of the till sample at the four study sites. The photograph (by ODM) depicts examples of chalcopyrite grains recovered from till samples from the Highland Valley Mine region. These results demonstrate that chalcopyrite is preserved in till in the near surface environment below the soil weathering depth and has not been completely oxidized since deglaciation.

Slide 15

The distribution and abundance of chalcopyrite grains fraction normalized to 10 kg bulk till (< 2 mm) are shown on a bedrock geology map generalized from McMillan et al. (2009) draped on a shaded digital elevation model (DEM) (SRTM at http://eros.usgs.gov/). The number of chalcopyrite grains are clearly elevated (>41 grains per 10 kg) in till collected within the Bethlehem and Valley pits but also over the Highland Valley phase near the eastern margin of the Guichon Creek Batholith. The chalcopyrite could be derived from known porphyry mineral occurrences (locations from MINFILE shown by green diamonds) or as yet undiscovered mineralized zones.

Slide 16

Similarly, copper content of the clay-sized fraction as determined by ICP-ES is elevated (>963 ppm) in till samples collected within the Bethlehem and Valley pits but also over the Highland Valley phase near the eastern margin of the Guichon Creek Batholith.

In May 2012, till sampling was hampered at high elevation (generally above approximately 1500 m above sea level) because of the persistent snow cover and insufficient till samples were collected to the south (down-ice) of the economic mineralization at Highland Valley Mine to establish glacial dispersal. However, those results demonstrate that copper content of the clay-sized fraction of till and chalcopyrite grain counts in till are two key indicators of porphyry mineralization. No further collection of till samples are anticipated.

GIBRALTAR MINE

Slide 17

Generalized geology of some key bedrock units in southern Interior Plateau and location of Gibraltar Mine study site.

Cu-Mo porphyry mineralization at Gibraltar Mine is hosted in the Late Triassic Granite Mountain Batholith which intruded the Permian Cache Creek Group (not shown on slide 17) (Rotherham et al., 1972; Drummond et al., 1976; Bysouth et al., 1995; Ash et al., 1999b).

Slide 18

Till and biogeochemical sample locations are depicted on a shaded digital elevation model produced from SRTM data. Till and biogeochemical samples were collected within at least a 10 km radius from the Gibraltar Mine site.

The glacial striation record from Gibraltar Mine region reveals a first general westward ice movement (blue arrow) followed by a northward movement (red arrows) (Anderson et al., 2012b). During the May 2012 field season, a single striated outcrop with at least 6 rat tails, as seen on slide 9, clearly indicating distinct and separate southward and northward movements was discovered approximately 4 km southwest of the mine site (at location of double-headed red arrow on map). The chronology between the movements to the north and south could not be established. The southward movement could be related to the northward migration of the ice-divide north of Gibraltar Mine or to a late-phase ice movement related to the readjustment of the ice profile during deglaciation.

The reconstruction of the ice-flow history at Gibraltar Mine indicates that pattern of glacial dispersal might have been influenced by westward, northward and southward ice movements and is likely to be complex.

Part of the mineralization was exposed to glaciation at Gibraltar Mine as depicted by copper isopleth and the cross-section of Gibraltar mineralization (Ash et al., 1999a) but bedrock was confined to less than 5% in the pre-mining area of mineralization (Rotherham et al., 1972).

Slides 19 and 20

The distribution and abundance of chalcopyrite grains (0.25-0.5 mm; > 3.2 s.g.) normalized to 10 kg bulk till (<2 mm) are shown on a bedrock geology map (see legend on slide 20) compiled from Ash et al. (1999b), Massey et al. (2005), and unpublished digital data (P. Schiarizza, pers. comm.) draped on a DEM (SRTM, http://eros.usgs.gov/).

Chalcopyrite grains in till are elevated (> 10 grains per 10 kg) to the west, north and south of the main economic mineralization exposed in Gibraltar, Pollyana and Granite Lake pits compared to the surrounding region (<10 grains per 10 kg). This multi-directional dispersal may reflect the complex glacial movements in the region described earlier and the numerous sub-economic porphyry copper occurrences in the intrusion.

Slide 21

Correlated with the area defined by elevated chalcopyrite grain counts, is the distribution of sites with enriched copper content (>377 ppm) in the clay-sized fraction of till. With a few exceptions, the dispersal patterns of the copper content of the clay and the chalcopyrite grains in the medium sand (0.25 – 0.5 mm) fraction of till are similar (compare slides 19 and 21).

The large zone with elevated chalcopyrite grains and copper content in the clay-sized fraction of till to the west, north and south of the mine likely results from a combination of the glacial erosion of numerous economic and sub-economic porphyry Cu mineralization (green diamonds) and the multi-directional ice flow to the west, north, and south creating an amoeboid dispersal train typical of regions which were under the influence of migrating ice-divides and multiple ice-flow directions (Shilts, 1993).

Slides 22 and 23

To demonstrate that the copper content of the clay-sized fraction and the abundance of chalcopyrite grains in till are correlated and can serve as indicators of buried porphyry mineralization, the same results are presented without the geological background but with the reconstructed ice-flow movements. For scale, the map extents are the equivalent of a 1:50 000 scale National Topographic System (NTS) map sheet. Both indicators (copper content of the clay and chalcopyrite grain counts) are clearly showing elevated values extending within 10 km from the mine. Was Gibraltar Mine undiscovered today, exploration focused within, and up-ice from this regional geochemical and mineralogical anomaly would greatly reduce exploration risk.

MT. POLLEY

Slide 24

Generalized geology of some key bedrock units in southern Interior Plateau and location of Mt. Polley Mine study site.

At Mt. Polley Mine, porphyry Cu-Au mineralization is hosted in the Late Triassic Mt. Polley Intrusive Complex (too small to be shown on slide 24) emplaced in the metasedimentary and volcanic-arc assemblage rocks of the Nicola Group (Fraser et al., 1995; Logan and Mihalynuk, 2005; Tosdal et al., 2008). Coarse grained chalcopyrite was present in the pre-mining bedrock exposure of the Northeast zone (Wight pit) at Mt. Polley Mine, and therefore was exposed to glacial erosion (C. Rees, pers. comm. 2013). Malachite, rather than chalcopyrite, was exposed to glacial erosion in the centre of Mt. Polley Mine (Springer and Cariboo zones) (C. Rees, pers. comm. 2013).

Slide 25

The study at Mt. Polley is part of a M.Sc. thesis undertaken by S. Hashmi at Simon Fraser University (under the supervision of Brent Ward), which will contribute a surficial geology map, the reconstruction of the glacial history, and a description of glacial dispersal applicable to mineral exploration for porphyry mineralization in drift covered terrain.

Till and biogeochemical sample locations are depicted on a shaded digital elevation model produced from the SRTM data (http://eros.usgs.gov/). Samples were collected principally in areas accessible by forestry roads to the southwest, west and northwest of the mine site (down-ice from the mine) with limited samples to the east (up-ice).

A striated bedrock outcrop near the Springer Pit bears evidence of a first ice flow to the west (blue arrow) followed by a northwest movement (red arrows). This chronology is attributed to ice movement out of the Cariboo Mountains at the onset of glaciation followed by northwest ice flow from the ice divide to the south (see above). Other striated sites in the Mt. Polley Mine region reveal northwesterly oriented striations. A number of striated sites were measured in the course of field work conducted in May 2013 and confirmed the existence of those two dominant ice movements in the Mt. Polley region.

Slides 26 and 27

The distribution of the relative abundance of chalcopyrite grains (0.25-0.5 mm; > 3.2 s.g.) normalized to 10 kg bulk till (<2 mm) is shown on a bedrock geology map (also, see legend in slide 28) compiled from Logan et al. (2010) and Massey et al. (2005) draped on a DEM (SRTM, http://eros.usgs.gov/).

The abundance of chalcopyrite grains in till is less at Mt. Polley than at Highland Valley and Gibraltar mines. However, the highest counts in this region (> 4 grains per 10 kg) are all located near the known mineralization at Mt. Polley Mine with one exception located 10 km to the northwest of the mine. The source of the chalcopyrite in that sample is undetermined since there is no known mineral occurrence in this region. Additional till sampling was completed in 2013 at less than one kilometre down-ice of the Northeast zone (Wight pit) to test for the presence of chalcopyrite in till.

Slide 28

In addition to chalcopyrite, gold grains were also identified in the fine sand- and silt-sized fractions of till (approximately 0.015 – 0.150 mm sized fraction) as part of the indicator mineral processing. Gold grain counts >32 grains per 10 kg of bulk sediment are located close to mineralization (<500 m) and up to approximately 7 km northwest (down-ice) from the mine. Given that fine gold is present in the mineralization at Mt. Polley (C.Rees, pers. comm. 2013), those results suggest that gold grains in till are indicative of porphyry mineralization at Mt. Polley.

The sample with the highest gold grain count (105 per 10 kg) is located in the north central sector of the study area. The source of the gold is undetermined but could be derived from the reworking of buried placer deposits (e.g. Bullion Pit) which stratigraphically occur below till of the last glaciation and therefore, might have been in part eroded by glaciers. Consequently, gold grains in till can be derived from different types of mineralization.

Slide 29

The dispersal of copper content in the clay-sized fraction of till at Mt. Polley extends ca. 4 km northwest (down-ice) from the mine with contents exceeding 463 ppm.

WOODJAM

Slide 30

Generalized geology of some key bedrock units in southern Interior Plateau and location of Woodjam.

Porphyry style mineralization at Woodjam is hosted in the Takomkane batholith and its satellite intrusions which have intruded the Nicola Group volcanic rocks.

Slide 31

Till and biogeochemical sample locations are depicted on a shaded digital elevation model produced from the SRTM data. No till samples were collected in a large sector southwest of the Takom and Southeast zones since the region is covered by thick ice-contact glaciofluvial sand and gravel deposits and associated diamicton.

The striation record of the Woodjam region includes evidence of the two dominant regional ice-flow events: a first movement to the southwest from the Cariboo Mountains (blue arrows) followed by northwestward ice flow (red arrows) from the ice-divide that was located to the south at glacial maximum.

Bedrock outcrops at Woodjam are limited in extent. The mineralization does not outcrop and only the propylitic alteration is visible on a few exposures (R. Sherlock, pers. comm. 2012).

Slide 32 and 33

The bedrock geology and legend along with the six mineralized zones identified at Woodjam (Deerhorn, Megabuck, Spellbound, South East, Three Firs, and Takom) are presented on slides 32 and 33. Bedrock geology is compiled from Massey et al. (2005), Logan et al. (2010) and unpublished digital data (P. Schiarizza, pers. comm.) draped on a DEM (SRTM, http://eros.usgs.gov/).

Deerhorn, Megabuck, Takom and Spellbound are copper-gold-molybdenum alkalic porphyry-type deposits present as quartz stockwork in the Nicola Group lithologies up to 1.5 km northwest of the Takomkane Batholith (Logan et al., 2007, 2010; Schiarizza et al., 2009a, b; Shroeter, 2009). The quartz stockwork are within contact aureoles of satellite intrusions of the batholith. The South East zone is a copper-molybdenum-gold calc-alkaline porphyry-type deposit within mafic to felsic phases of the Takomkane batholith (Schiarizza et al., 2009a, b; Logan et al., 2011; Anderson et al, 2012b).

In the winter of 2013, Consolidated Woodjam Copper announced the discovery of a sixth mineralized zone, the Three Firs, located approximately 2 km southwest from the Takom. The location of the Three Firs mineralized zone is approximate on the map.

The number of chalcopyrite grains (0.25-0.5 mm; >3.2 s.g.) normalized to 10 kg bulk till (<2 mm) are not as abundant as at Gibraltar Mine and Highland Valley Mine regions. However, chalcopyrite grain counts (>8 chalcopyrite grains per 10kg) are greatest from samples located within 2 km of known mineralized zones.

Slide 34

As for the Gibraltar Mine region, to demonstrate that the number of chalcopyrite grains in till can serve as indicators of buried porphyry mineralization, the same results are presented on a map without the geological background but with the reconstructed ice-flow movements. The map covers the equivalent of a 1:50 000 scale NTS map. By itself, the number of chalcopyrite grains in till is an indicator of the presence of porphyry-style mineralization in the Woodjam region. Was the Woodjam district undiscovered today, exploration focused within, and up-ice from, this regional mineralogical anomaly would greatly reduce exploration risk.

Slide 35

As part of this project, a number of potential indicator minerals of porphyry mineralization, including epidote, are being evaluated. The percentage of pistachio green epidote in the 0.25-0.5 mm size range of the heavy mineral concentrates (specific gravity > 3.2) could be indicative of propylitic alteration associated with porphyry mineralization (the modal estimates of the epidote have a +/- 10% precision). In the Woodjam region, samples with the most abundant epidote (>40%) are all located near the known mineralized zones. However, epidote is not solely derived from propylitic alteration and the percentage of epidote in samples collected in the Woodjam region distal from mineralization varies from almost nil and up to 40%. This first set of results suggests that the abundance of pistachio green epidote in the heavy mineral fraction of till could be indicative of propylitic alteration associated to porphyry mineralization. Future research will include a comparative study of the epidote composition associated to alteration and epidote associated to other sources (e.g., Nicola Group volcanic rocks that were metamorphosed to greenschist grade).

Slide 36

To illustrate the epidote abundance in the heavy mineral concentrates of till, the upper left photograph depicts 80% epidote in sample 11PMA-017A-1 collected near the Spellbound mineralized zone. The epidote is interpreted to be derived from propylitic alteration in bedrock as shown in the lower right photograph taken from the Takom zone at Woodjam.

Slide 37

As for the other study sites, the copper content of the clay-sized fraction of till is indicative of copper mineralization. Samples with the highest copper content are dominantly located near the known mineralized zones with notable exceptions located approximately 10 km northwest of Woodjam. The source of copper in till in that region is uncertain. More detailed sampling was completed there in 2013 to confirm and potentially define the source of copper.

Geochemical results from the four study sites indicate that the copper content of the clay-sized fraction of till is a regional indicator of porphyry mineralization. As part of an exploration program, once a high potential region is defined by till geochemistry, follow-up sampling could include the study of indicator minerals in till.

OTHER INDICATOR MINERALS OF INTEREST

Slide 38

In addition to chalcopyrite and epidote, other potential porphyry indicator minerals have been identified in till including and not limited to: Mn-epidote, tourmaline, apatite, jarosite, and garnet (andradite; not illustrated). For instance, jarosite and andradite were found to be indicator minerals of porphyry mineralization at the giant Pebble porphyry Cu-Au-Mo deposit in Alaska (Kelley et al., 2011; Eppinger et al., 2013).

CONCLUSION

Till geochemistry and mineralogy combined with the interpretation of the ice-flow history represents an effective method for detecting porphyry mineralization that was exposed to glacial erosion but is now covered by glacial sediments in the Interior Plateau of the Cordillera. As demonstrated here, the copper content of the clay-sized fraction and the relative abundance of chalcopyrite grains in the heavy mineral fraction of till (>3.2 sg, 0.25-0.5 mm) are indicators of porphyry mineralization present in till. Other minerals, such as green epidote, are potential indicators of alteration associated with the mineralization.

Future studies will focus on the compositions of selected indicator minerals in till and bedrock so as to assess the fertility of the porphyry system from which they were derived. Part of these studies will be conducted in collaboration with the University of Victoria and the Mineral Deposit Research Unit at the University of British Columbia. Additionally, this project will assess the utility of biogeochemistry of tree bark as a tool for exploring for and vectoring towards covered mineralization in complementarity with till geochemistry and mineralogy.

COLLABORATORS

Slide 39

Studies on indicator minerals in till on this project will be completed in collaboration with Dante Canil and students at the University of Victoria. A M.Sc. (L. Pisiak) and one undergraduate student (C.Grondahl) are underway to investigate and compare magnetite composition in till and bedrock samples from the Mt. Polley area. An additional study by C. Grondahl comparing chalcopyrite from till and bedrock at Mt. Polley may be undertaken.

A study agreement with the Mineral Deposit Research Unit (MDRU) (F. Bouzari) at the University of British Columbia for the study of apatite, rutile and titanite is currently in progress.

PUBLICATIONS

Slides 40, 41, and 42

A number of open files, one current research paper and talks related to this project have been published. The references are presented on slides 41 and 42. To obtain a free copy of those publications, visit the GEOSCAN web site at: http://geoscan.nrcan.gc.ca. Simply enter the open file number or the name and initials of the first author in the search box.

More publications (listed on slide 43) are currently under progress.

ACKNOWLEDGEMENTS

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Kamloops Exploration Group – Mineral Exploration in BC – Canada Begins Here

New TGI-4 Till Geochemistry and Mineralogy Results near the Highland Valley, Gibraltar, and Mount Polley Mines, and Woodjam District: An Aid to Search for Buried Porphyry Deposits

Alain Plouffe[1], Travis Ferbey[2], Bob Anderson[1], Sarah Hashmi[3] and Brent Ward[3]

SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD

1. Geological Survey of Canada; 2. BC Geological Survey Branch; 3. Simon Fraser University

Slide 1

Imperial Metals | Taseko | Consolidated Woodjam Copper | Gold Fields | Highland Valley Copper Teck | Canada

TGI4: Program and Project Overview

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

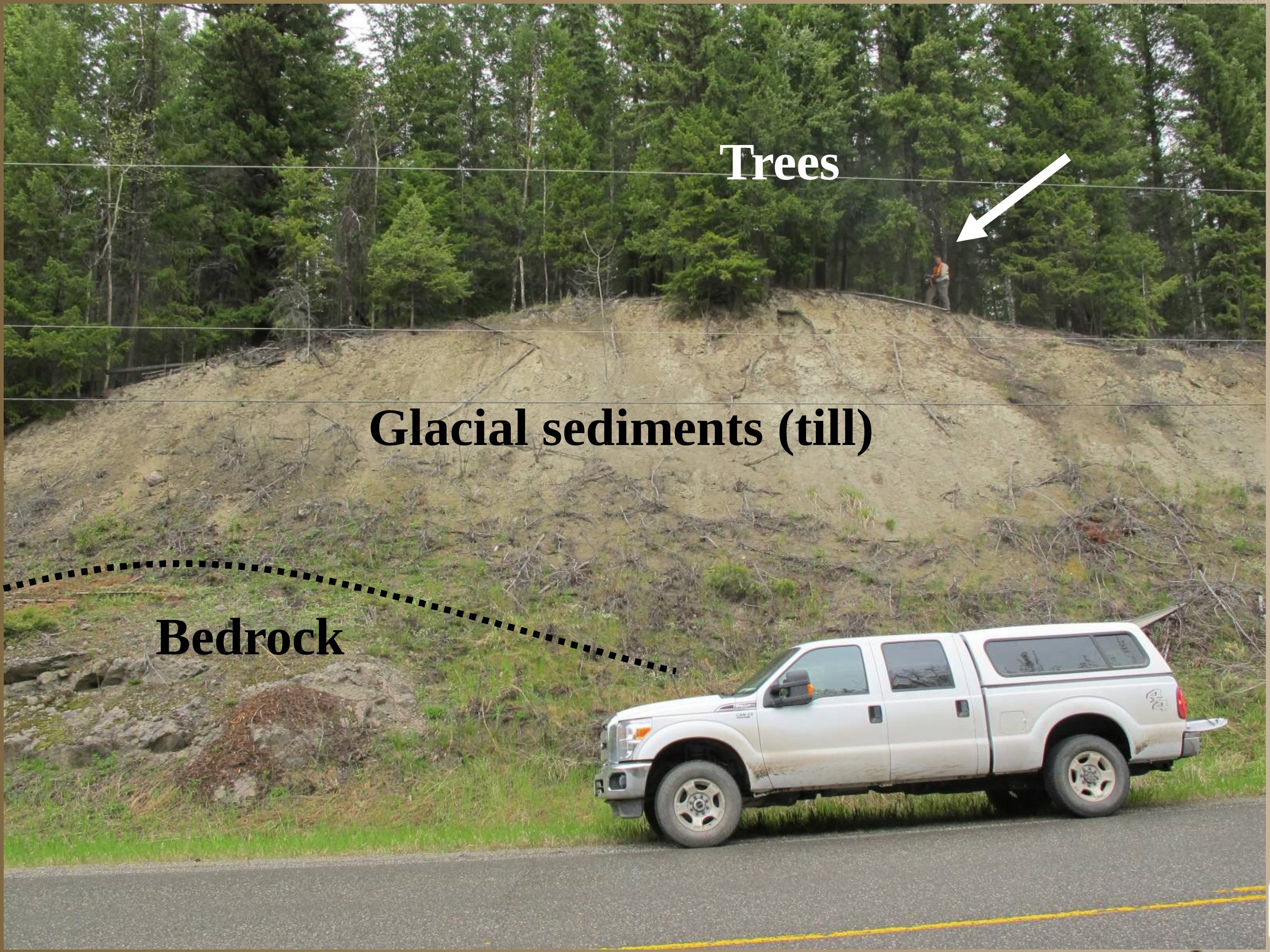
- **5 yrs; 2010-2015**
- **Ore-system oriented (VMS, Lode gold, Ni-Cu-PGE-Cr, Specialty metals, SEDEX, Uranium, Intrusion-related)**
- **Activities under Intrusion-related ore system**
- **Activities at: Gibraltar, Woodjam, Highland Valley District, Mt. Polley**

Objective

"Provide geoscience knowledge and develop innovative techniques for effective targeting of buried porphyry mineral deposit"

- **Till geochemistry and mineralogy, and biogeochemistry near porphyry systems**
- **Reconstruct ice-flow histories**
- **Detailed structural studies at Gibraltar (M.Sc. Thesis project; UBC)**
- **This presentation: first set of till geochemistry and mineralogy results**

Objective



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Gold Fields
Consolidated Woodjam Copper

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Highland Valley Copper
Teck

Gerald Grubisa, Chris LeClair, Mathieu Veillette, and Ron Grayden
(Teck Highland Valley Copper Partnership)

Imperial Metals

Amber Marko (Imperial Metals Corporation)

ACKNOWLEDGEMENTS

Field assistants:

K.-L. Robillard

D. Sacco

N. Evanoff

TILL SAMPLE SURVEY

Average sample spacing: 1-2 km

TILL SAMPLE PROCESSING FLOW CHART

Bulk till sample

ca. 10 kg

Heavy mineral separation (0.25 - 2 mm; s.g. >3.2 and 3.2 - 2.8)

Identification of indicator minerals

ca. 2 kg

clay-sized fraction (<0.002 mm)

silt and clay-sized fraction (<0.063 mm)

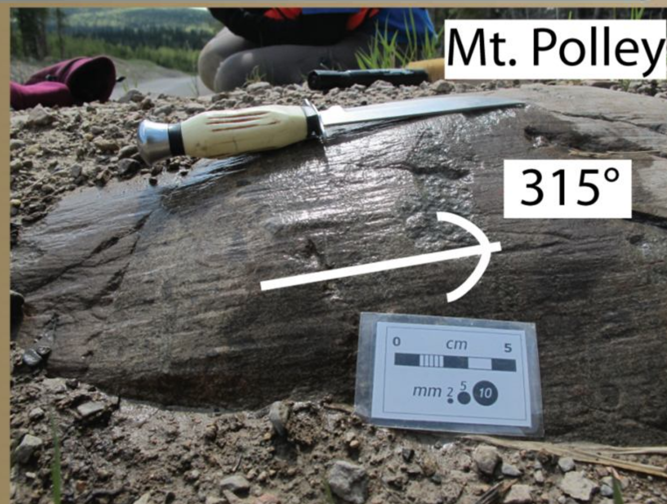
Aqua regia
ICP-MS
(trace elements)

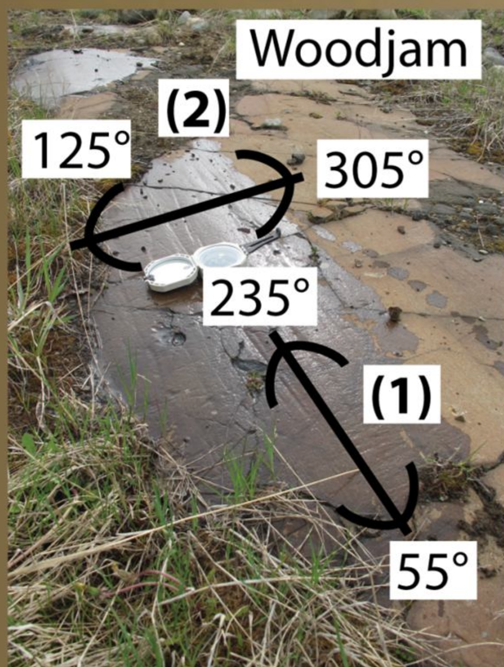
$LiBO_2$ / LiB_4O_7 HNO_3 fusion
ICP-ES
(major and trace elements)

$LiBO_2$ / LiB_4O_7 HNO_3 fusion
ICP-ES

QUALITY ASSURANCE / QUALITY CONTROL

ICE-FLOW INDICATORS

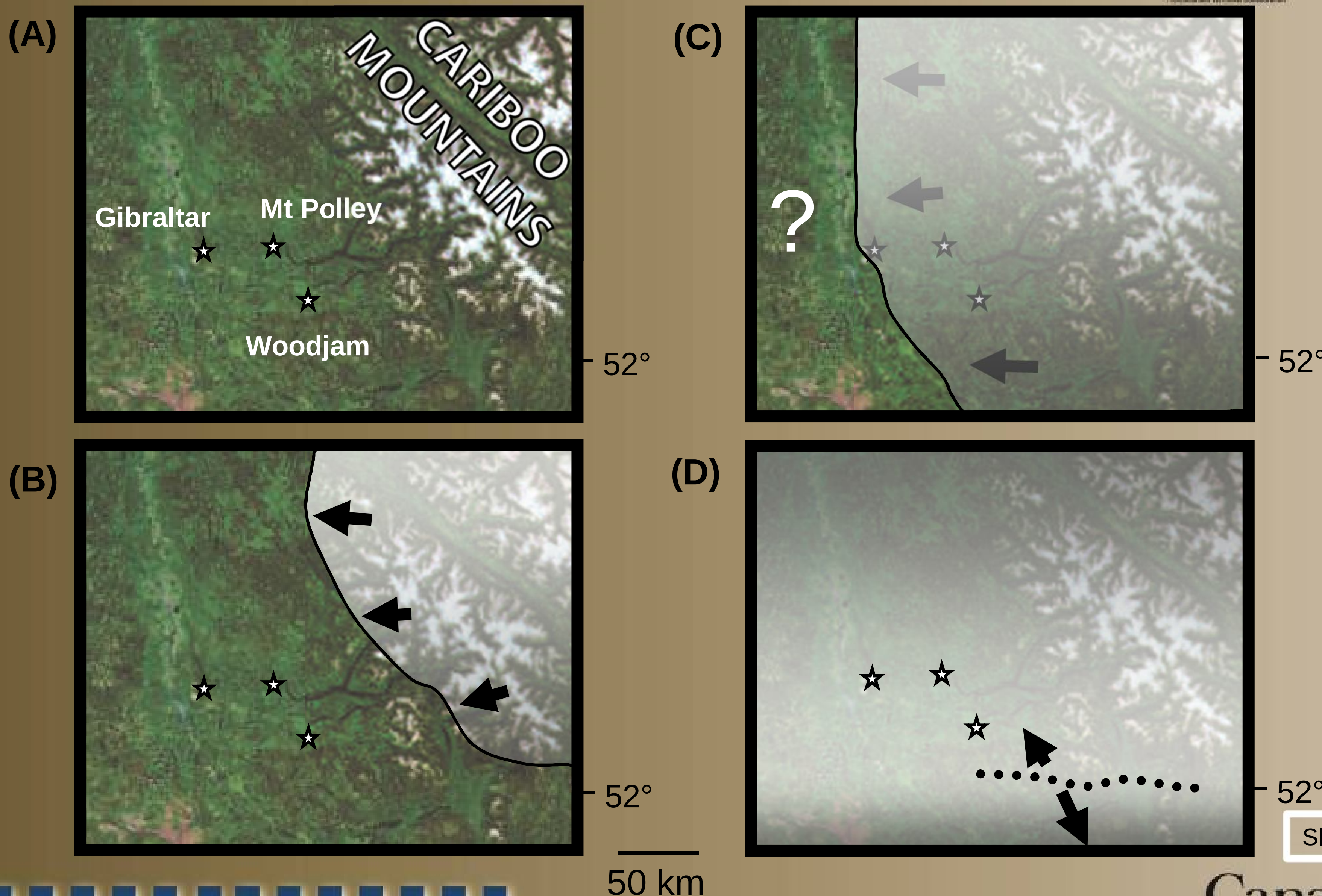




ICE-FLOW HISTORY

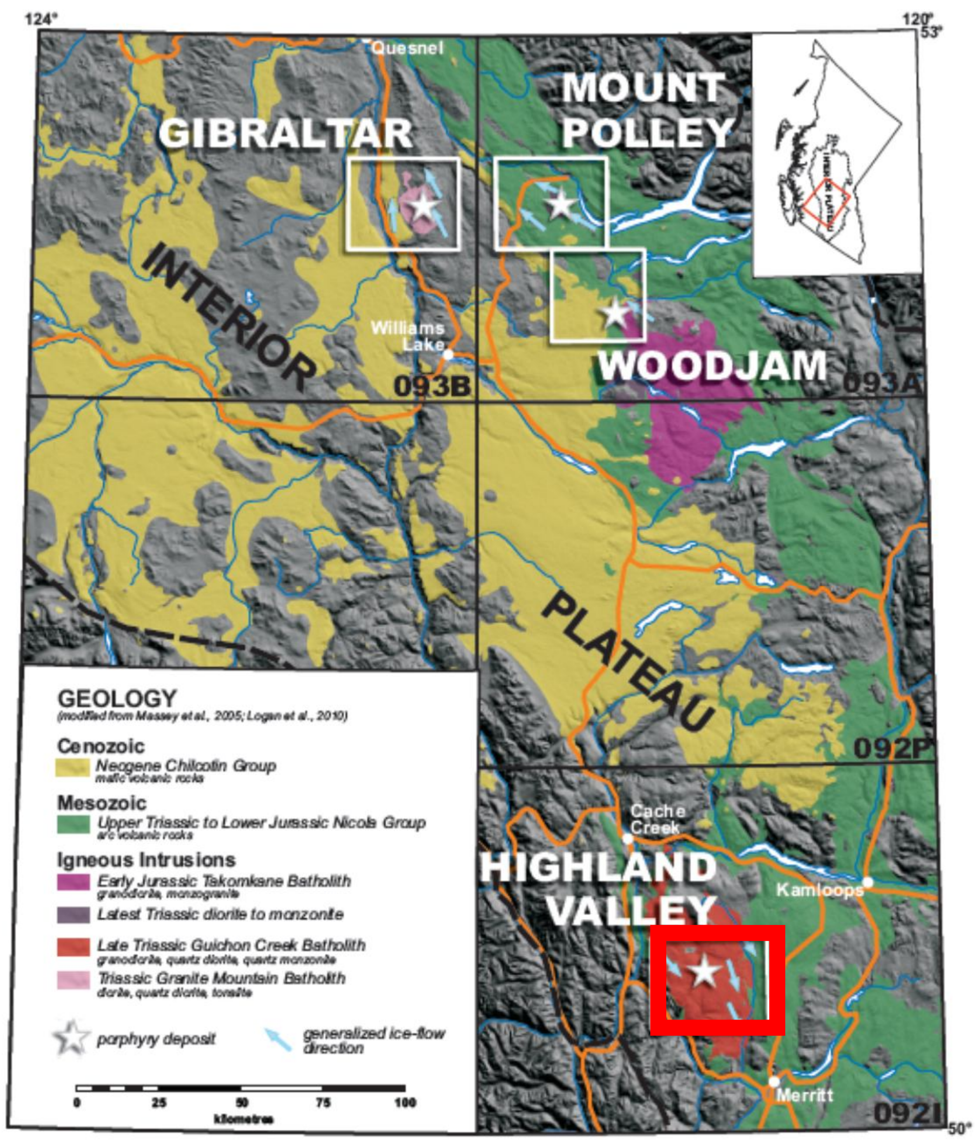
Canada

ICE-FLOW HISTORY



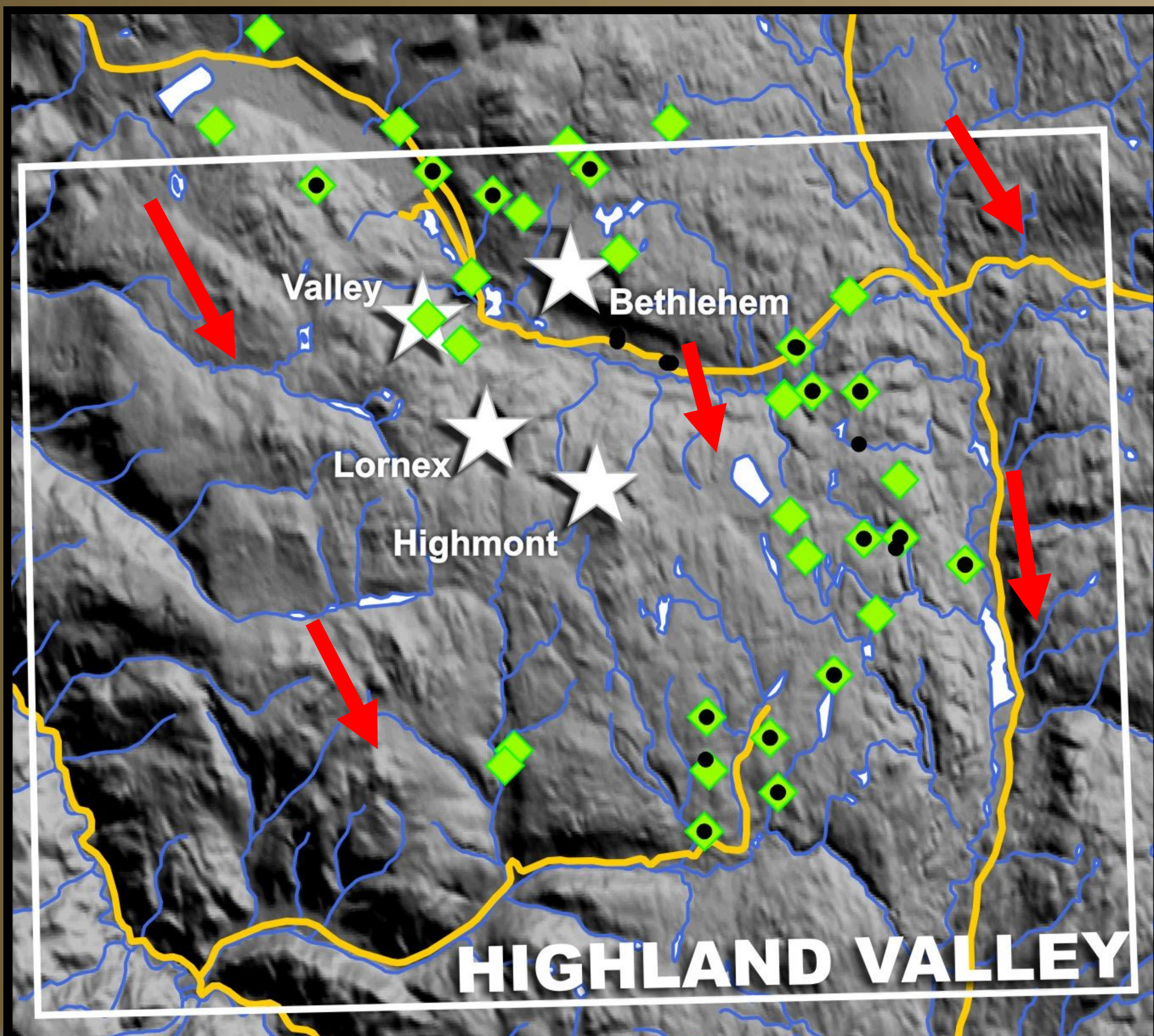
STUDY SITES: Highland Valley

Some bedrock units in south central BC



Canada

HIGHLAND VALLEY: ice flow

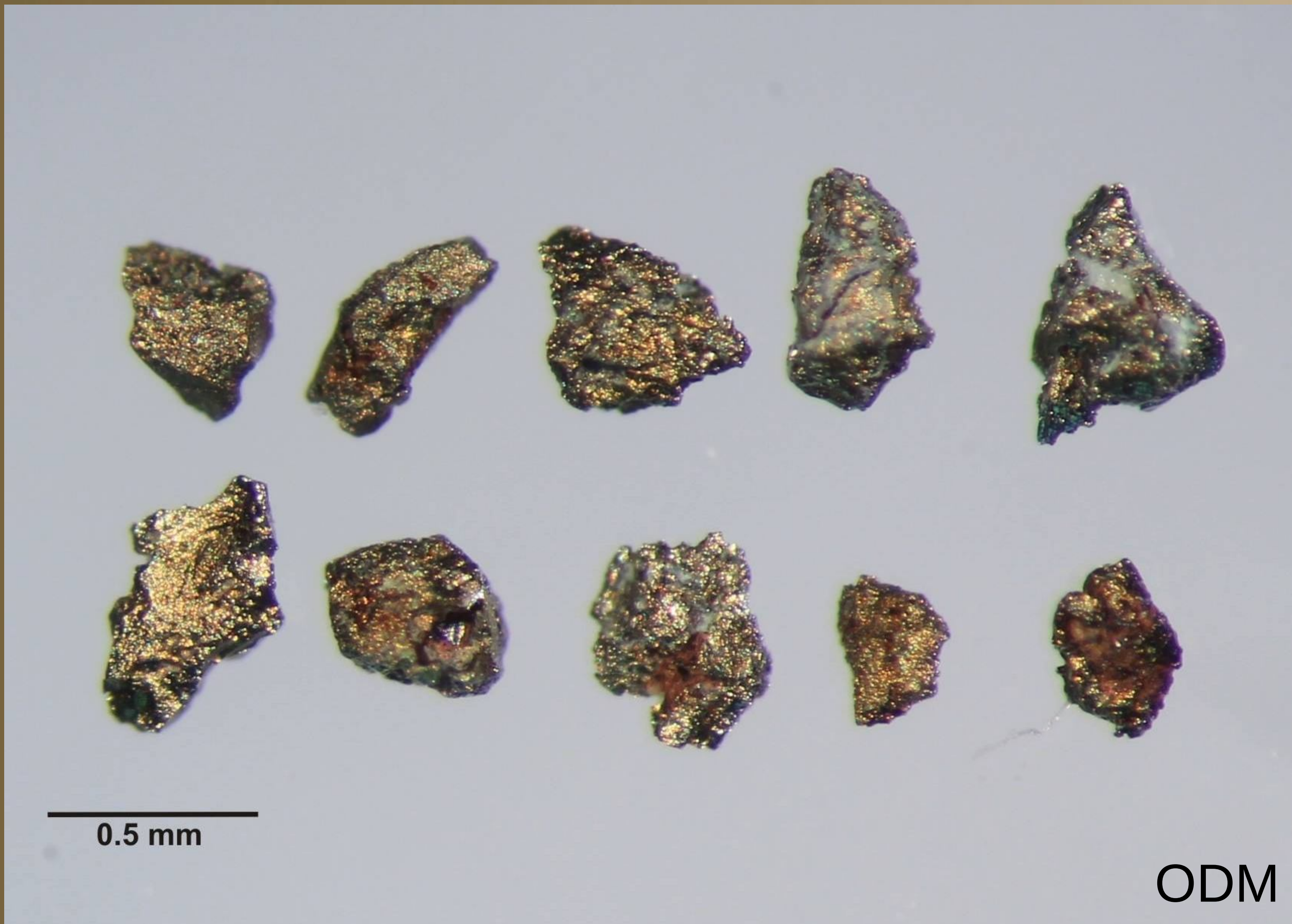


SAMPLES

- Biogeochemistry
- Till matrix geochemistry
  Till mineral separation
- Porphyry mineralization
- Generalized ice-flow
- Roads

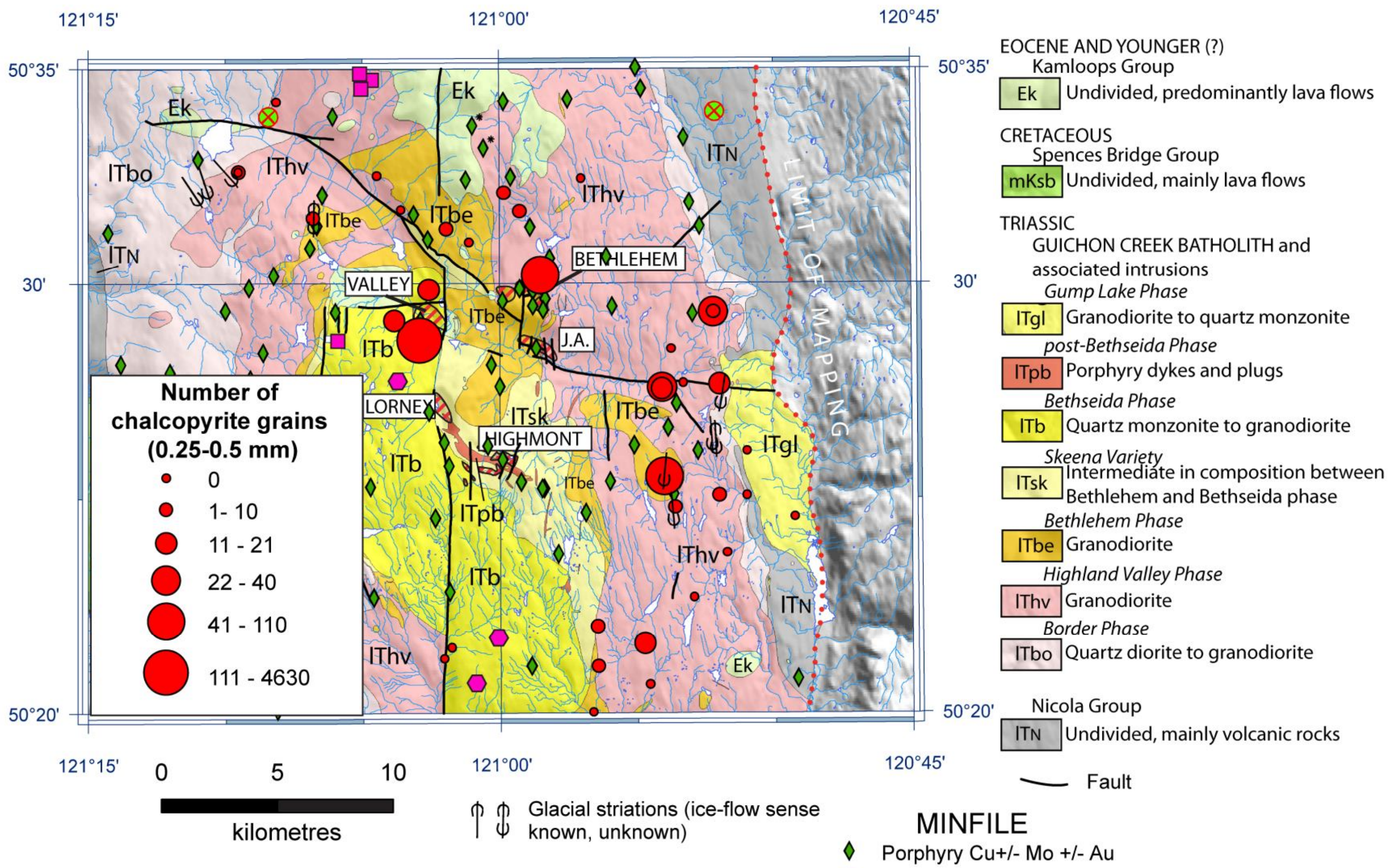
10 km

HIGHLAND VALLEY: chalcopyrite in till



HIGHLAND VALLEY: chalcopyrite

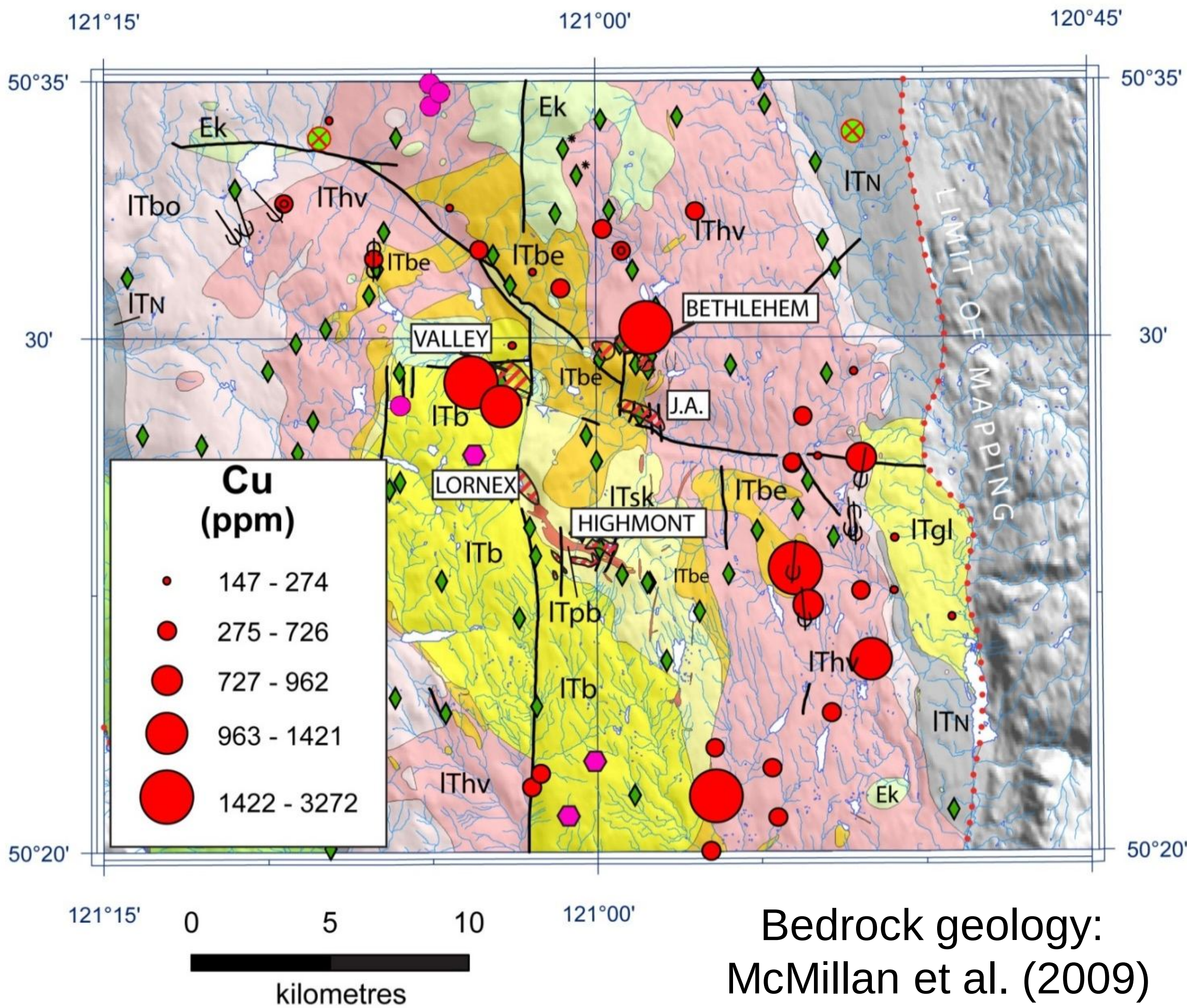
Number of chalcopyrite grains / 10 kg of bulk sediment < 2 mm



Bedrock geology:
McMillan et al. (2009)

HIGHLAND VALLEY: copper

Cu in the clay-sized fraction (<0.002 mm) of till

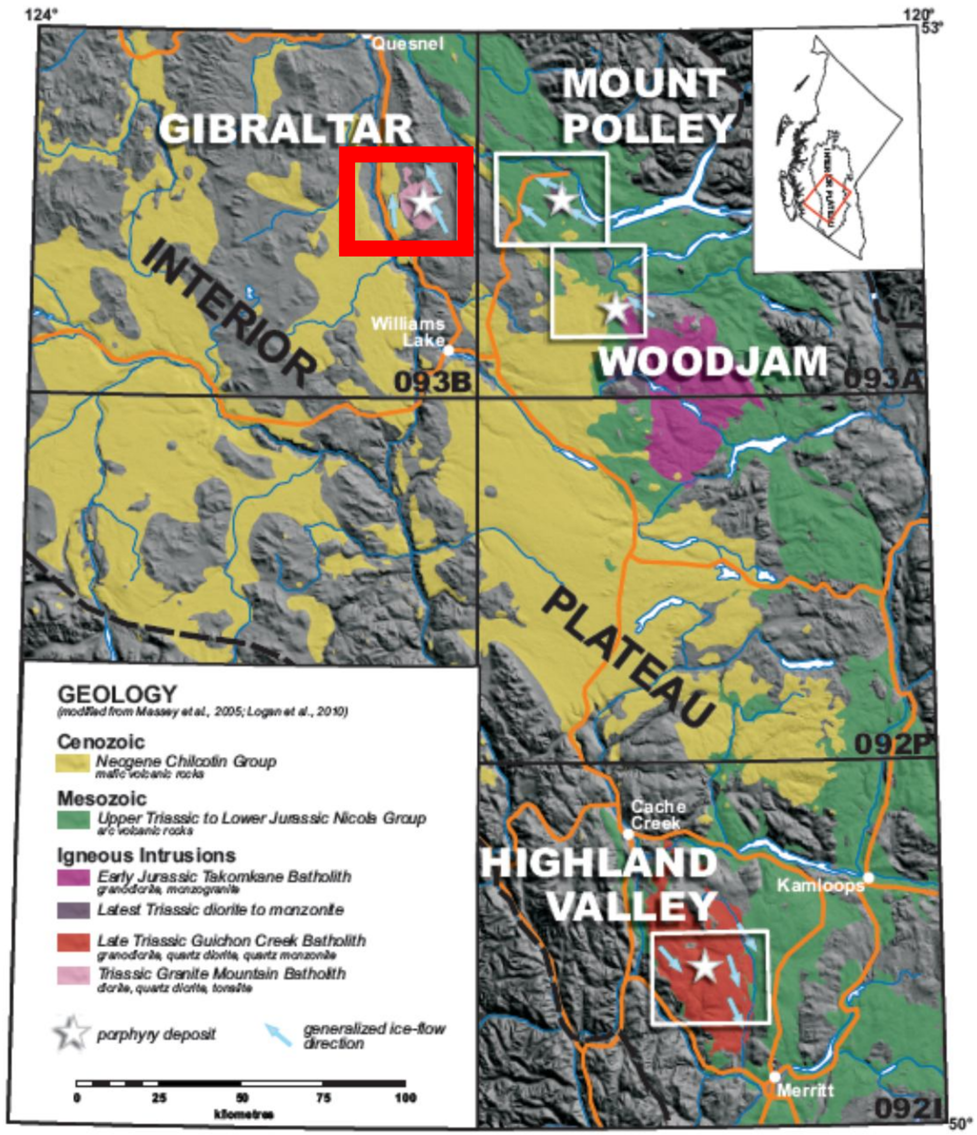


Bedrock geology: McMillan et al. (2009)

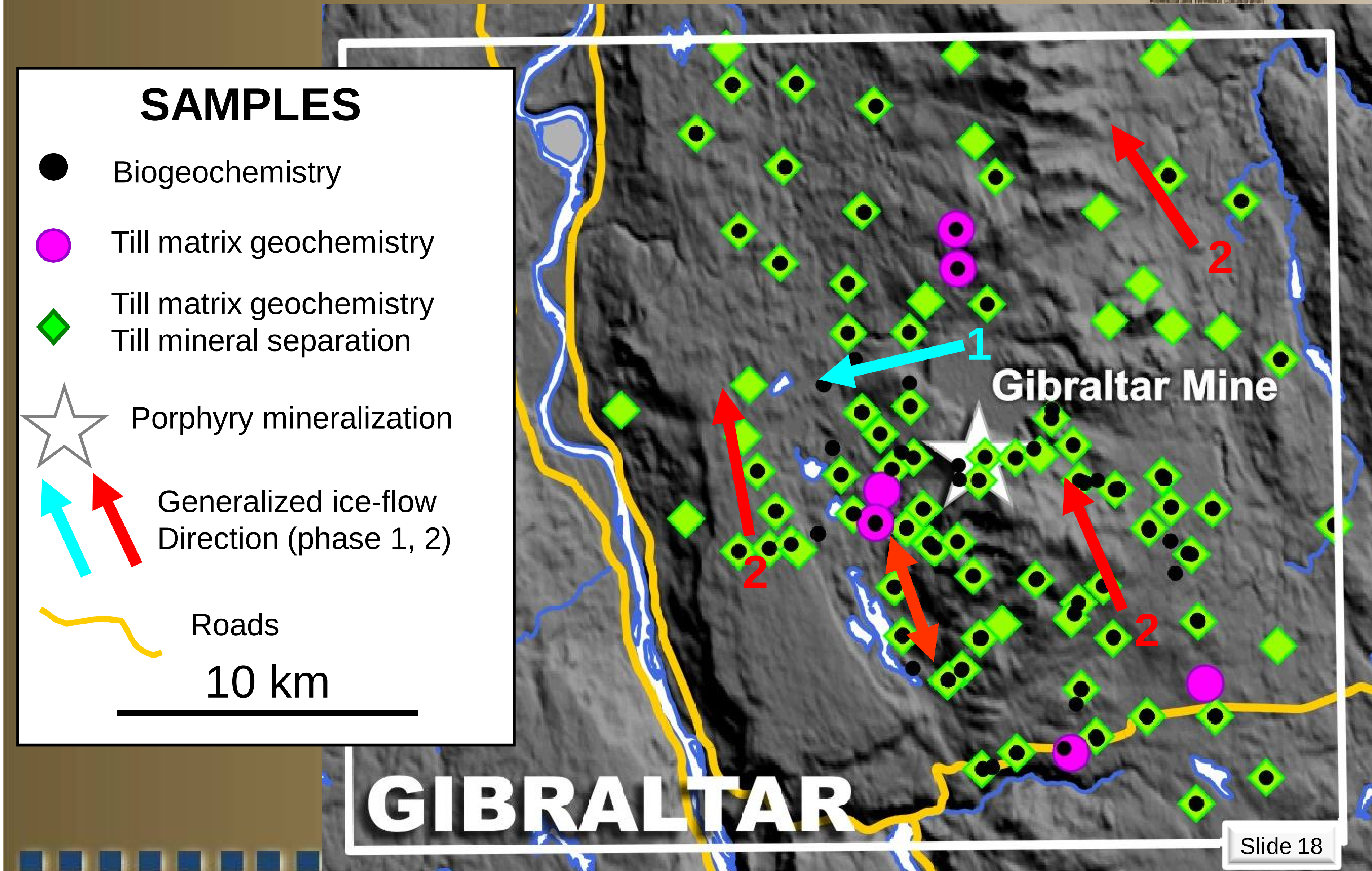
$LiBO_2$ / $Li_2B_4O_7$ HNO_3 fusion ICP-ES

STUDY SITES: Gibraltar

Some bedrock units in south central BC

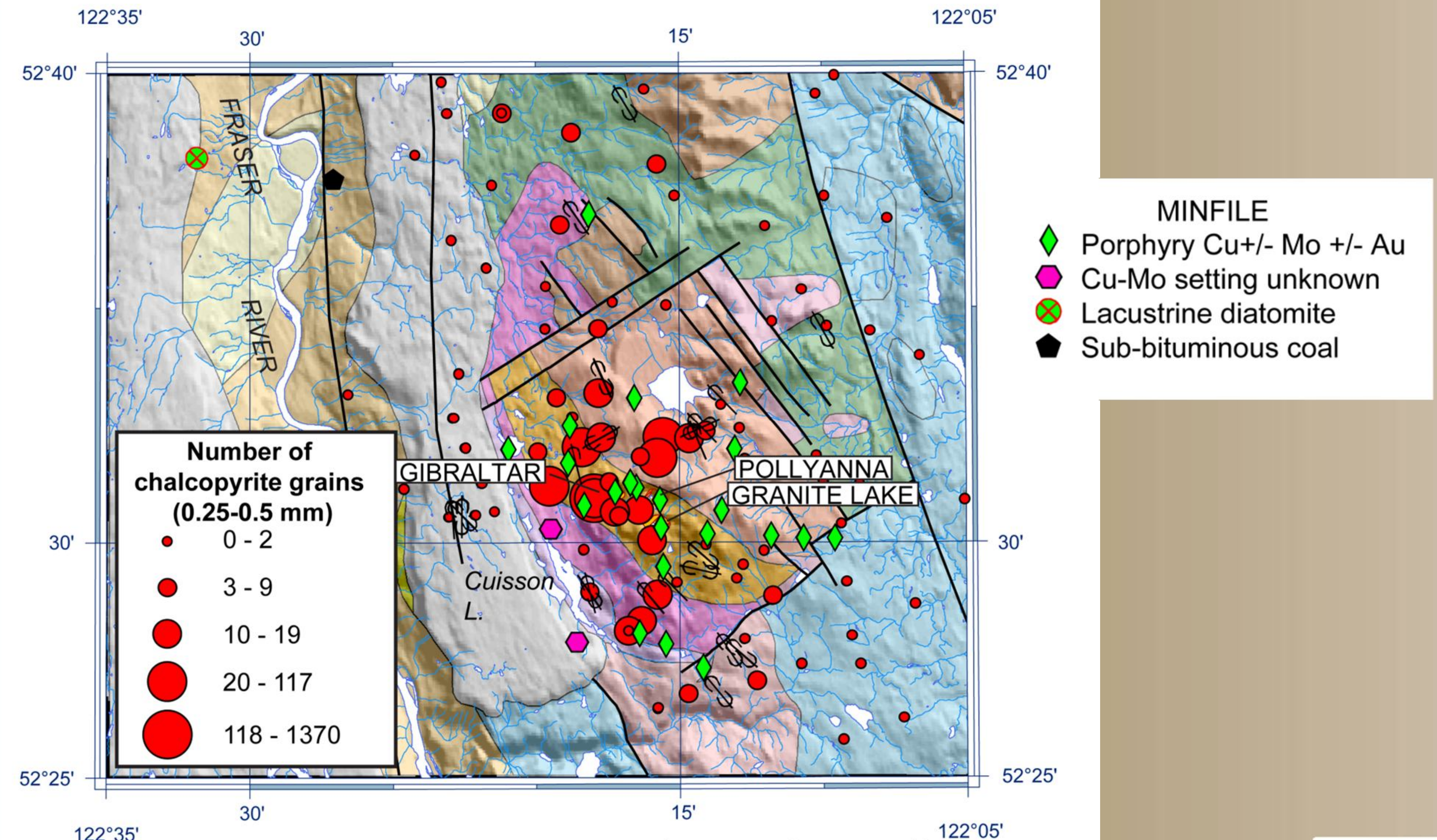


GIBRALTAR: ice flow



GIBRALTAR: chalcopyrite

Number of chalcopyrite grains / 10 kg of bulk sediment < 2 mm



Bedrock geology: Ash et al. (1999b), Massey et al. (2005) and P. Schiarizza unpublished data (2012); bedrock geology legend in next slide

GIBRALTAR: bedrock geology legend

STRATIFIED ROCKS

Neogene

Chilcotin Group

NC — Basaltic volcanic rocks with lesser sedimentary rocks

Oligocene to Pliocene

OPs — Conglomerate

Eocene to Oligocene

Endako Group

EEv — Basaltic volcanic rocks with lesser sedimentary rocks

EEs — Sedimentary rocks

Quesnel Terrane

Ashcroft Formation

lmJs — Polymictic volcanic and plutonic-clast conglomerate

Upper Triassic and Lower Jurassic

Nicola Group

uTrN — Volcanic sandstone-siltstone

Cache Creek Terrane

Carboniferous - Lower Jurassic

Cache Creek Complex

PMCC — Undivided marine sedimentary and volcanic rocks

METAMORPHIC ROCKS

Eocene ?

MTm — Chlorite-sericite-quartz-feldspar schist; contain zones of foliated granodiorite

INTRUSIVE ROCKS

Middle Cretaceous

Sheridan stock (ca. 108 Ma)

Kqd — Quartz diorite, quartz monzonite, granodiorite, granite

Late Triassic

Granite Mountain Batholith (ca. 215 Ma)

TrJGb — Quartz diorite, tonalite (Border phase)

LTrGmqd — Melanocratic quartz diorite

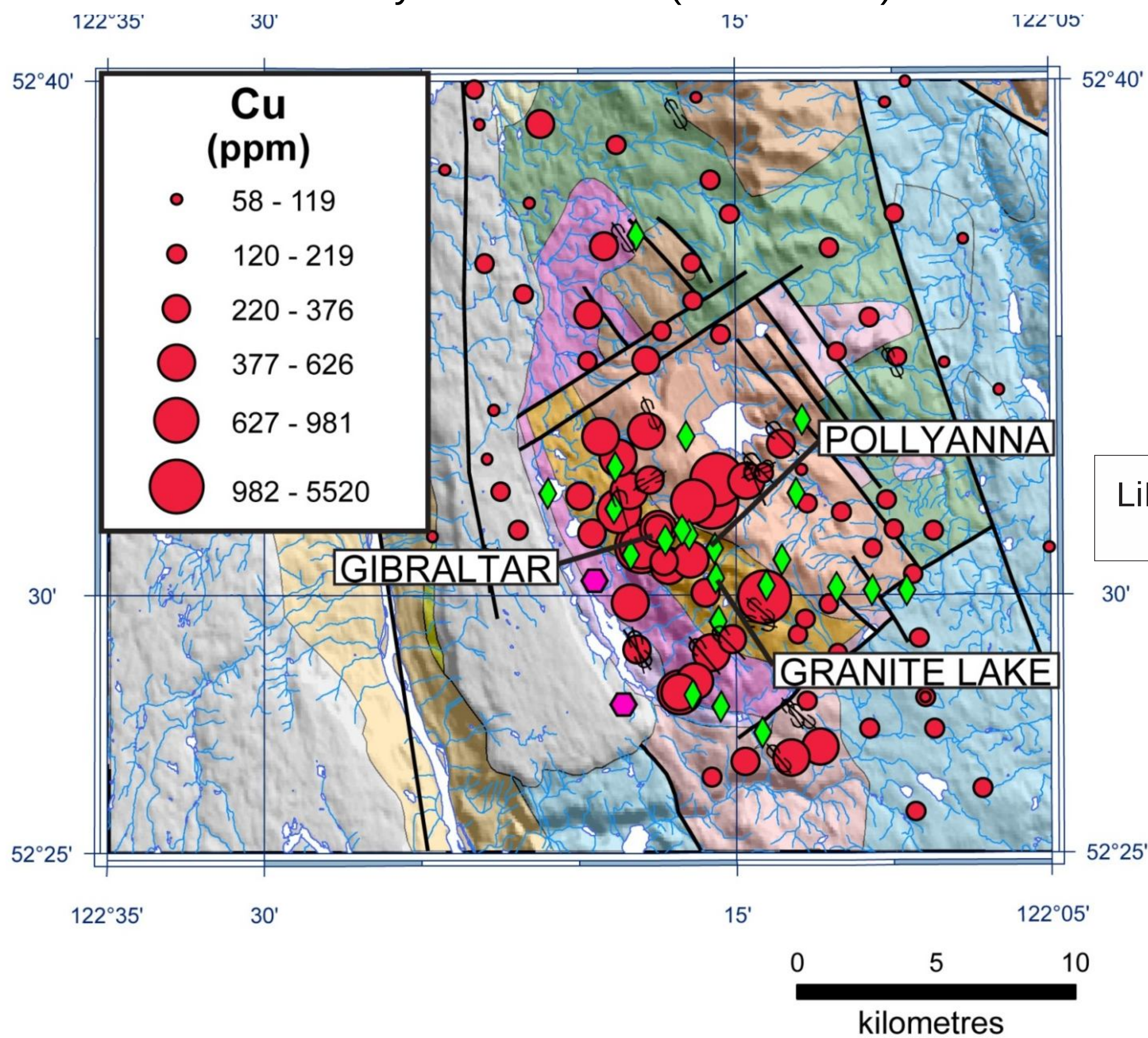
LTrGft — Foliated tonalite (Mine phase)

LTrGlt — Leucocratic tonalite, trondhjemite (Granite Mountain phase)

Bedrock geology: Ash et al. (1999b), Massey et al. (2005) and P. Schiarizza unpublished data (2012)

GIBRALTAR: copper

Cu in the clay-sized fraction (<0.002 mm) of till

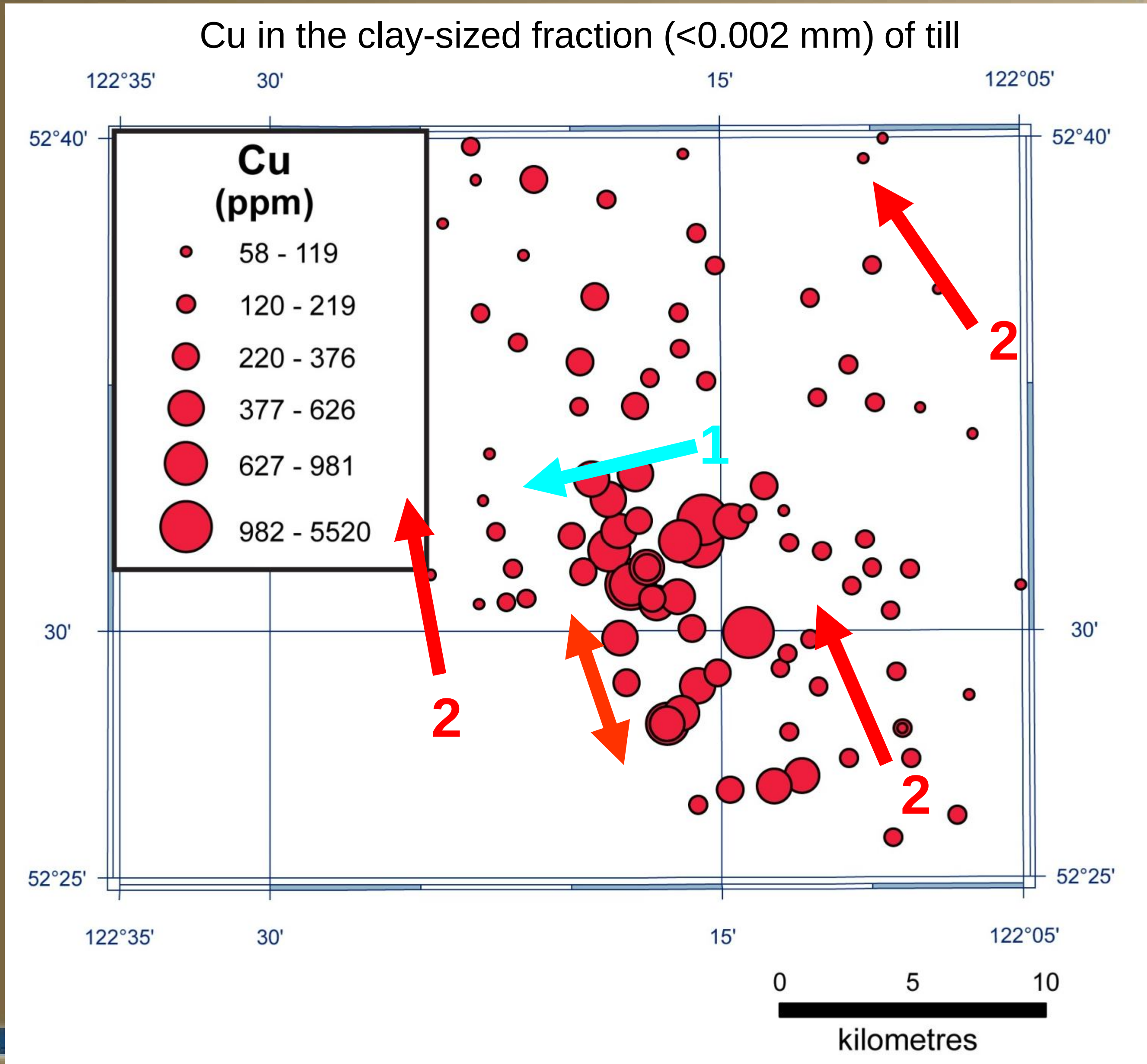


MINFILE
- Porphyry Cu+/- Mo +/- Au
- Cu-Mo setting unknown
- Lacustrine diatomite
- Sub-bituminous coal

$LiBO_2$ / LiB_4O_7 HNO_3 fusion
ICP-ES

Canada

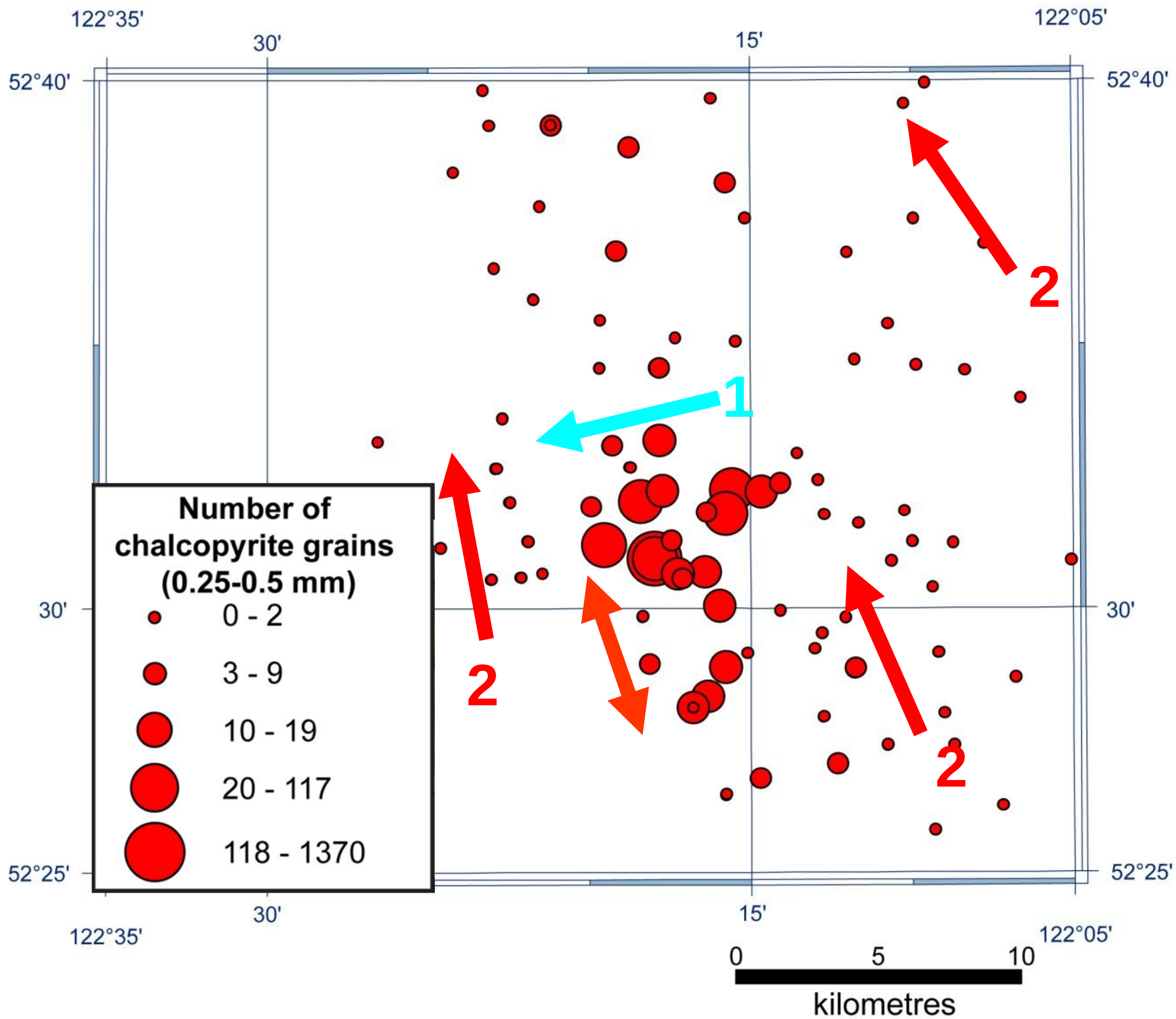
GIBRALTAR: copper



Canada

GIBRALTAR: chalcopyrite

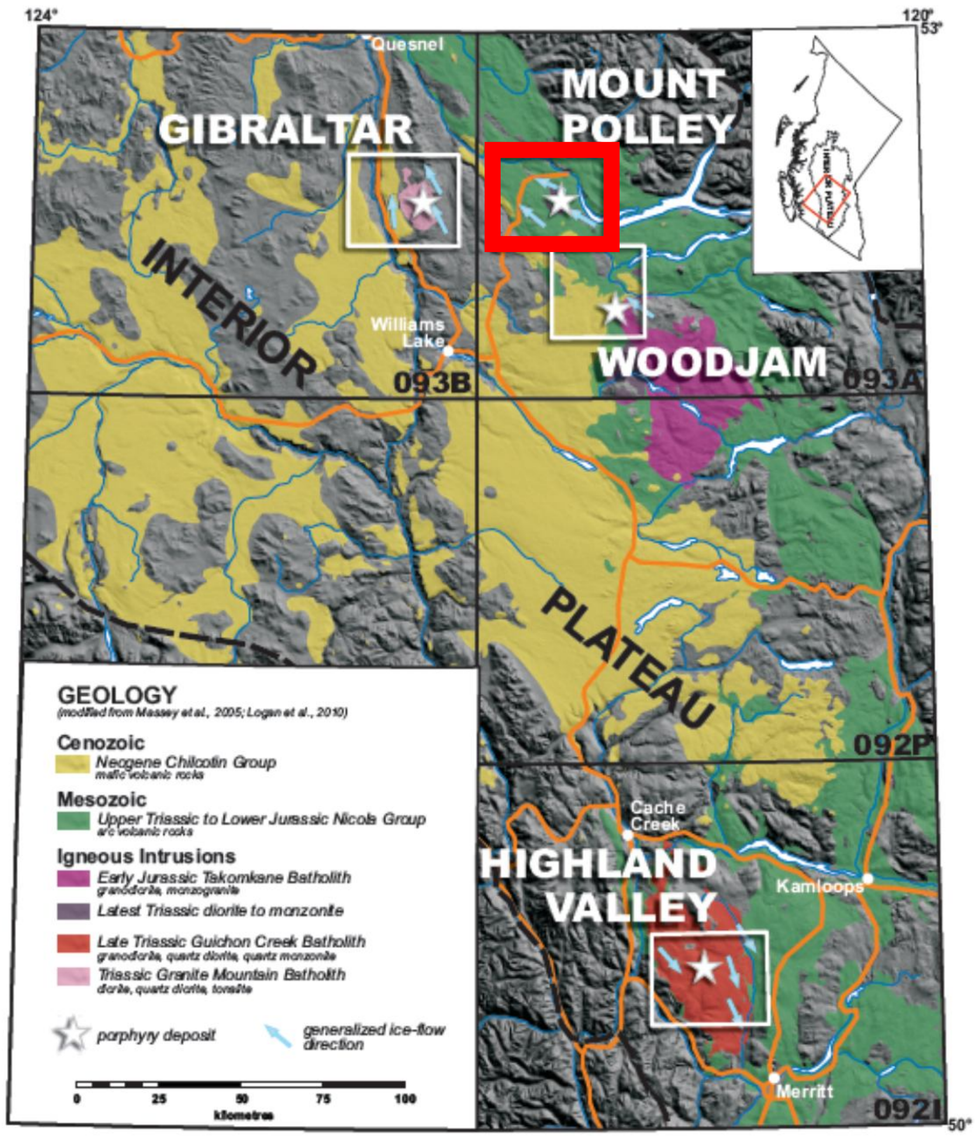
Number of chalcopyrite grains / 10 kg of bulk sediments <2 mm



Canada

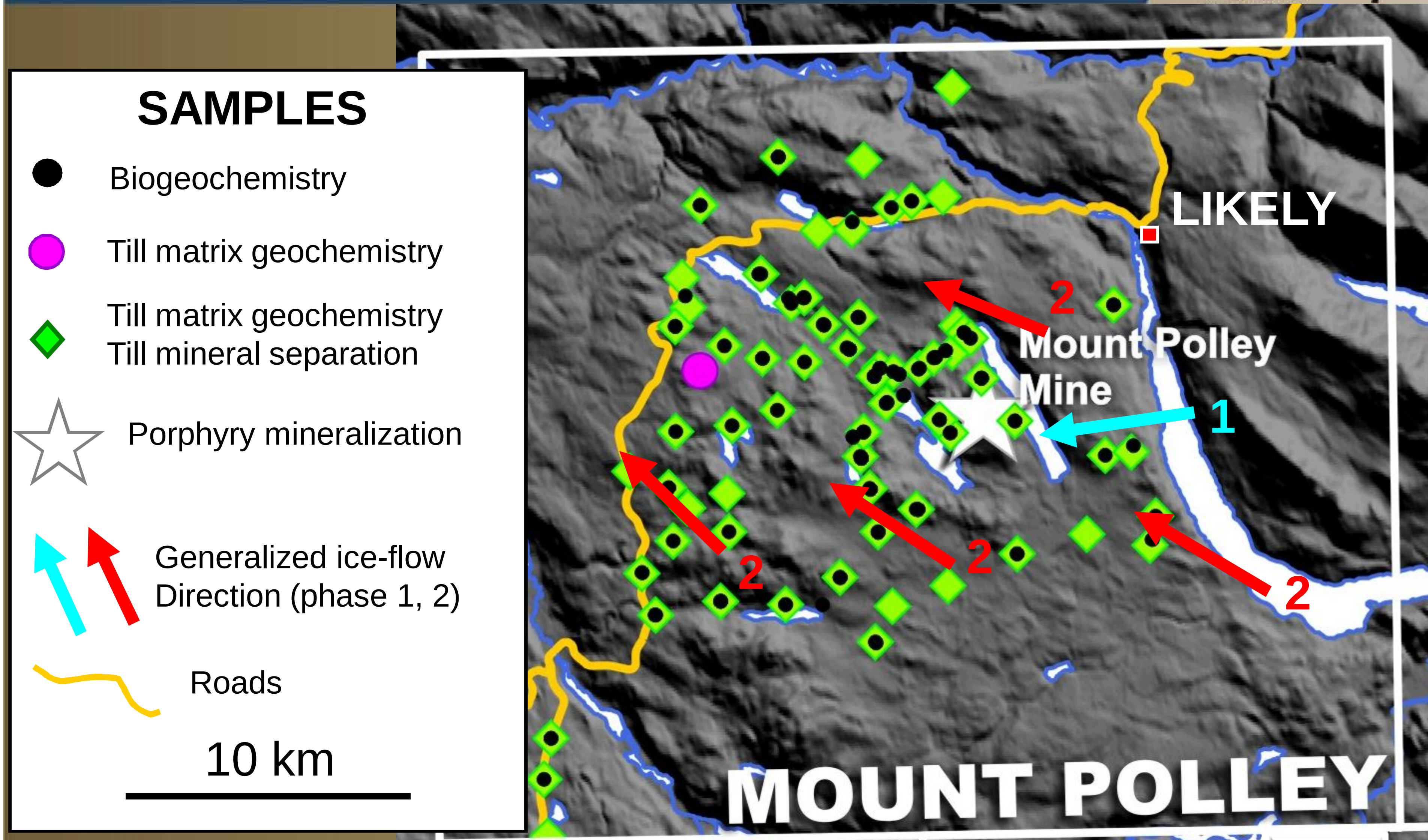
STUDY SITES: Mt. Polley

Some bedrock units in south central BC



Canada

Mt. POLLEY: ice flow



M.Sc. Thesis, Sarah Hashmi, SFU (B.C. Ward)

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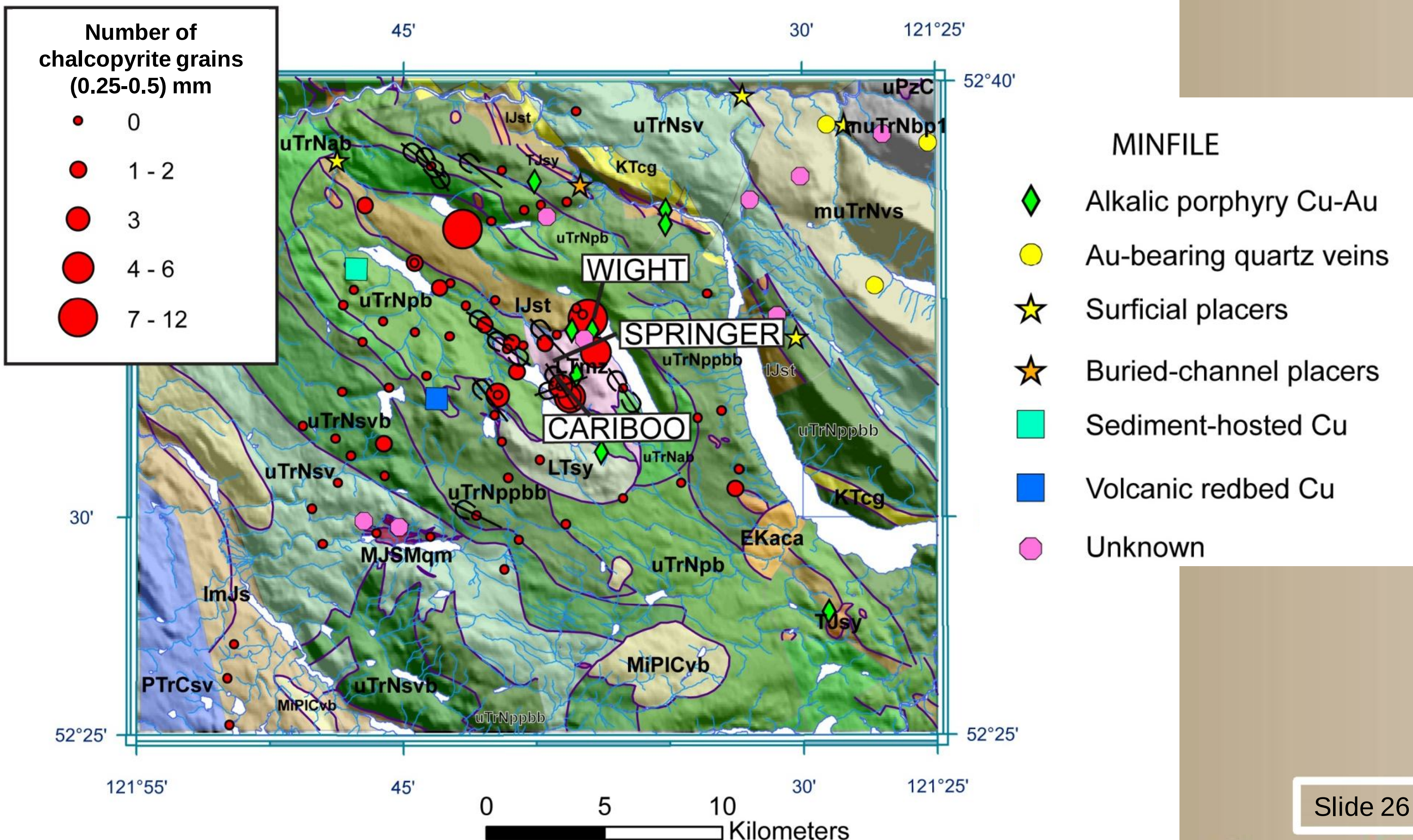
Mt. POLLEY: chalcopyrite

Number of chalcopyrite grains / 10 kg of bulk sediments <2 mm



Bedrock geology: Massey et al. (2005) and Logan et al. (2010); bedrock geology legend in next slide

Canada

Mt. Polley: bedrock geology legend

Quaternary to Neogene
Chilcotin Group
MiPlCvb Basaltic volcanic rocks

Paleogene
Kamloops Group
EKaca Calc-alkaline volcanic rocks

Cretaceous
Bowron River Coal Beds
KTcg Undivided sedimentary rocks

Middle Jurassic
Ste. Marie Plutonic Suite
MJSMqm Quartz monzonitic intrusive rocks

Lower to Middle Jurassic
lmJs Undivided sedimentary rocks

Lower Jurassic
Ashcroft Formation
lJst Argillite, greywacke, wacke, conglomerate turbidites

Slide Mountain Terrane
Carboniferous to Permian
Crooked Amphibolite
uPzC Serpentinite ultramafic rocks

Quesnel Terrane
Late Triassic to Early Jurassic
TJsy Syenitic to monzonitic intrusive rocks
LTsy Syenitic intrusive rocks
Mt. Polley Intrusive Complex
LTmz Syenitic to monzodioritic intrusive rocks

Upper Triassic
Nicola Group
uTrNsvb Basaltic volcaniclastic rocks
uTrNppbb Basaltic volcanic rocks
uTrNab Basaltic volcanic rocks
uTrNpb Volcaniclastic rocks
uTrNsv Undivided sedimentary rocks

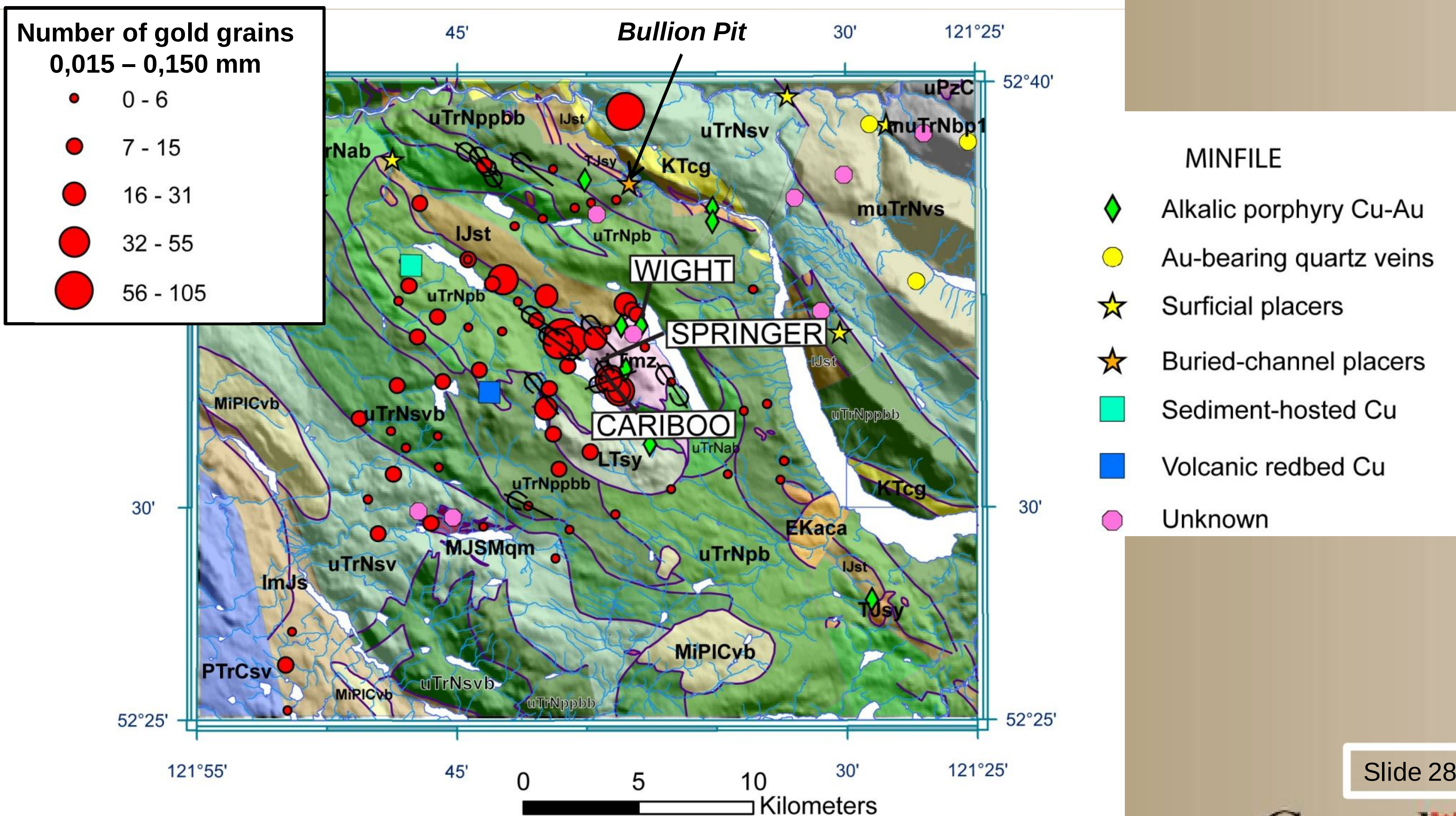
Middle to Upper Triassic
Nicola Group
muTrNbp1 Undivided sedimentary rocks
muTrNvs Transitional mixed volcanic and sedimentary rocks

Cache Creek Terrane
Permian to Triassic
Cache Creek Complex
PTrCsv Marine sedimentary and volcanic rocks

Bedrock geology: Massey et al. (2005) and Logan et al. (2010)

Mt. POLLEY: gold grains

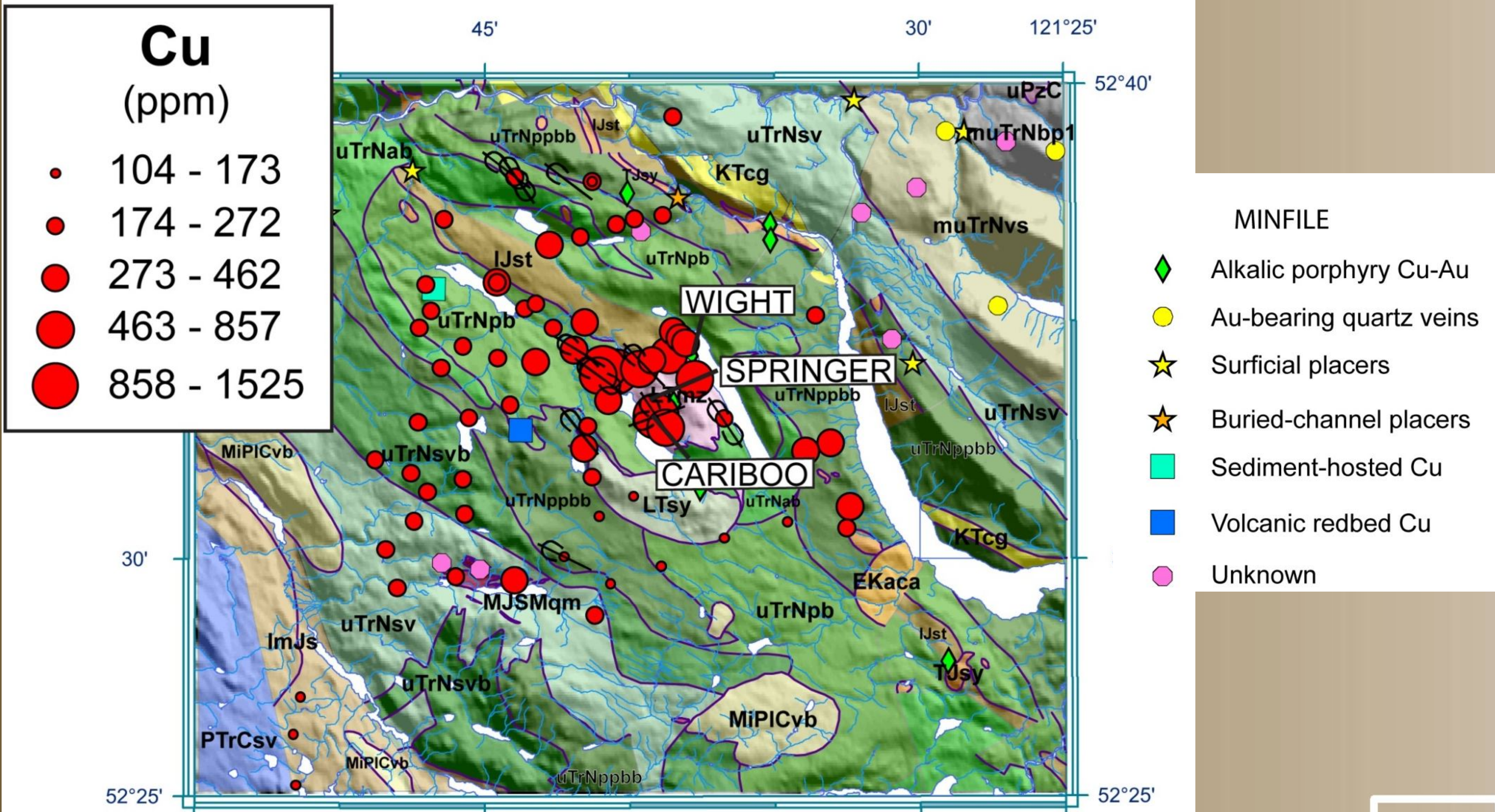
Number of gold grains / 10 kg of bulk sediments <2 mm



Canada

Mt. POLLEY: copper

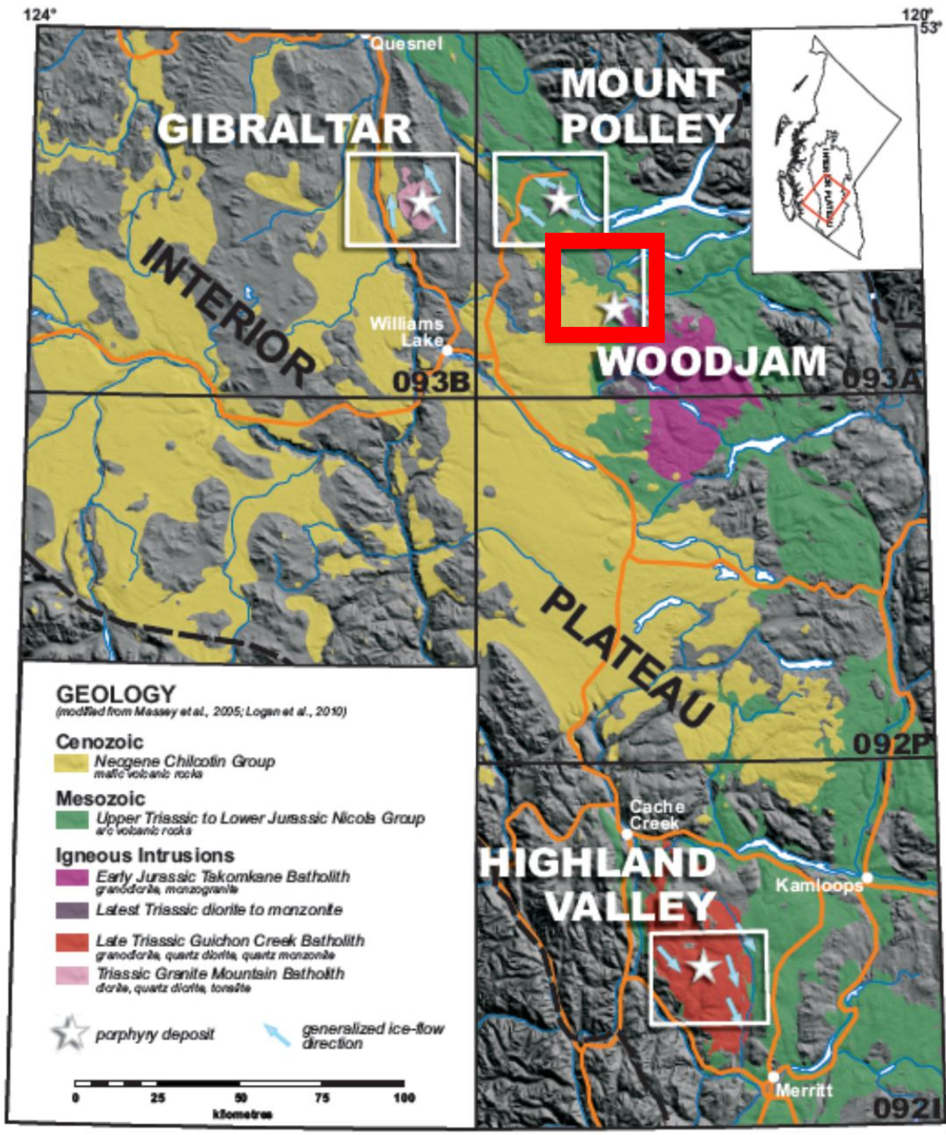
Cu in the clay-sized fraction (< 0.002 mm) of till



LiBO$_2$ / LiB$_4$O$_7$ HNO$_3$ fusion
ICP-ES

STUDY SITES: Woodjam

Some bedrock units in south central BC



Canada

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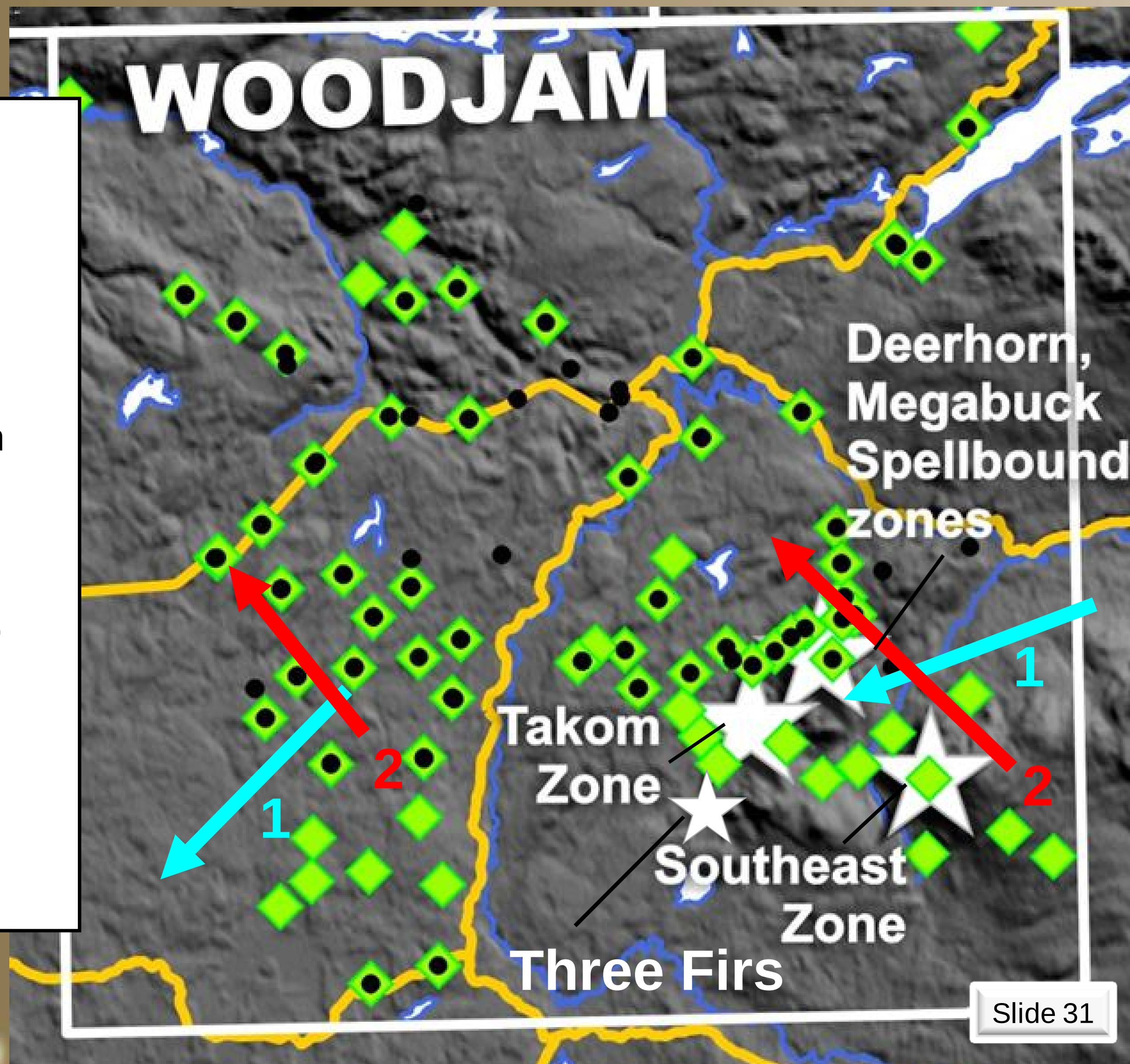
WOODJAM: ice flow

SAMPLES

- Biogeochemistry
- Till matrix geochemistry
  Till mineral separation
- Porphyry mineralization
- Generalized ice-flow Direction (phase 1, 2)
- Roads

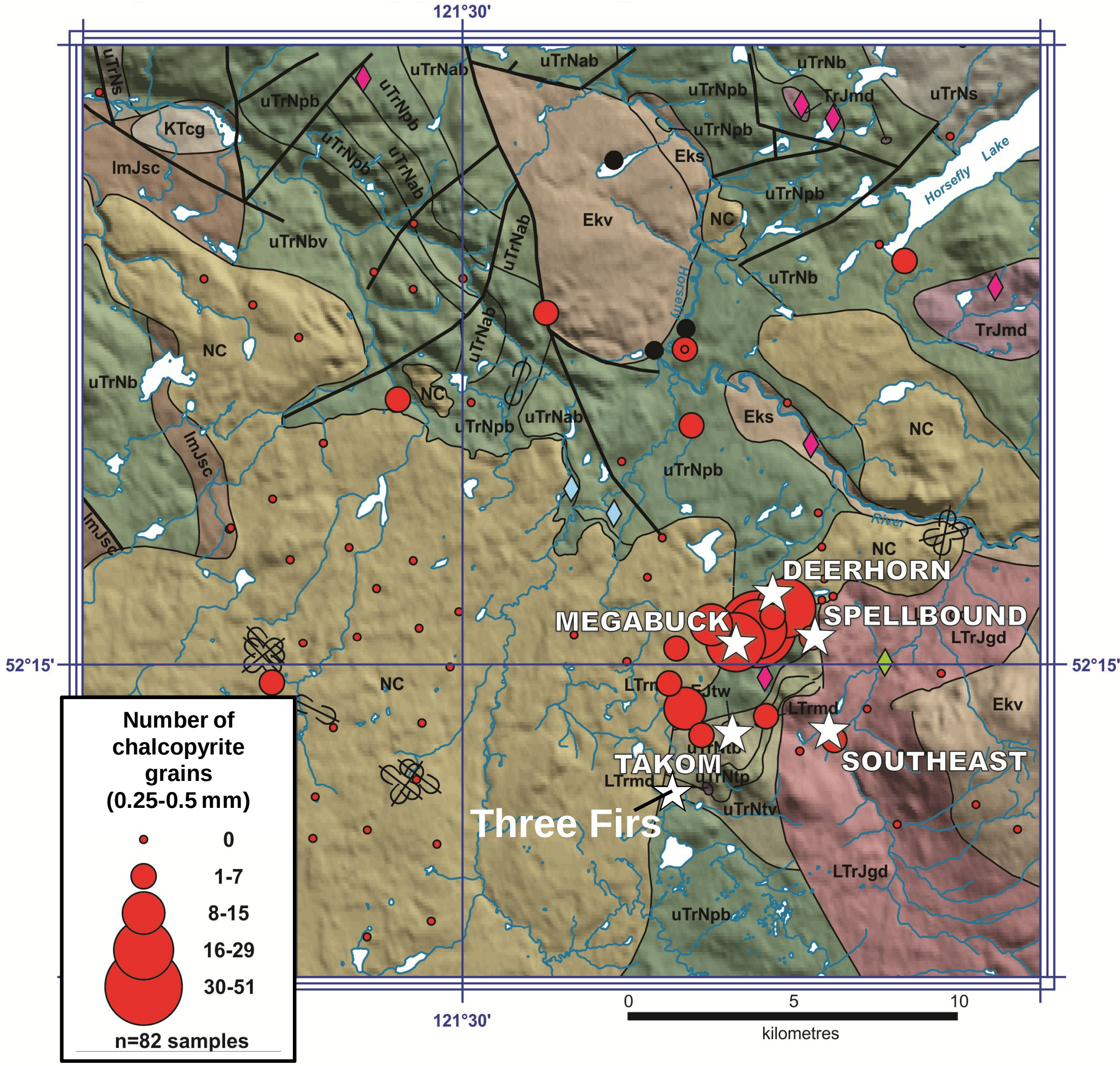
10 km



WOODJAM: chalcopyrite

TGI 4 Ore Systems

Number of chalcopyrite grains / 10 kg of bulk sediment <2 mm



MINFILE

- calc-alkaline Cu +/-Mo+/-Au
- alkalic porphyry Cu-Au
- volcanic redbed Cu
- placer Au
- porphyry mineralization

Bedrock geology: Massey et al. (2005), Logan et al. (2010), and P. Schiarizza unpublished data (2012); bedrock geology legend in next slide

Canada

WOODJAM: bedrock geology legend

GEOLOGY
(Massey et al., 2005; Logan et al., 2010; P. Schiarizza, unpublished data, 2012)

STRATIFIED ROCKS

Neogene
Chilcotin Group
- **NC** Basaltic volcanic rocks

Eocene
Kamloops Group
- **Eks** Shale, siltstone and sandstone
- **Ekv** Andesite, trachyandesite

Cretaceous
- **KTcg** Undivided sedimentary rocks

Jurassic
- **lmJsc** Undivided sedimentary rocks

Triassic
Nicola Group
- **uTrNpb** Polymict volcanic breccia
- **uTrNs** Undivided sedimentary rocks
- **uTrNbv** Pyroxene and feldspar phyric basalt breccias, volcaniclastic units and sandstone
- **uTrNab** Analcime basalt breccias, tuffs and flows, fine-grained volcaniclastics
- **uTrNb** Pyroxene and hornblende basalt flows, breccias and tuffs
- **uTrNtb** Polylithic breccia to conglomerate
- **uTrNts** Sandstone breccia
- **uTrNtv** Basalt to mafic volcanic breccia
- **uTrNtp** Coarse plagioclase porphry

INTRUSIVE ROCKS
Triassic to Jurassic
- **LTrmd** Syenitic to monzonitic intrusive rocks
- **TrJmd** Syenitic to monzonitic intrusive rocks

Takomkane Batholith
- **EJtw** Granodioritic intrusive rocks
- **LTrJgd** Granodioritic intrusive rocks

MINFILE
- calc-alkaline Cu±Mo±Au
- alkalic porphyry Cu-Au
- volcanic redbed Cu
- placer Au

ICE-FLOW INDICATORS
Glacial striations (ice-flow sense known, unknown)

Bedrock geology: Massey et al. (2005), Logan et al. (2010), and P. Schiarizza unpublished data (2012)

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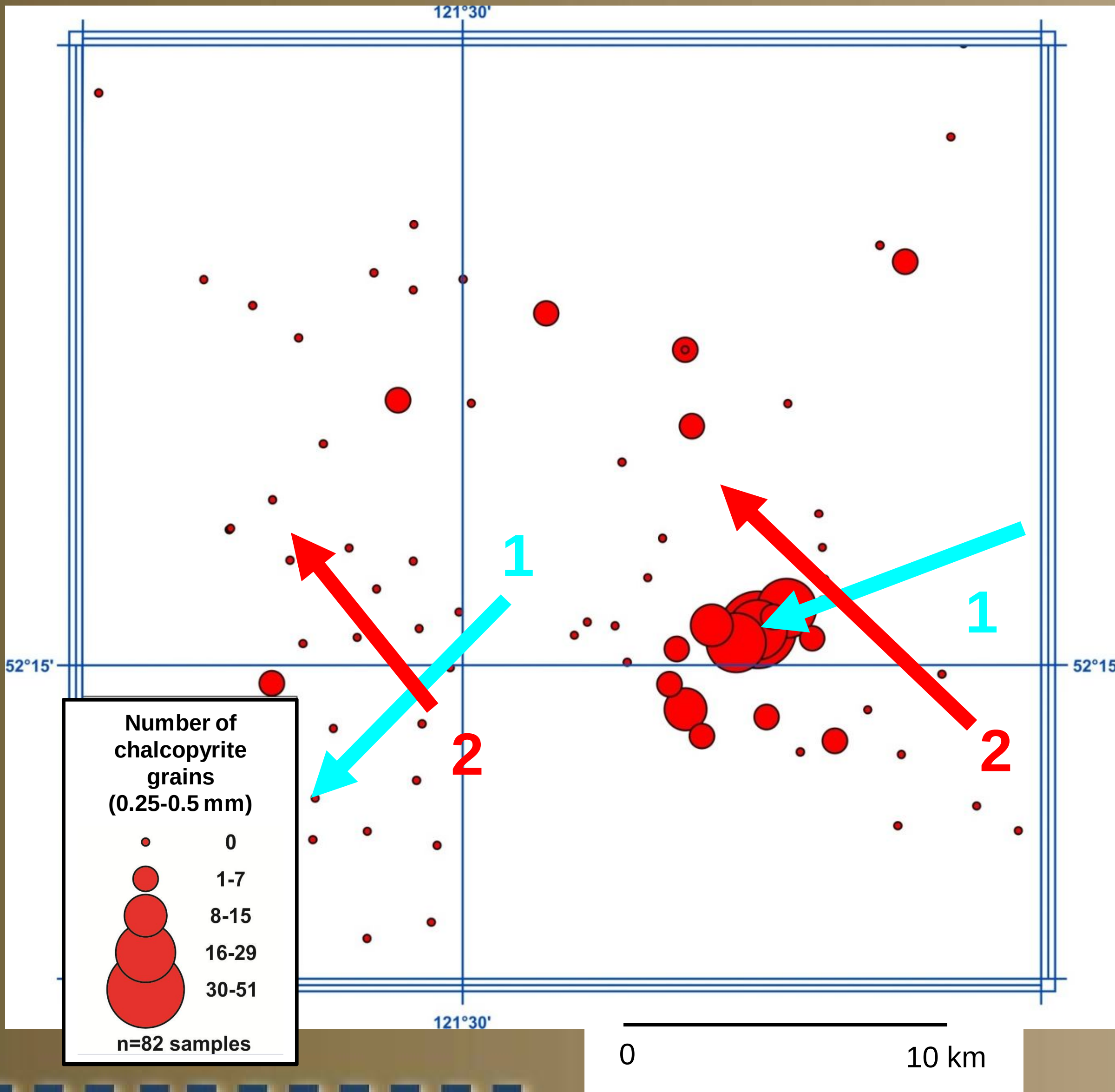
WOODJAM: chalcopyrite



Canada

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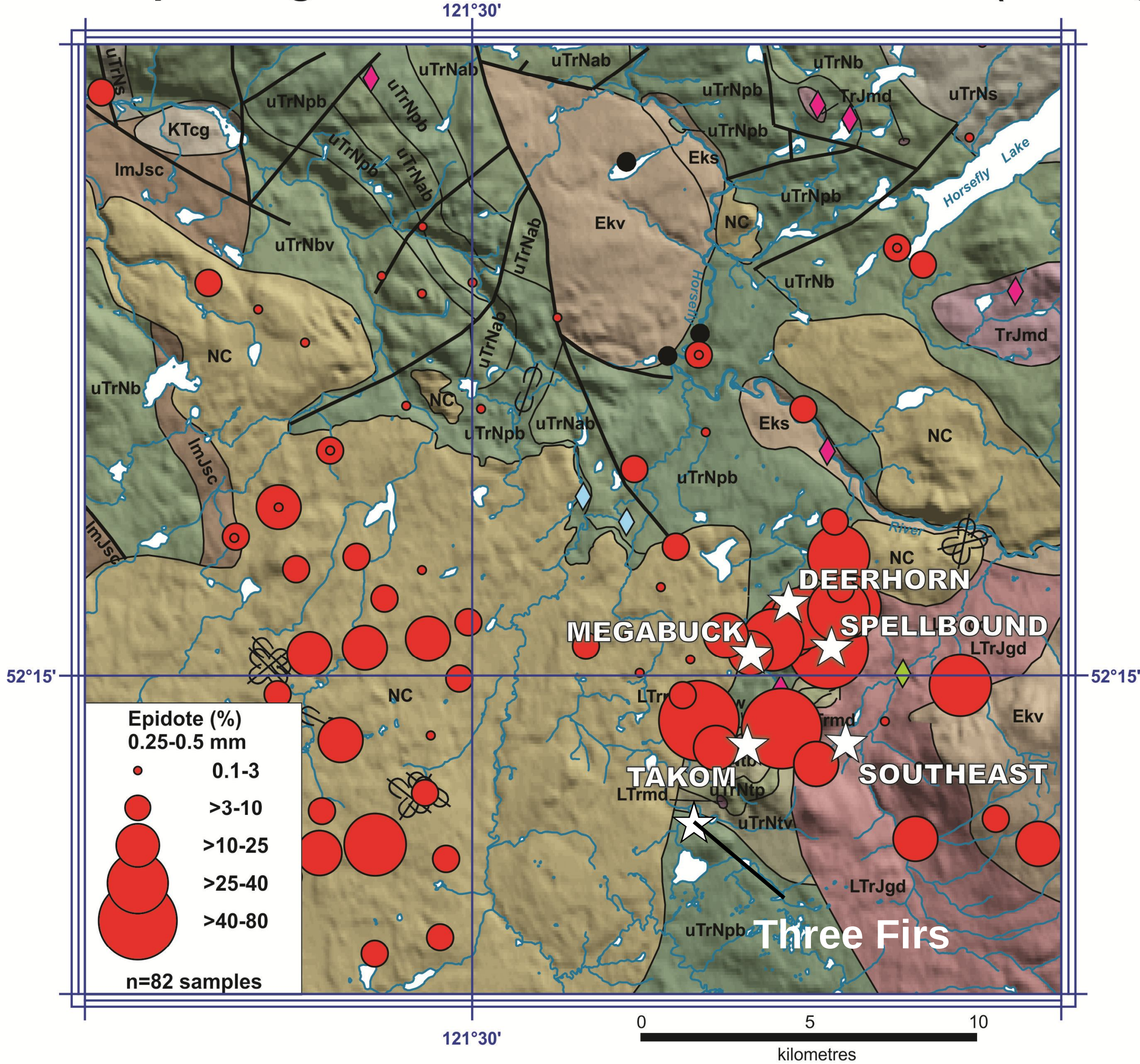
WODJAM: epidote

Percent epidote grains in 0.25-0.50 mm concentrate (>3.2 s.g.)



Canada

WOODJAM: epidote

Epidote in till

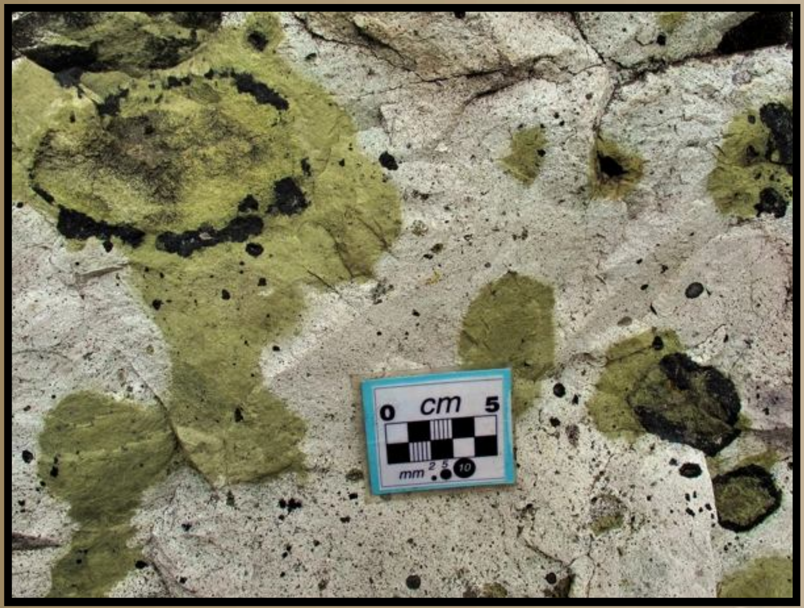
Width of field of view: 5 mm

Source: ODM, March 2012; modal estimates +/-10% precision

Sample 11PMA-017A-1 (WOODJAM)

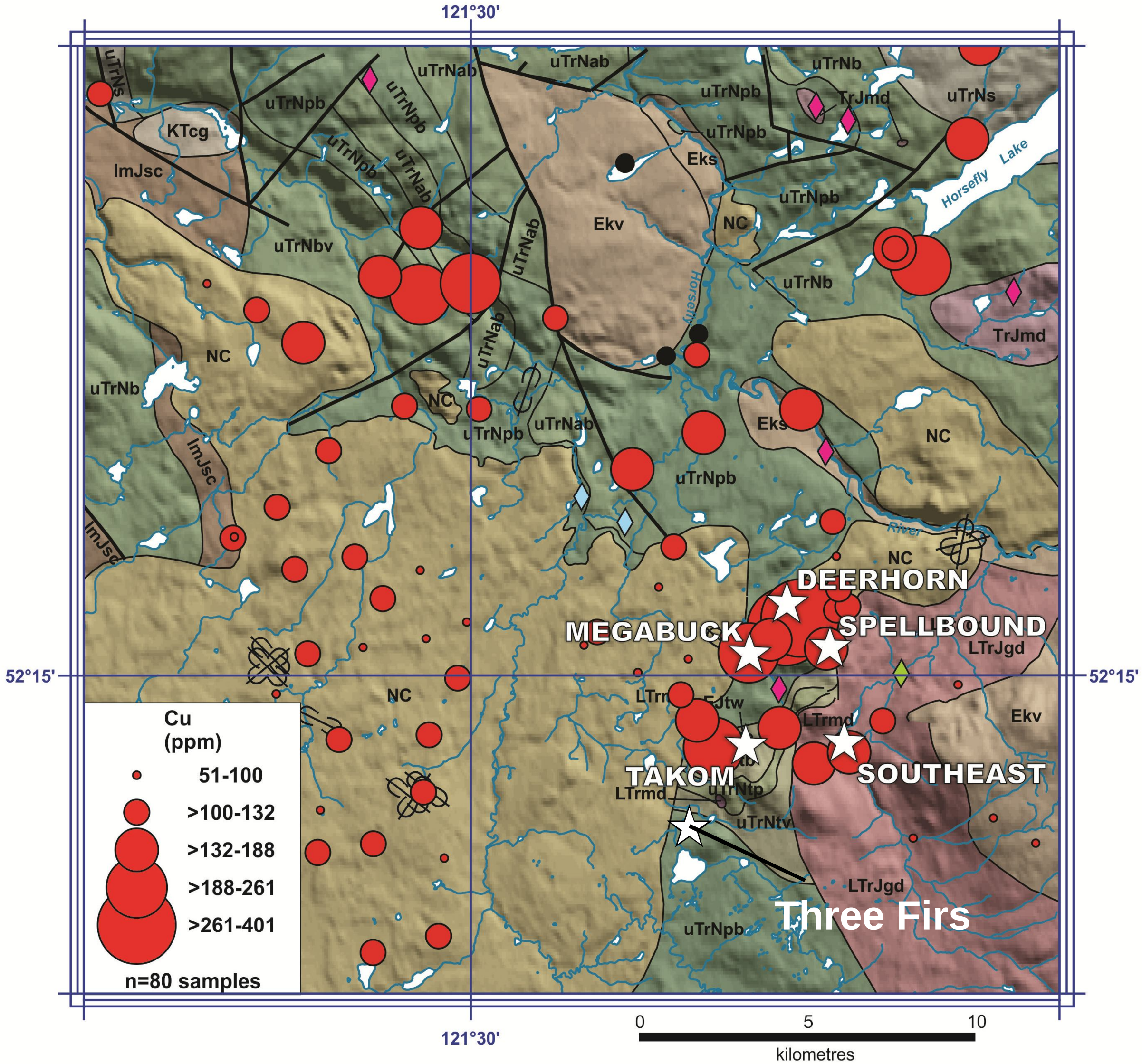
80% Epidote (0.25-0.50 mm)

Epidote-tourmaline alteration at Takom Zone



WOODJAM: copper

Cu in the clay-sized fraction (<0.002 mm) of till



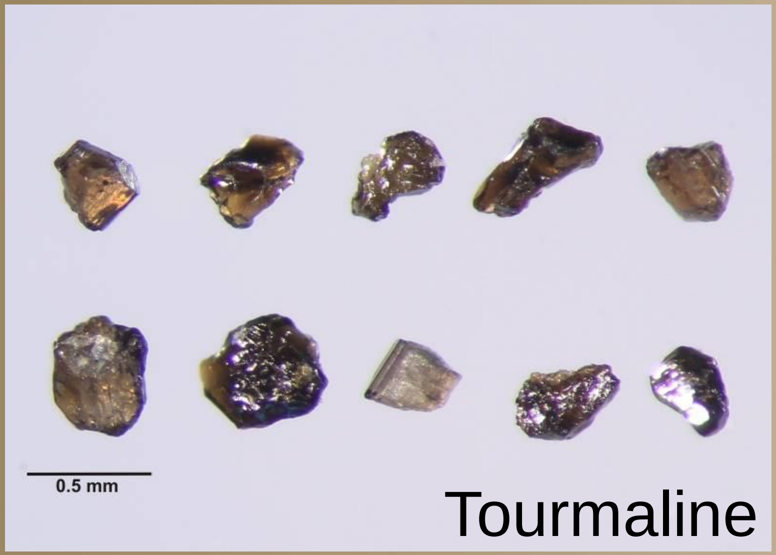
MINFILE

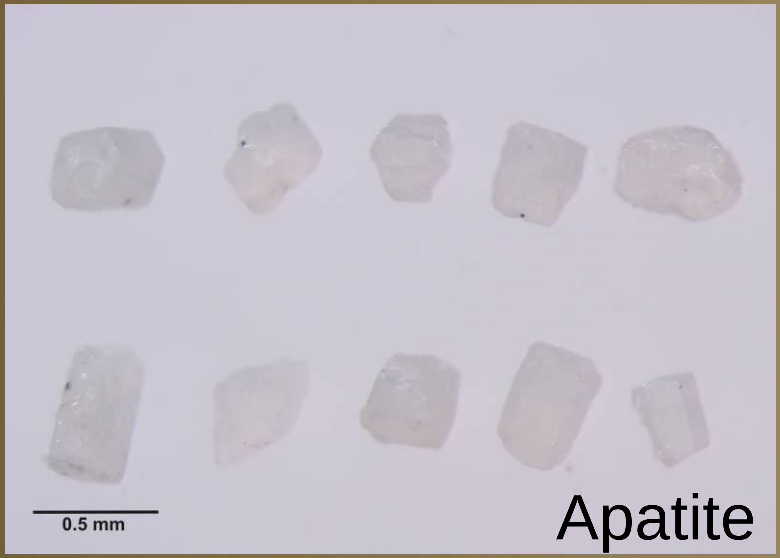
- calkalkaline Cu±Mo±Au
- alkalic porphyry Cu-Au
- volcanic redbed Cu
- placer Au

$LiBO_2$ / LiB_4O_7 HNO_3 fusion ICP-ES

Canada

Other indicator minerals of interest

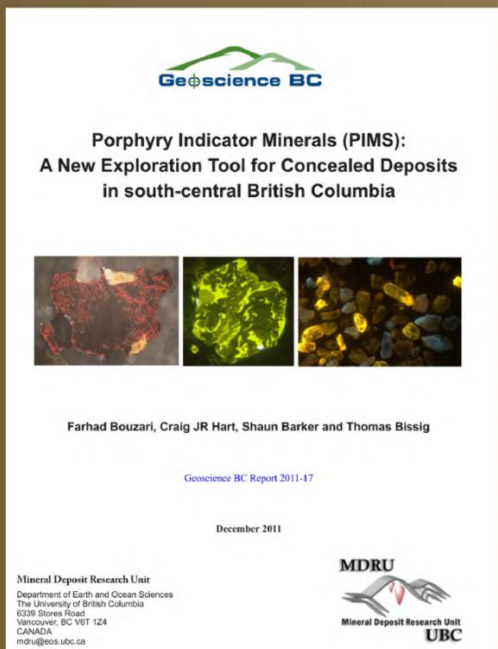




Photographs by ODM (2013)

PIM: Other studies and collaborators

MDRU


Geoscience BC

Porphyry Indicator Minerals (PIMS):
A New Exploration Tool for Concealed Deposits
in south-central British Columbia

Farhad Bouzari, Craig JR Hart, Shaun Barker and Thomas Bissig

Geoscience BC Report 2011-17

December 2011

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MDRU
Mineral Deposit Research Unit
UBC

University of Victoria
Dante Canil
Magnetite composition at Mt. Polley

Potential for other collaborators…

Canada

Other publications from this project:

Anderson, R. G., Plouffe, A., Ferbey, T., and Dunn, C. E., 2012. The search for surficial expressions of buried Cordilleran porphyry deposits; a new TGI4 activity in the southern Canadian Cordillera; Geological Survey of Canada, Open File 7081, poster. (Shown at Roundup 2012 and KEG 2012).

Anderson, R. G., Plouffe, A., Ferbey, T. F., and Dunn, C. E., 2012. The search for surficial expressions of buried Cordilleran porphyry deposits; background and progress in a new TGI4 activity in the southern Canadian Cordillera; Geological Survey of Canada, Current Research.

Anderson, R. G., Plouffe, A., Ferbey, T., and Dunn, C. E., 2012. The search for surficial expressions of buried Cordilleran porphyry deposits; preliminary findings in a new TGI4 activity in the southern Canadian Cordillera; Geological Survey of Canada, Open File 7266, 82 p. (Talk at KEG 2012).

Plouffe, A., Ferbey, T., Levson, V.M., and Bond, J.D., 2012: Glacial history and drift prospecting in the Canadian Cordillera: recent developments; Geological Survey of Canada, Open File 7261, 51p. (talk at PDAC 2012)

Plouffe, A., Ferbey, T., Anderson, R.G., Hashmi, S., Ward, B.C. and Sacco, D., 2013. The use of till geochemistry and mineralogy to explore for buried porphyry deposits in the Cordillera -- preliminary results from a TGI-4 Intrusion-related Project; Geological Survey of Canada, Open File 7367; 1 sheet, doi:10.4095/292555.

Talks related to this project activity:

Ferbey, T., Plouffe, A. and Anderson, R.G., 2012, Using indicator minerals to search for base and precious metals in British Columbia; British Columbia Geological Survey Open House, November 2012, Victoria, BC.

Ferbey, T., Plouffe, A., Hashmi, S., and, Anderson, R.G., 2013, Drift prospecting and porphyry indicator minerals in BC; Rock Talk, Smithers Exploration Group, February 2013, Smithers, BC.

Plouffe, A., 2013. How to find the source or provenance region of mineralized boulders in the glaciated Cordillera; presentation at the Roundup short course on exploration through cover.

Plouffe, A., Ferbey, T., Levson, V.M., and, Bond, J.D., 2012: Glacial history and drift prospecting in the Canadian Cordillera: recent developments; talk at PDAC 2012.

Other publications: in preparation

Plouffe, A., Anderson, R.G., and Ferbey, T., in prep. Till geochemistry and mineralogy near three porphyry systems in British Columbia: Gibraltar Mine, Highland Valley Mine and Woodjam prospect; Geological Survey of Canada, Open File XXXX.

Plouffe, A., in prep. How to find the source or provenance region of mineralized boulders in the glaciated Cordillera; Geological Survey of Canada, Open File XXXX. (presentation at the Roundup short course on exploration through cover)