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The search for surficial expressions of buried Cordilleran porphyry deposits; preliminary findings in a new TGI4 activity in the southern Canadian Cordillera

R.G. Anderson, A. Plouffe, T. Ferbey, and C.E. Dunn

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A Targeted Geoscience Initiative 4 Contribution

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The search for surficial expressions of buried Cordilleran porphyry deposits; preliminary findings in a new TGI4 activity in the southern Canadian Cordillera

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SUMMARY

The Targeted Geoscience Initiative 4 is a 5-year federal program to provide public geoscience knowledge to improve deep mineral exploration effectiveness in seven principal ore systems, including those at intrusion-related base- and precious metal districts. In southern British Columbia, case studies were conducted around the Highland Valley, Gibraltar, Mount Polley and Woodjam porphyry deposits.

Activities in the national Intrusion-related Ore Systems include research on arc-related porphyry systems (mainly in the Canadian Cordillera) and non-arc setting porphyry-like and intrusion related systems (mainly in the Canadian Appalachians). The research will attempt to test the following hypotheses:

1. Tectonic setting and crustal structures dictate type, metal budget and where porphyry style mineralisation occurs and thus can predict locations of buried/hidden systems.

2. Distinctive geological, mineralogical and geochemical characteristics exist that can differentiate not only deposit sub-types but also the degree of fertility of hidden/deep mineralization.

In the Canadian Cordillera, preliminary inter-jurisdictional activities focussed on two aspects related to hypothesis 2: the composition and inferred source area for glacial till eroded from rocks; and, the composition of tree bark, as a geochemical probe into local sediments and bedrock. The initial stage of investigation comprised pilot studies at the Woodjam area, and Gibraltar and Highland Valley deposits in autumn 2011. The identification and interpretation of complex ice-flow directions from landform- to outcrop-scale ice-flow indicators help trace geochemical and indicator mineral anomalies in till back to their bedrock source. Initial results for heavy mineral concentrates from till indicate the potential usefulness of epidote as an indicator of propylitic alteration associated with some types of intrusion-related deposits. More research will be dedicated to the development of epidote as a porphyry indicator mineral.

The studies presented here tested the utility of tree bark and till for detecting buried mineralization and provide new insights into effective ways of exploring for deep and hidden mineralization.

INTRODUCTION

This open file contains slides of a talk given at a special session entitled “25 Years Supporting Mineral Exploration in BC.’ presented at the Kamloops Exploration Group (KEG) 25th annual KEG Conference and Trade Show, April 3rd - 4th 2012 in Kamloops, British Columbia.

The slides of the original talk have been augmented by additional notes and a reference list for citations included in the slides. In view of the interest shown by mineral explorationists in the content of the talk, this information is being released as an open file so that it is be readily available to a wider audience.

The talk, provided here in report format, is divided into 5 parts (**Slide 2**):

1. Synopsis of TGI-4 (5 yrs; 2010-2015)
2. Intrusion-related deposits, southern Canadian Cordillera examples, and methodologies used in this study
3. Glacial processes: lessons learned from previous drift-prospecting studies in the Cordillera
4. Three scoping studies: Gibraltar, Woodjam, Highland Valley areas
5. Future studies

A number of studies related to the glacial history and stratigraphy, and the application of drift prospecting for mineral exploration have been conducted in the southern Cordillera. They include but are not limited to: Fulton (1965, 1967, 1969, and 1975); Tipper (1971a, b, c); Ryder (1976; 1981); Fulton and Smith (1978); Clague (1988, 1989); Ryder et al. (1991); Fulton et al. (1992); Bobrowsky et al. (1993, 1995, 2002); Kerr et al. (1993); Levson (2001); Paulen (2001); Lett (2008, 2011); Ferbey and Levson (2009) and Ferbey et al. (2009); Plouffe et al. (2009, 2010 and 2011a, b, c); and Ferbey (2011),

Biogeochemical studies in the Canadian Cordillera build upon previous studies by, and rely on protocols developed in, Dunn (1995, 2007), Dunn and Hastings (1998), Dunn and Thompson (2007, 2009), and Dunn and Anderson (2011).

Summaries of the bedrock geology for areas included in the scoping studies are from the following previous work: 1) Gibraltar (Drummond, (1973); Bysouth et al. (1995); Ash et al. (1999a, b), Ash (2001) and Oliver et al., (2009) and references therein); 2) Woodjam [Fjordland Exploration Inc. (2007), Schiarizza et al. (2009a, b); Schroeter (2009); and Blackwell et al. (2010)), and, 3) Highland Valley district (Northcote (1969); McMillan (1976, 1985, 2005); Monger and McMillan (1984); McMillan et al. (1996, 2009); and Ash et al. (2007) references therein).

Our work on porphyry indicator minerals (PIM) complements that of Bouzari et al. (2010; 2011a, b) in that it focuses on mineral species recovered in heavy mineral concentrates (HMC) from till that are likely derived from the eroded plutonic host, mineralization and alteration envelopes of porphyry deposits

Further information related to activities in the TGI4 Intrusion-related Ore Systems Project in the Canadian Cordillera is available in Anderson et al. (2012a, b).

SUPPLEMENTARY INFORMATION FOR SLIDES

Title Slide

Slide 1

The slide illustrates the principal aim of our initial inter-jurisdictional activities: to identify the geochemical and mineralogical signals which vector towards known intrusion-related deposits such as those hosted at Highland Valley Cu and Gibraltar Cu deposits. A search for these same signals may be conducted in covered greenfields areas of the Interior Plateau, as seen from the rim of the Gibraltar pit.

Outline

Slide 2

1. Synopsis of TGI-4 [5 yrs; 2010-2015]
2. Canadian Intrusion-related deposits, Project hypotheses, and southern Canadian Cordillera examples
3. Glacial processes: Lessons from previous drift-prospecting studies in the Cordillera
4. Three scoping studies: Gibraltar, Woodjam, Highland Valley District
5. Future studies

Synopsis of Targeted Geoscience Initiative 4 (TGI-4) National Program

Slides 3-6

The Targeted Geoscience Initiative 4 (TGI-4) is a collaborative federal geoscience program that provides industry with the next generation of geoscience knowledge and innovative techniques, which will result in more effective targeting of buried mineral deposits.
The program is in response to two important factors affecting the Canadian mineral exploration industry:

1. Canada's reserves of metals have been declining for more than 28 years.
2. Deeper exploration for new resources is required because of the increasing rarity of surface discoveries (e.g. **Slide 3**).

The TGI-4 program aims to develop more robust means of measuring whether a geological system may contain deeply buried ore (system fertility) and providing a direction to that ore (exploration vectors), thereby reducing the investment risk and cost. To succeed, the program must develop new and improved geoscience knowledge and techniques to better understand, model and detect Canada's major mineral systems. In addition, TGI-4 aims to train and mentor students to increase the number of highly qualified personnel available to the mineral industry as the next generation of mineral exploration professionals (**Slide 6**),

Slides 7-8

TGI-4 is a knowledge-based, thematic program that uses an ore-forming systems analysis approach to project definition (**Slide 7**). Projects and activities are not centred in a geographic region as with the TGI-3 Program (**Slide 8**) but are thematic, national in scope and represent the best examples of ore systems in Canada. The projects integrate data and knowledge from multiple mining camps across the country for a given ore system. This approach will guarantee that the best-suited deposits are used to support the development of the next generation of exploration-related geoscience knowledge and methods.

Projects include those focusing on method development and on the principal Canadian ore systems which include (**Slides 7 and 9**):

Base Metals
Intrusion-related
VMS
SEDEX

Precious Metals
Lode gold
Ni-Cu-PGE-Cr

Other
Specialty metals
Uranium

See map for location of study areas in **Slide 9**

Scientific hypotheses underpin the program and define the critical knowledge gaps within ore systems.

Canadian Intrusion-related deposits, Project hypotheses, and southern Canadian Cordillera examples

Slides 9-12
Amongst the best examples of intrusion-related ore systems in Canada include (**Slide 9**): arc-related porphyry systems (mainly in the Canadian Cordillera; Cu-Mo (Au) endowments); and, non-arc setting porphyry-like and intrusion related systems (mainly in the Canadian Appalachians; Mo-W, Sn-In endowments).

Our preliminary work seeks to test and identify factors pertinent to hypothesis 2 in the project-level hypotheses (**Slide 10**):

1. Tectonic setting and crustal structures dictate type, metal budget and where porphyry style mineralisation occurs and thus can predict locations of buried and/or hidden systems.

2. Distinctive geological, mineralogical and geochemical characteristics exist that can differentiate not only deposit sub-types but also the degree of fertility of hidden/deep mineralization

In British Columbia (**Slide 11**), the Interior Plateau physiographic region is an ideal study area to develop and test new technologies for deep exploration because it is underlain by well known porphyry deposits (e.g., New Afton, Highland Valley, Gibraltar, and Mount Polley) and its potential for additional economically viable porphyry deposits (e.g., Woodjam) which are obscured by glacial deposits and unmineralized Tertiary basalt flows.

The principal impediment for mineral exploration in the southern Interior Plateau in the southern Cordillera is the abundance of Tertiary (e.g., Chilcotin) basalt and glacially-derived sediment cover in areas that may host prospective intrusion-related deposits. **Slide 11** shows the abundance of mineral occurrences of all types (and their degree of development) around the perimeter of the Interior Plateau.

Bedrock mapping shows that an important metallotect, the Nicola volcano-plutonic arc, extends through the Interior Plateau but its potential to contain further porphyry deposits is poorly known because of the hindrance of cover rocks and sediments to exploration.

The 2011 pilot studies undertaken in the Woodjam Cu-Mo-Au district and at the Gibraltar and Highland Valley Cu-Mo deposits over a two week period in autumn 2011 included the collection of 66 biogeochemical samples and 47 till samples for geochemical and mineralogical analysis. As much as practicable, biogeochemical and till samples were collected at the same site (**Slide 12**); ice-flow indicators (e.g., glacial striations) were measured at a number of locations.

Glacial Processes: Lessons from Previous Drift-Prospecting Studies in the Cordillera

Ice flow direction(s) and application to boulder tracing

Slides 13-15
During the last glaciation (Late Wisconsinan), all of Canada was covered by glaciers except for northwestern Yukon which did not receive enough precipitation for the development of glaciers (**Slide 13**). These glaciers had a major impact on the landscape by eroding bedrock and pre-glacial sediments and transporting them away from source.

The southern sector of the Cordillera was completely covered by the Cordilleran Ice Sheet during the last glacial maximum (Late Wisconsinan Fraser Glaciation; **Slide 13**). Following glaciation, an extensive cover of unconsolidated glacial sediments was deposited over prospective rocks in a vast sector of the Interior Plateau.

Porphyry deposits not protected by rocks or unconsolidated sediments were eroded by glaciers during the last glaciation. The resultant glacial sediments may be geochemically enriched in a suite of elements, or might contain minerals indicative of, porphyry mineralization. The objectives of this TGI4 research activity are to determine which elements and indicator minerals are enriched in till (glacial sediment directly deposited by glaciers) and are indicative of bedrock fertility, and to what distance from the bedrock source can the enrichment in till be detected. The success of this approach is largely based on the reconstruction and interpretation of the ice-flow history. For each study site, the ice-flow history will be reconstructed by mapping the distribution of surficial sediments and ice-flow indicators to produce geology maps .

As seen in the recent compilation by Ferbey (2011; **Slide 14**), there have been several regional and detailed till geochemical and indicator mineral studies in central and southern British Columbia. Our study areas (shown in blue) will contribute new or more detailed ice movement direction information and high quality geochemical and mineralogical data from till.

Drift prospecting in the Cordillera has proven successful in identifying hidden deposits as seen in the list of examples on **Slide 15**

Slides 16-20
Slide 16 shows a cross-section through a valley glacier with the internal movement of ice. Glaciers with water at their base are termed warm-base glaciers. Warm-base glaciers were common in the Cordillera during the last glaciation. Such glaciers erode the substrate over which they are flowing and transport the resulting debris in the direction of ice movement.

In the hypothetical scenario depicted in **slides 17** (cross-section) **and 18** (plan view), a mineralized zone exposed to glacial erosion (panel 1 on both slides) is eroded by a glacier and mineralized debris is transported in the direction of ice movement (down-ice direction) (panel 2) (see also Plouffe et al., 2012). After deglaciation, a glacial dispersal train composed of mineralized debris of all sizes can be identified in the till (panel 3). The scale of the dispersal train will be dependant on several factors including, but not limited to 1) the size of the mineralized zone exposed to glacial erosion, 2) the compositional contrast between the mineralization and the country rocks, 3) the till thickness, 4) the bedrock topography and position of the mineralization outcrops relative to glacial flow, and 5) the properties of the glacier (velocity, temperature, etc). From this example, it becomes clear that knowing the direction of ice movement is key for tracing the bedrock source of mineralized debris identified in till.

Another factor controlling the glacial flow is the location and migration of glacial divides. Important findings regarding the ice-flow movements have been achieved in the Canadian Cordillera in the last decade or so. For example, in west central British Columbia, at the onset of the last glaciation, an ice divide existed above the Coast Mountains (**slide 19**; panel 1**)**. Ice was flowing east and west from the divide, similar to streams flowing in opposite direction from a drainage divide. At glacial maximum, the ice divide migrated eastward onto the Interior Plateau (Stumpf et al., 2000) (panel 2). During deglaciation, the ice divide migrated westward to the Coast Mountains (panel 3). (panel 4). This ice-divide migration has significantly influenced glacial dispersal. For example, at the Huckleberry Cu-Mo deposit (**slide 20**) evidence of early-eastward, westward, and late-eastward ice flow was found (Ferbey et al., 2012).

Slide 21
On this broad compilation of the extent of, and ice-flow directions for the southern Cordilleran Ice Sheet, the region with ice divide migration just discussed is shown by the red rectangle at the top left corner of the map.

Another example of recent findings regarding ice-flow history comes from the Bonaparte Lake area (green rectangle). The Bonaparte Lake area is located south of an ice divide from which ice was generally flowing north and south. Two of the main TGI4 study areas, shown with blue ellipses), include: Highland Valley area to the south and the Gibraltar and Woodjam areas to the north.

Slide 22
The regional geomorphology of the Bonaparte Lake map area was first mapped and interpreted by Tipper (1971a,b,c). His map is shown in the background of this slide with drumlins and crag-and-tail, pitted terrain, melt water corridors (green), eskers, moraines, and glacial lake sediments shown in blue. From the available data, he demonstrated that glaciers first formed in the Cariboo Mountains at the onset of the glaciation and then flowed generally to the south in the Bonaparte Lake map area from the ice divide located to the north. The extent of glaciers and the amount of glacial transport from the first ice movement out of the Cariboo Mountains was not known. More recent mapping by Plouffe et al. (2010, 2011c) indicated that the Cariboo Mountains glaciers reached the Lac la Hache (LlH on slide 22) and Loon Lake (LL) regions in the western sector of the map area (red arrows). This regional westward flow was followed by progressively more southerly ice movements (green and then blue arrows) resulting from the formation of the ice divide to the north of the map area.

The more complex ice-flow history for the Bonaparte Lake map area has important implications for boulder tracing and determining the bedrock source of till geochemical anomalies.

Slide 23
The newly-discovered two-fold history of ice movement in the Bonaparte Lake map area enabled interpretation of geochemical anomalies identified in till samples. For example, Tb concentrations in the HMC of till samples overlie and occur down ice of felsic phases of the Takomkane, Raft and Thuya batholiths. Dispersal of elevated Tb contents (in ppm, determined on the HMC (via instrumental neutron activation analysis)) to the west (shaded red zones) and to the south (shaded blue zones) of these batholiths, as shown on the slide, are likely the result of the earlier (red arrows) and subsequent (blue arrows) ice flow (Plouffe et al., 2011c). The presence of large numbers of thorianite grain in the HMC of the same till samples account for the high Tb concentrations.

Slide 24
The newly-discovered two-fold history of ice movement in the Bonaparte Lake map area had a practical application in the tracing of felsic, gold-rich, mineralized rhyolite boulders in the northeastern corner of the area (e.g., Plouffe et al., 2011a). There, the boulders overlay mafic phases of the Thuya Batholith (red and orange units on slide; see Schiarizza et al., 2002) which intruded strata of the mafic Nicola Group (shades of green and greenish-grey; see Schiarizza et al., 2002).

The search for the bedrock source of the boulders was originally conducted using a single, southeasterly ice-flow direction, and a provenance envelope shown in yellow.

Slide 25
If the potential of newly-discovered two-fold history of ice movement in the Bonaparte Lake map area is taken into account (i.e., early movement of the boulders by the newly-discovered west-southwesterly ice flow (red arrow) and subsequent transport to the southeast by later glaciation (blue arrow)), the potential exploration envelope (shown in yellow) extends to the east.

Slide 26
In this schematic representation of a glacial dispersal train, it is assumed that mineralization in bedrock is exposed to glacial erosion. Mineralized bedrock might not always be exposed. For instance, the present areal extent of mineralization exposed in open pit mines does not represent the size of mineralized outcrop exposed to glacial erosion. The areal extent of mineralization exposed to glacial erosion affects the size and length of a glacial dispersal train in till.

Two examples will be discussed. The first, a simple, single stage dispersal of bedrock by a glacier which includes a small apophysis of mineralized and altered plutonic rock as source rock at the time of glaciation.

Size and length of dispersal train (boulder train, geochemical and mineralogical anomalies in till) influenced by extent of mineralization exposed to subglacial erosion

Gibraltar

Slides 27-28
Prior to glaciation, only an apophysis of an ore body (mineralization in pink) might have been exposed to glacial erosion (panel 1, **slide 27**) (see also Plouffe et al., 2012). Only this small part of mineralization was exposed to glacial erosion (panel 2) resulting in a limited dispersal compared to the overall extent of the ore body (panel 3). In other words, in the current open pit mine, the extent of exposed mineralization might be misleading and does not reflect the pre-mine development and preglacial conditions (panel 4).

As an example, the glacial dispersal train down ice of the Gibraltar deposit is likely to be more representative of the extent of the "discovery" outcrop than the eventual larger area of mineralized and altered rocks in the mine (**slide 28**).

A corollary is that patterns of mineralogical and geochemical alteration determined from the host rocks must be carefully interpreted to be accurately applied to till geochemical anomalies and PIM identified in the till samples.

Highland Valley District

Slides 29-30

A second example of the "present is *not* the key to the past" relates to the presence of pre-glacial sediments which overlie and therefore prevent mineralized and altered outcrop from being glacially eroded. In this example, pre-glacial sediments (orange, yellow and blue) are in large part covering the ore body (pink) (panel 1, **slide 29**) and protecting it from glacial erosion (panel 2) (see also Plouffe et al., 2012). Again, the resulting dispersal train is limited in extent compared to the size of the ore body (panel 3) and the extent of mineralization in the current open pit mine does not reflect preglacial conditions (panel 4).

As an example, the dispersal train down ice of the Valley Pit at the Highland Valley deposit, currently being defined as part of our TGI-4 study, will be representative of the extent of the ore body exposed to glacial erosion (**slide 30**).

Three Scoping Studies: Gibraltar Mine, Woodjam area and Highland Valley District

Gibraltar

Bedrock Geology, Mineralization and Alteration

Slides 31-41

Gibraltar Mine (**Slide 31**), centred within the Granite Mountain Batholith (**Slide 32**), is one of British Columbia's largest and longest producing copper-molybdenum porphyry deposits (Oliver et al., 2009). The six ore zones which make up the deposit are hosted by the well-mapped and well-explored composite peraluminous Late Triassic Granite Mountain Batholith (e.g., Drummond, 1973; Bysouth et al., 1995; Ash, 2001; Ash et al., 1999a, b; Oliver et al., 2009; and references within) and this summary is taken from those references.

The Late Triassic Granite Mountain Batholith demonstrably intruded the Permian Cache Creek Group (**Slide 32**). Hornblende-bearing diorite and quartz diorite (southern border phase) and biotite-hornblende tonalite (Mine or northern border phase) hosted deposition of sulphides (chalcopyrite, molybdenite, pyrite and minor sphalerite). Trondhjemite (Granite Mountain phase) and minor, late leuco-trondhjemite (quartz- and quartz-feldspar porphyry) are generally barren (Oliver et al., 2009).

The country rocks, batholith and early phases of the ore deposits and alteration were poly-deformed (**Slide 33**), with the development of gently southwesterly-dipping and -plunging planar and linear fabrics, and metamorphosed to upper greenschist grade in the Early Jurassic; structures are cross-cut by late molybdenite-bearing veins. Epidote and chlorite alteration of the mafic minerals in all phases is characteristic, even distal to the deposit.

The Gibraltar deposit displays well developed and closely associated hydrothermal alteration patterns and zonation of base metals. Quartz, sericite, chlorite, epidote and carbonate are the common alteration minerals; distal, weak propylitic alteration linked with lowest grade copper changes to quartz-sericite-pyrite (QSP) alteration correlated to moderate copper-molybdenum grades. Highest grade copper is commonly associated with either intense QSP or quartz-sericite-chlorite zones or with zones of "darkened chlorite." Potassium-enriched zones of chlorite-biotite-iron carbonate are commonly spatially linked to intense fabric development. The characteristic and marked sulphide zonation includes chalcopyrite-molybdenum in the core through chalcopyrite to chalcopyrite-sphalerite and finally to sphalerite at the margins of the batholith and is reflected in relative enrichments of Cu, Mo and Zn in the till compositions around the deposit (Plouffe et al., 2011b; **Slide 34**).

Previous work: till and biogeochemical results

An orientation survey was completed at the Gibraltar deposit (Plouffe et al., 2011b) to characterize the outer tree bark geochemistry and the geochemical and mineralogical composition of till down- and up-ice from economic mineralization (e.g., **Slides 34-35**). Results from this orientation survey were compared to elevated concentrations identified in a “greenfields” regional mineral exploration till and tree bark survey to the south (Plouffe et al, 2010; Dunn and Anderson, 2011).

The results revealed that Cu and Mo were more enriched in lodgepole pine and Engelmann spruce outer bark near Gibraltar deposit compared to a large survey area to the south in the Bonaparte Lake map area (Dunn and Anderson, 2011). Similarly, minor elements (Au, Ag, Ba, Cu, Mo, Te, Zn) and one major oxide (Al_2O_3) were enriched to various degree in till down-ice from the Gibraltar ore bodies compared to background concentrations reported from the Bonaparte Lake map area (Plouffe et al., 2010). Furthermore, elemental enrichment in till mimicked the metal zoning identified in bedrock mineralization by Bysouth et al. (1995; **Slide 34**).

However, the number of samples and the extent of the till sampling were not large enough to adequately define the form and length of the glacial dispersal train at Gibraltar Mine area. This limitation led to the present TGI4 study.

Ice-Movement Indicators and 2011 Till Sampling Sites

A modern surficial geology map and reconstructed ice-flow history is lacking for the Gibraltar Mine region and this is one of the expected outputs of this TGI4 project. Ice-flow direction indicators were measured at seven sites (**Slide 36**). At two sites, northeast-southwest oriented striations might be related to a first ice flow from the northern sector of the Cariboo Mountains at the onset of the last glaciation, similar to the early advance observed in the Bonaparte Lake region (Plouffe et al., 2011c). However, most striations trend north-northwest and are likely related to ice flow derived from the ice divide to the south. The impact of both ice movements on glacial dispersal at the Gibraltar deposit area remained to be evaluated.

During the scoping study, till veneer (<2 m thick) and blanket (>2 m thick) were observed in the Gibraltar deposit region with limited glaciofluvial sediments associated with meltwater channels. A total of 19 till samples were collected in the region of the Gibraltar Mine including samples from the open-pit walls where undisturbed till is exposed and the remnants of the forest remain (**Slides 36-37**).

Biogeochemical Sampling

Biogeochemical stations were established at many of the till sites (**Slides 36-37**) and 21 bark samples were collected at fourteen sites, including three sites at the rim of the open pit areas (e.g., **Slide 3**7). An additional two localities were directly above granite outcrop. Spruce and pine are common and were the tree species sampled; poplar, aspen and fir are also present. The woodlands sampled were generally dry, open to moderately dense forests developed on flat to gentle slopes.

Porphyry Indicator Minerals (PIM)

A principal objective of this TGI4 project is to identify the near-surface expression of hidden porphyry mineralization via the geochemical composition of till and tree bark. Furthermore, it will include an assessment of PIM from the HMC recovered from till.

At the scale of sampling in this study (approximately 1 sample per kilometre in road accessible areas), it is more likely that the larger footprints of porphyry systems will be identified. If we consider the classic porphyry model of Lowell and Guilbert (1970) (**Slide 38**), the propylitic alteration “footprint” of a typical calc-alkaline porphyry system represents an exploration target more likely to be identified in our sampling than the areally smaller, inner phyllic, argillic and potassic alteration zones. Furthermore, given the geological constraints on source area described above (**Slides 26-30**), the propylitic alteration zone is also more likely to have been exposed to glacial erosion (**slide 39)**.

Our work on PIM will be done in collaboration with efforts by the Mineral Deposit Research Unit at the University of British Columbia (e.g., Bouzari et al., 2010; 2011a, b; **Slide 40**)

In the orientation survey conducted at Gibraltar Mine (Plouffe et al., 2011b), till HMC assemblages consist of almandine, hematite (goethite) and epidote (**slide 41**). Key sulphide minerals included pyrite and chalcopyrite. The suitability of red rutile as a potential PIM for the Gibraltar deposit could not be confirmed in that study owing to the presence of red rutile in background till samples (see Plouffe et al., 2011b for details). The large modal amount of epidote in the 0.25 to 0.5 mm fraction of till HMC near the alteration zone of the intrusion suggests that this mineral may be useful in identifying hidden propylitic alteration. However, the differentiation between epidote derived from hydrothermal alteration and that formed in greenschist-grade metamorphism of host or country rocks or other processes is important and will be a future focus of this study.

Woodjam

Bedrock Geology, Mineralization and Alteration

Slides 42-45

The 56,170 ha Woodjam gold-copper-molybdenum prospect is located at and around the village of Horsefly, about 45 kilometres east of Williams Lake (**Slide 42**). It occupies low elevation, relatively flat terrain typical of the Interior Plateau (Schroeter, 2009; Fjordland Exploration Inc., 2007 (http://www.fjordlandex.com/woodjam_property.html)).

The area encompasses at least five mineralized zones including (north to south): Deerhorn, Megabuck, Spellbound, South East, and Takom (**Slide 43**). The zones are rarely exposed at surface and were geophysically defined by the coincidence of large areas of high chargeability and low resistivity IP signatures, with regional-scale northeast-trending magnetic highs demarcating the alteration zone produced by the contact of the Takla Group volcanic rocks with the Takomkane Batholith (Fjordland Exploration Inc., 2007 (http://www.fjordlandex.com/woodjam_property.html)).

The Deerhorn, Megabuck, Takom and Spellbound zones are copper-gold-molybdenum alkalic porphyry-type deposits (Schroeter, 2009). They occur as mineralized quartz stockworks and breccias in the Takla Group volcanic and volcaniclastic country rock up to 1.5 kilometres west of the north-trending contact with the Takomkane Batholith (Schiarizza et al., 2009a, b; Logan et al., 2007) within contact aureoles of monzonite satellite intrusions (**Slide 43;** bedrock geology after Blackwell et al., 2010). The South East Zone is a large scale calc-alkalic copper-molybdenum-gold porphyry-type deposit comprising pyrite, chalcopyrite, molybdenite and trace bornite along fractures, in quartz veinlets and as disseminations wholly within mafic to felsic intrusive phases of the Takomkane Batholith (e.g., http://www.fjordlandex.com/woodjam_property.html; Logan et al., 2007; Schiarizza et al., 2009a, b).

Ice-Movement Indicators and 2011 Till Sampling Sites

No surficial geology map is available for the Woodjam area. The preliminary interpretation of the ice-flow patterns at Woodjam presented here derives from multiple sources. Glacial striations measured as part of the exploration program conducted by Gold Fields Canada Exploration and Fjordland Exploration Inc. indicated two dominant and generalized trends: east-west and northwest-southeast (J.W. Hertel, pers. comm., 2011). Two striated outcrops were measured as part of this study (**Slide 44**).

The northwest-southeast striations are related to the regional ice-flow pattern generally to the northwest as identified by Prest et al. (1968), Tipper (1971b), Clague (1989) and Ryder et al. (1991) for the southeastern sector of the Interior Plateau where the Woodjam area is located. On the other hand, the east-west striations are interpreted to be related to ice advance from the Cariboo Mountains (Plouffe et al., 2010, 2011c; Anderson et al., 2012b). This interpretation implies that the Woodjam district was under the influence of an early westward ice flow from the Cariboo Mountains at the onset of the last glaciation followed by a northwest ice movement from the ice divide at 52° latitude. However, the impact of both ice movements on glacial transport remains to be evaluated and will be the focus of this study.

A total of 18 till samples were collected at Woodjam (**Slide 44**). The Woodjam area is generally covered by a till blanket (>2m thick) with rare bedrock exposures. Based on diamond drilling results,, glacial sediment thickness is known to be highly variable but locally exceeds 250 m over the South East Zone and is up to 278 m thick elsewhere (J.W. Hertel, pers. comm. 2012).

Biogeochemical Sampling

In the Woodjam area, twenty-seven bark samples were collected at fifteen biogeochemical sites including many at the till sites and four sites above Miocene Chilcotin Group volcanic outcrop (**Slide 44**). Six sites were located at or near the Deerhorn, three at or near Megabuck and one at the Spellbound zone. Spruce dominates over pine, and poplar, aspen and fir are also present in the forests. The woodlands sampled were generally dry, open to moderately dense forests developed on flat to moderate slopes.

Porphyry Indicator Minerals

Preliminary examination of till HMC from this pilot study shows a mineral assemblage which includes garnet, tourmaline, and significant epidote. As at Gibraltar, epidote appears to have potential as an important PIM as its modal amount in the 0.25 to 0.5 mm size fraction of till HMC increases from approximately five percent outside the mineralized district to 80 percent in a sample collected over the Spellbound occurrence and 40 percent over or near the Deerhorn occurrence (**Slide 45**). As well, the presence of dark brown to black tourmaline in till is in accord with its occurrence as an unusual alteration mineral at some of the porphyry occurrences in the district (e.g., Takom).

Highland Valley District

Bedrock Geology, Mineralization and Alteration

Slide 46-50

The Highland Valley District, the southernmost of the pilot study areas (**Slide 46**), represents the largest group of operating Cu mines in Canada. The porphyry Cu-Mo deposits of the Highland Valley District are contained within the Guichon Creek Batholith (GCB) (McMillan, 2005; McMillan et al., 2009). The following summarizes accounts by McMillan (1976, 1985) and Woodsworth et al. (1991).

The GCB (**Slide 47**), which hosts the Highland Valley District deposits, is a large composite Late Triassic intrusion within the Mississippian to Upper Triassic Cache Creek Complex and volcanic and sedimentary rocks of the Upper Triassic Nicola Group (Monger and McMillan, 1984 and references therein; McMillan, 1985; McMillan et al., 2009). The batholith is covered by glacial deposits of varied thicknesses, with its northern part overlain by Eocene volcanic rocks of the Kamloops Group.

The batholith comprises four phases, which in relative decreasing age, include the Border, Highland Valley, Bethlehem and Bethsaida phases. The Guichon and Chataway units are 'varieties' within the Highland Valley phase, and the Skeena, a 'variety' within the Bethsaida phase. Contacts between the phases, though locally sharp, are commonly gradational and define an annular zoning with the older phases towards the outer margins of the batholith and the younger phases within the central area, including various felsic porphyry dyke types, the largest of which is the Gnawed Mountain sub-phase. The Bethlehem Suite is generally more felsic than the Highland Valley Suite.

The batholith's northerly elongation suggests control by basement structures manifest in syn- and post-intrusion faults including the north-trending Lornex and Guichon Creek faults and northwest-trending Barnes Creek, Highland Valley and Skuhun Creek faults (**Slide 4**7). Mid- to upper crustal emplacement is suggested by: interphase intrusive relations and dykes; probable semi-concordant to discordant batholith-country rock contacts; intrusion into slightly older Nicola Group volcanic country rocks; and a 0.2-0.8 kilometre wide albite-epidote to hornblende hornfels facies metamorphic aureole (Northcote, 1969; McMillan, 1976). Interpretation of geological and geophysical observations, including gravity, magnetic, velocity and Lithoprobe seismic reflection data, indicate the GCB to be a funnel-shaped feature extending to depths of ~10 kilometres (Roy and Clowes, 2000). The mineral deposits are located in the centre of the structure above the stem of the batholith and near the intersection of the major brittle structures described above.

Mineralization at Highland Valley has a Cu-Mo association with little gold and is hosted in calc-alkalic to calcic plutonic rocks. The major vein- and fracture-controlled ore deposits (Valley, Lornex, Highmont, Bethlehem and JA) occur within the central part of the batholith where they are hosted by the Bethlehem and Bethsaida phases, but smaller deposits (Krain and South Seas) occur within the older Guichon phase.

Surficial Geology and 2011 Till Sampling Sites

Previous Work

The Quaternary geology and geomorphology of a large area east of Highland Valley deposit was studied by R.J. Fulton during the 1960s and 1970s (Fulton, 1965; 1967; 1969; 1975; Fulton and Walcott, 1975; Fulton and Smith, 1978). Ryder (1976; 1981) reported on the Quaternary geology of the Ashcroft and Lytton regions, northwest and west of Highland Valley Mine. Detailed stratigraphic study of the Quaternary succession in the Merritt region revealed the presence of deposits from four glaciations and two interglaciations (Fulton et al., 1992). Bobrowsky et al. (1993) reported on the unconsolidated sediment stratigraphy in the Valley pit at Highland Valley Mine which includes glaciolacustrine sediments of Middle Wisconsinan age or older and one till unit most likely related to the Late Wisconsinan glaciation. Kerr et al. (1993) reported a copper dispersal train defined by concentrations >200 ppm in the till C-horizon, up to one kilometre down-ice from the Galaxy porphyry copper-gold deposit in the Iron Mask Batholith southwest of Kamloops (see also Lett, 2011). Also, they observed elevated copper concentrations in the stems, leaves and flowers of rabbitbush (*Chrysothamnus nauseosus*) sampled as part of a biogeochemical survey within the region of the dispersal train. Bobrowsky et al. (2002) completed a Quaternary geology reconnaissance study in the Merritt and Logan Lake region.

Based on the regional ice-flow patterns depicted in Prest et al. (1968), Tipper (1971b), Clague (1989) and Ryder et al. (1991), along with glacial striations reported by Bobrowsky et al. (2002) and measured as part of our investigation (**Slide 48**), glaciers originating from the ice divide located at the 52° latitude were generally moving to the south in the region of the Highland Valley Mine during the last glaciation (see **Slide 21**).

One of the key characteristics of the Valley pit at the Highland Valley Mine is the presence of an unconsolidated sediment succession of Quaternary age which is over 300 metres thick and overlies mineralized bedrock (see **Slide 30**). This sediment succession was preserved in a buried valley (Bobrowsky et al., 1993). The lower part of the succession includes non-glacial sediments and glacial lake sediments which predate the last glaciation (Bobrowsky et al., 1993). The preservation of these unconsolidated sediments underneath the till of the last glaciation indicates that a large part of the mineralized bedrock was not available for erosion during the last glacial event. Therefore, neither the mineralogy nor bulk composition of that part of the mineralized zone covered by pre-glacial sediments should be found in the till down-ice from the deposit.

The plateau region outside the Witches Brook valley is generally underlain by till veneer and blanket. Glacial lake sediments are present in Witches Brook valley and are most likely related to the damming of the valley during deglaciation.

2011 Till and Biogeochemical Sampling Sites

During the autumn 2011 fieldwork, till samples were collected from nine sites in the walls of the Valley and Bethlehem pits and surrounding region (**Slide 48**). Six of the till localities and one site (without till sampling) yielded biogeochemical material for a total of 18 bark samples (e.g., **Slide 49**). All but 3 biogeochemical sampling sites were above bedrock outcrop, including 4 stations near the rim of the Valley and Jersey (Bethlehem) open pit areas. Spruce and pine are common, with poplar, aspen and fir also components of the forests. The woodlands sampled were generally dry, moderately open forests developed on gentle to moderate slopes.

Porphyry Indicator Minerals

Preliminary examination of till HMC from this pilot study shows a mineral assemblage dominated by epidote (20 to 60 modal percent). As at the Gibraltar and Woodjam areas, epidote abundance in Highland Valley in the 0.25 to 0.5 mm size fraction of till HMC could become an important PIM (**Slide 50**). More extensive till sampling conducted overlying the alteration zone and distally from it was completed in the spring of 2012 which will serve to further test the usefulness of epidote as a PIM.

Conclusions and Proposed Future Studies

Slides 51-53

The Targeted Geoscience Initiative 4 is a 5-year federal program to provide public geoscience knowledge to improve deep mineral exploration effectiveness in seven principal ore systems including Intrusion-related Ore Systems. Activities in the national Intrusion-related Ore Systems include research on arc-related porphyry systems (mainly in the southern Canadian Cordillera) and non-arc setting porphyry-like and intrusion related systems (mainly in the Canadian Appalachians). The research will attempt to test the following hypotheses:

1. Tectonic setting and crustal structures dictate type, metal budget and where porphyry style mineralisation occurs and thus can predict the locations of buried/hidden systems.
2. Distinctive geological, mineralogical and geochemical characteristics exist that can differentiate not only deposit sub-types but also the degree of fertility of hidden/deep mineralization.

In the southern Canadian Cordilleran studies, preliminary, inter-jurisdictional activities focussed on testing two aspects related to hypothesis 2: the composition and inferred source area for glacial till derived from eroded bedrock and mineral deposits; and, the composition of tree bark samples. Both serve as geochemical probes into the subsurface. The initial stage of investigation consisted of pilot studies at the Gibraltar Mine, Woodjam area, and Highland Valley District in autumn 2011. The work led to some “lessons learned” or, intrinsic constraints on interpreting till geochemical and mineralogical results with respect to identifying buried sources of mineralization and alteration associated with it.

The identification and determination of complex ice-flow directions from map- to outcrop-scale ice movement indicators in the 3 scoping studies will help trace geochemical and indicator mineral anomalies back to the original buried deposits. Initial HMC results from the till samples indicate that epidote could be a useful PIM.

The studies are testing the usefulness of tree bark and till as exploration media whose compositions may indicate the location of buried mineralization and thereby help increase the effectiveness of deep mineral exploration.

Future work with provincial survey and academic partners will test aspects of hypothesis 1 and further our testing of hypothesis 2 (**Slide 52**).

Specifically, under hypothesis 1, we expect that regional and detailed studies of the bedrock geological setting of the Gibraltar Mine will help evaluate the importance of its apparent setting in the oceanic Cache Creek Terrane to mineralizing events. In the Quesnel Terrane, which hosts the Guichon Creek Batholith and the porphyry mineral endowment at Highland Valley, future studies focused on fault systems will assess their longevity as crustal structures and investigate their importance as both a local exploration guide for mineralization and as analog for potential mineralization other districts.

Under hypothesis 2, and following from the promising early results in our scoping studies, future work will focus on further developing innovative technologies involving PIM from till samples. This work will be done in collaboration with efforts by the Mineral Deposit Research Unit at the University of British Columbia (e.g., Bouzari et al., 2010, 2011a, b; **Slide 40**)

A principal objective of this study is to collect till and biogeochemical (tree bark) samples from sources of mineralization that are geologically well understood (i.e., mines). This sampling will continue both at regional- and deposit-scales with the goal of better defining the character, diversity and extent of geochemical and mineralogical anomalies.

The collection and interpretation of ice-flow data will continue. The data will be used to model glacial processes that created geochemical and mineralogical dispersal patterns.

Finally, an important outcome of the field studies will be to train the next generation of mineral exploration personnel (highly qualified personnel – HQP) via hands-on experience in the field-testing of these hypotheses.

Further information related to activities in the TGI4 Intrusion-related Ore Systems Project in the Canadian Cordillera is available in Anderson et al. (2012a, b) (**Slide 53**).

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The search for surficial expressions of buried Cordilleran porphyry deposits; preliminary findings in a new TGI4 activity in the southern Canadian Cordillera

By: R.G. Anderson, A. Plouffe, T. Ferbey, and C.E. Dunn

A Contribution to a Session on
25 Years Supporting Mineral Exploration in BC.
Presented at the
Kamloops Exploration Group (KEG),
The 25th annual KEG Conference and Trade Show, April 3rd - 4th 2012

Valley deposit; July 2011

Gibraltar deposit; July 2011

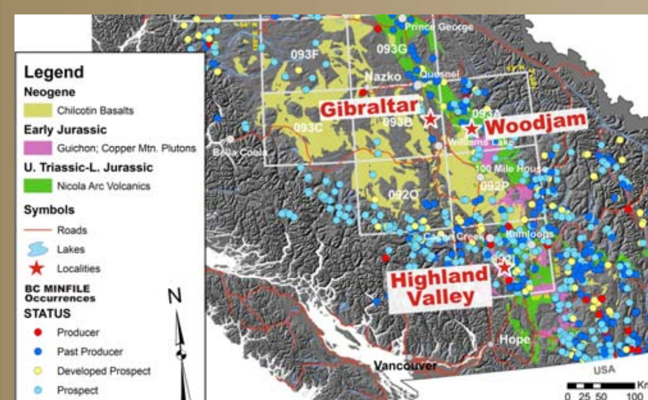
View W to Interior Plateau from rim of Gibraltar pit; July 2008

Taseko Gibraltar | fjordland EXPLORATION INC. | Gold Fields | Highland Valley Copper Teck | Canada

Talk Objectives

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

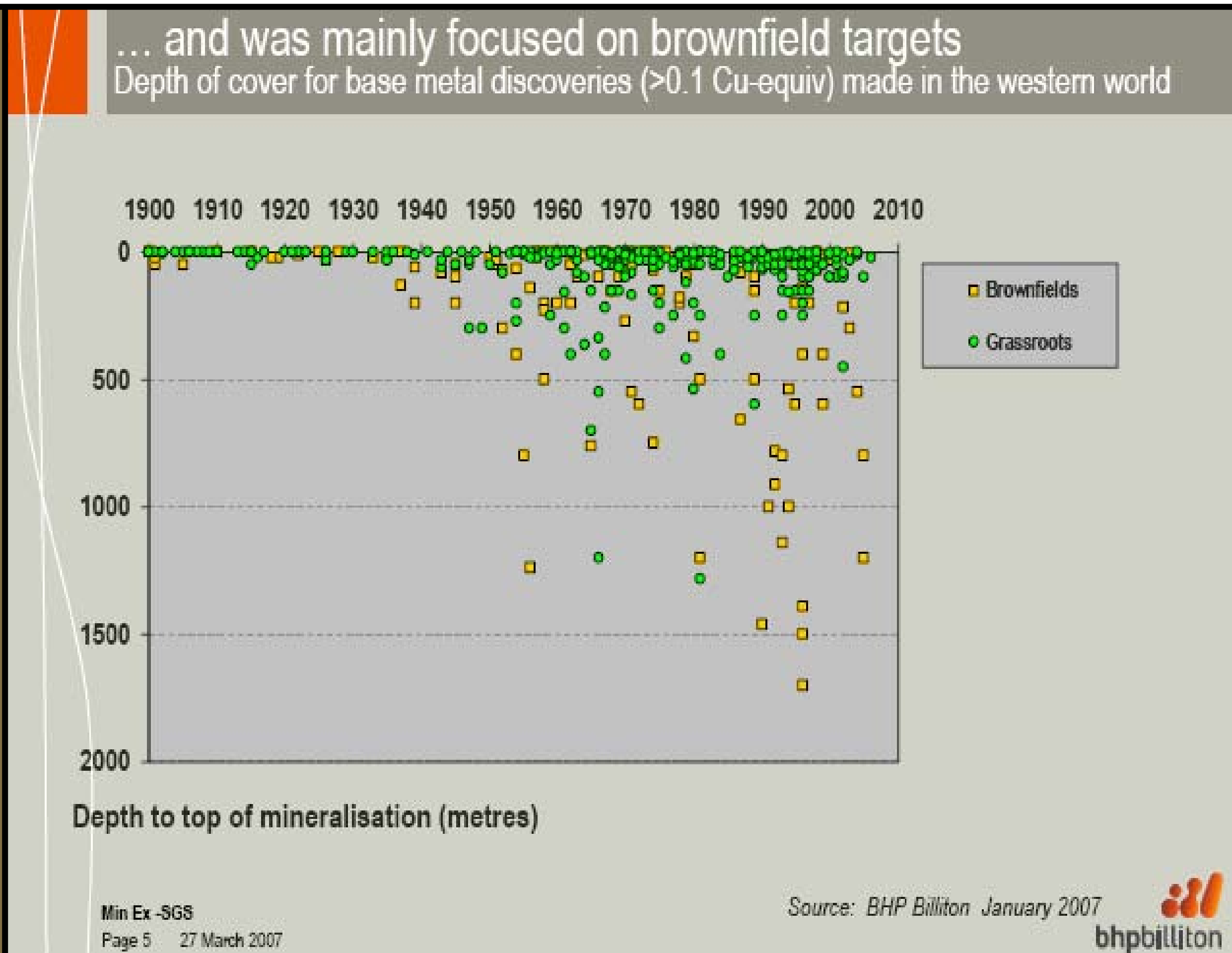
- Synopsis of TGI-4 national program [5 yrs; 2010-15]
- Southern Canadian Cordillera intrusion-related deposit study areas
- Glacial processes: Lessons learned from previous drift prospecting studies in the Cordillera
- 3 scoping studies: Gibraltar, Woodjam, Highland Valley District
- Future studies



Canada

TGI-4 Objectives -- Increasing depth of cover

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

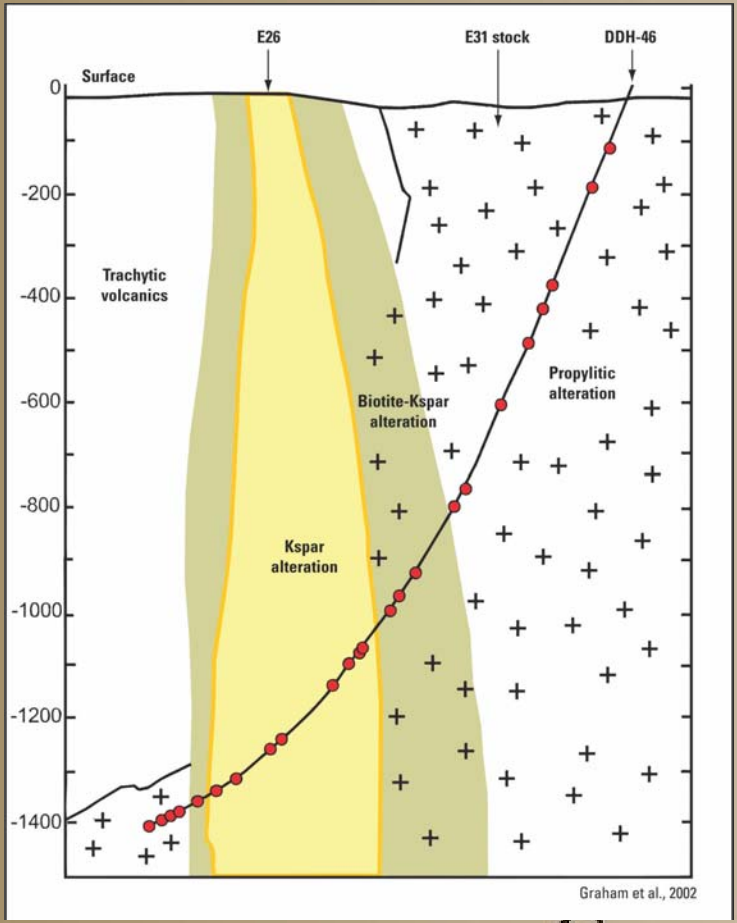


Source: Hronsky March 2007

TGI-4 Objectives – Fertility and vectors

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

1) **Develop more robust measures** of whether a geological system may contain deeply buried ore (**system fertility**), as well as indicators that provide the direction to that ore (**exploration vectors**), in order to reduce exploration risk

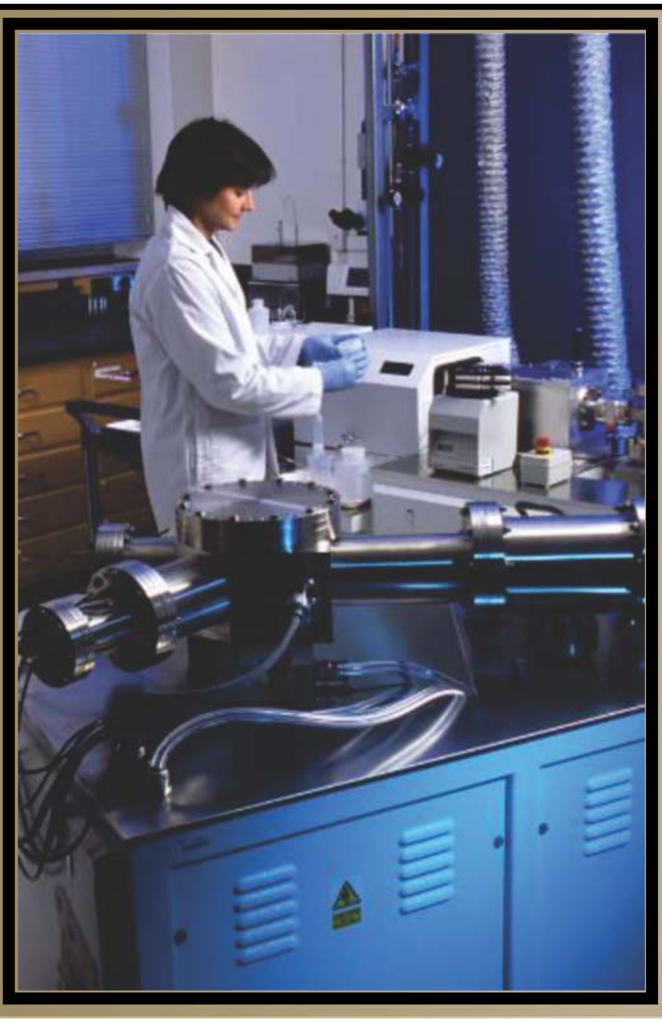


Canada

TGI-4 Objectives -- Innovation

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

2) **Develop <u>new geoscience knowledge</u>** and **<u>innovative techniques</u>** to model and detect Canada's major mineral systems.



Canada

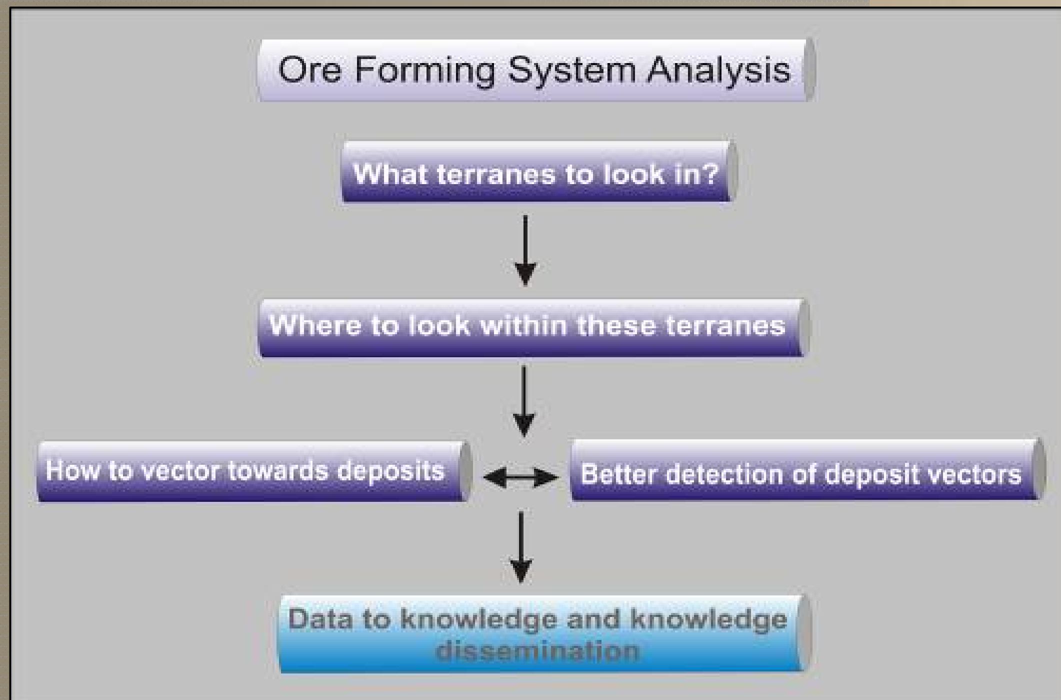
TGI-4 Objectives – training of students

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

3) **Train and mentor students** to increase the number of HQP available to the mineral industry.

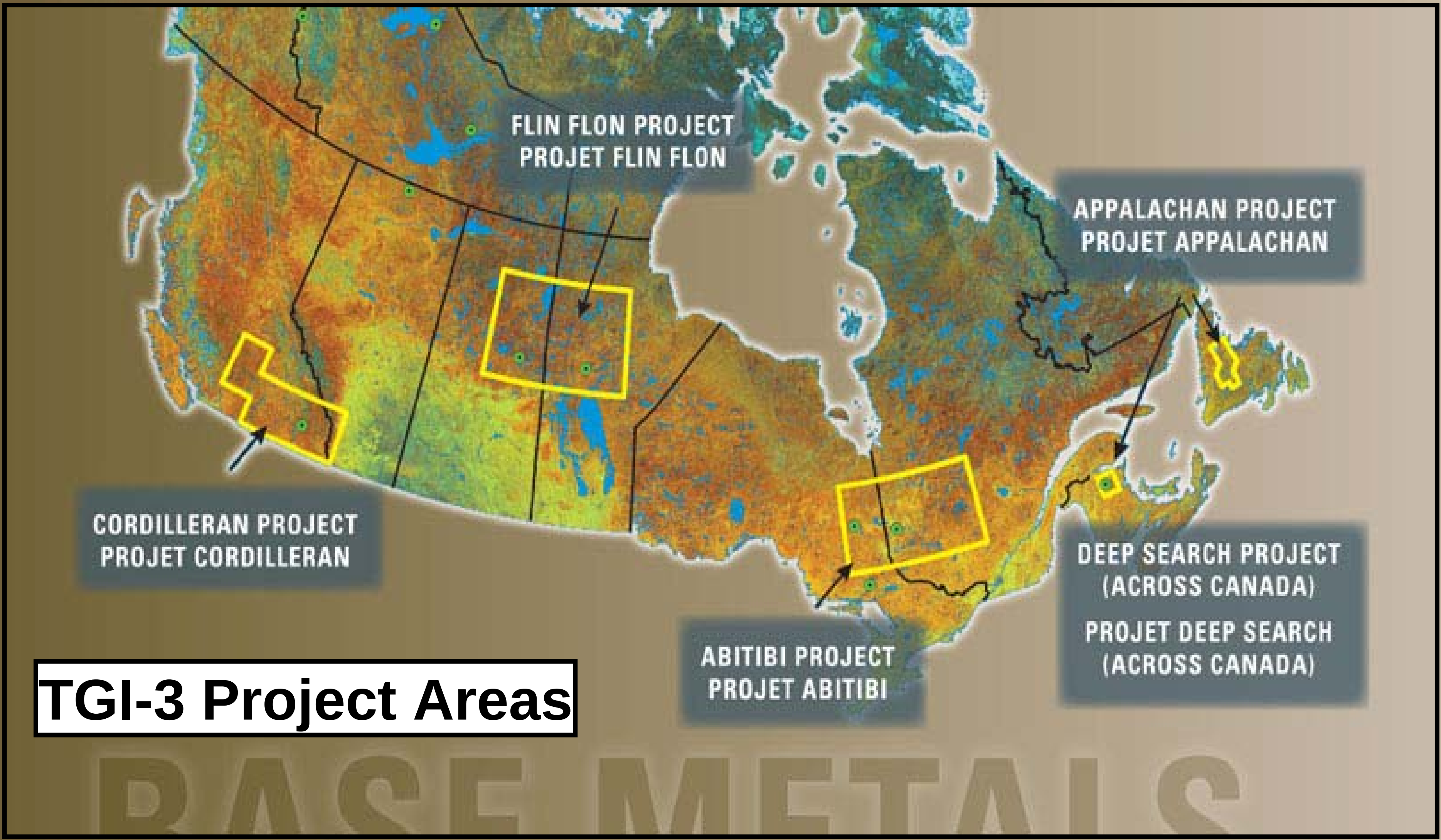
TGI-4 Methodology – Ore system approach to project definition

- Base Metals:
  - Intrusion-related (Cu-Mo, Cu-Au, Mo-W, Sn-In)
  - Ni-Cu-(PGE)-Cr
  - Pb-Zn SEDEX
  - Polymetallic VMS
- Precious Metals:
  - Lode Gold
  - (Ni-Cu)-PGE
- Other:
  - Uranium
  - Specialty Metals
- Method Development



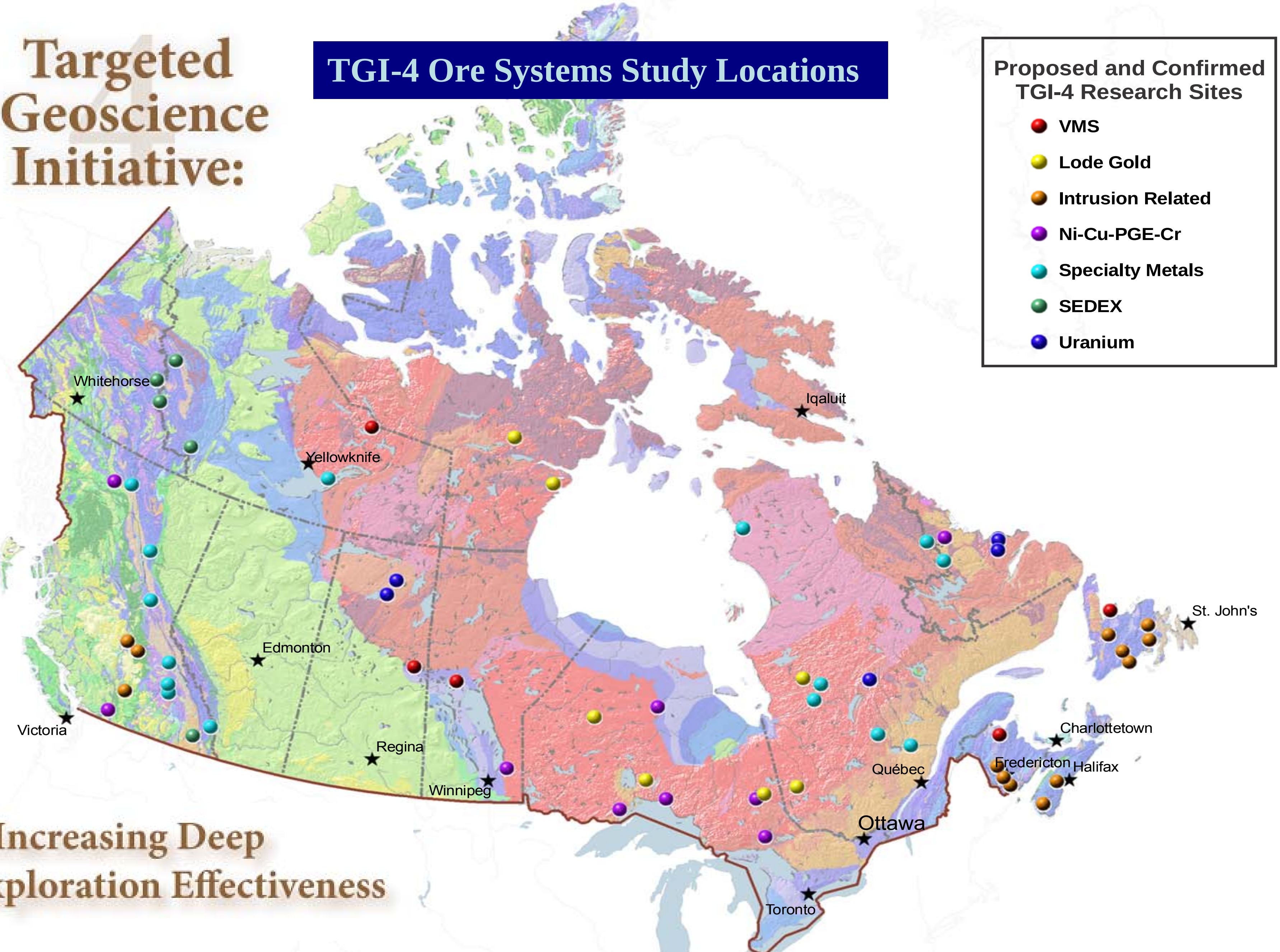
Ore Systems focus on processes of formation, not characteristics of ore deposits

TGI-3 Regional Projects vs. TGI-4 National Scope



Targeted Geoscience Initiative:

TGI-4 Ore Systems Study Locations

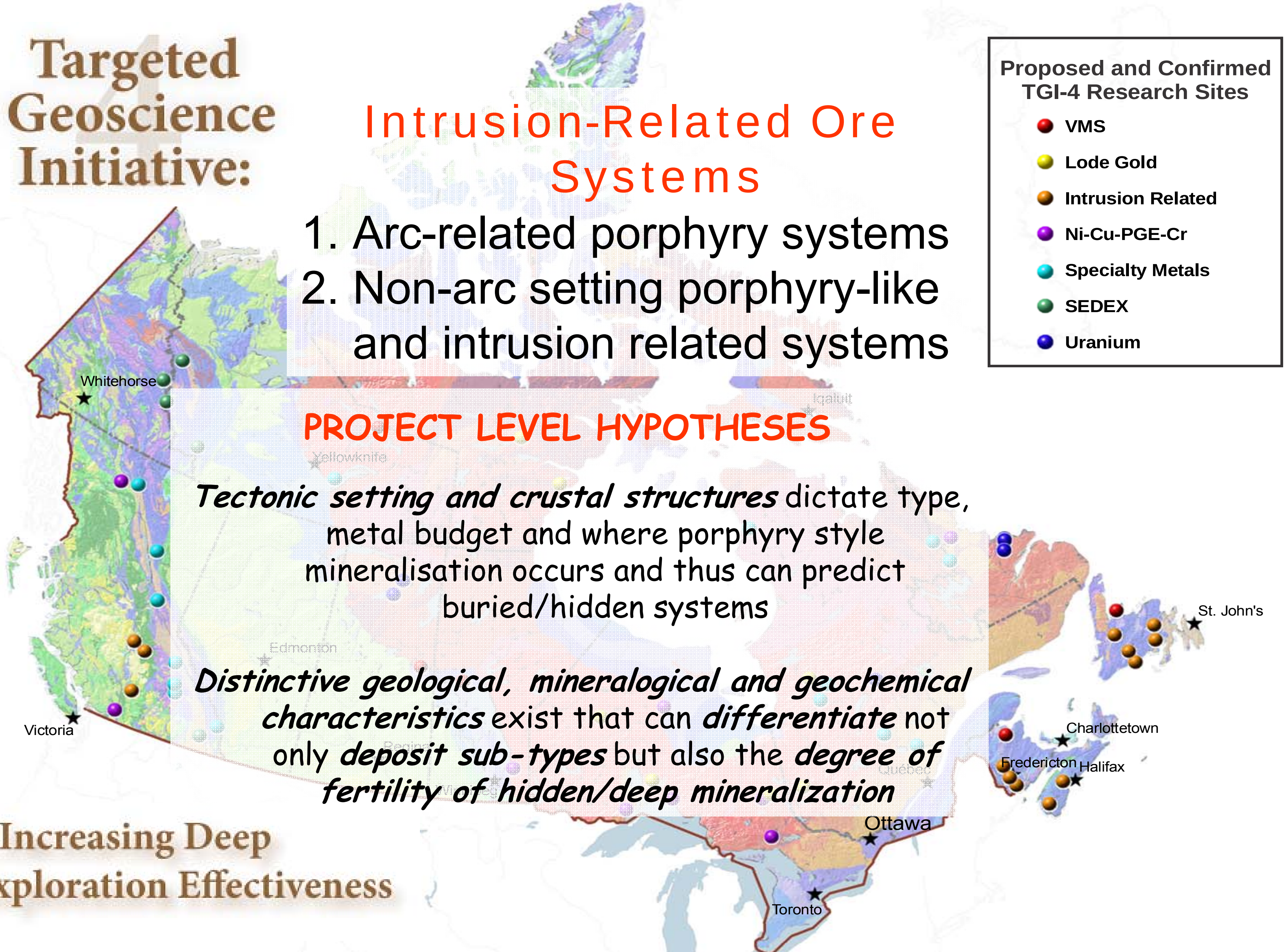


...Increasing Deep Exploration Effectiveness

Targeted Geoscience Initiative:

Intrusion-Related Ore Systems

1. Arc-related porphyry systems
2. Non-arc setting porphyry-like and intrusion related systems



PROJECT LEVEL HYPOTHESES

Tectonic setting and crustal structures dictate type, metal budget and where porphyry style mineralisation occurs and thus can predict buried/hidden systems

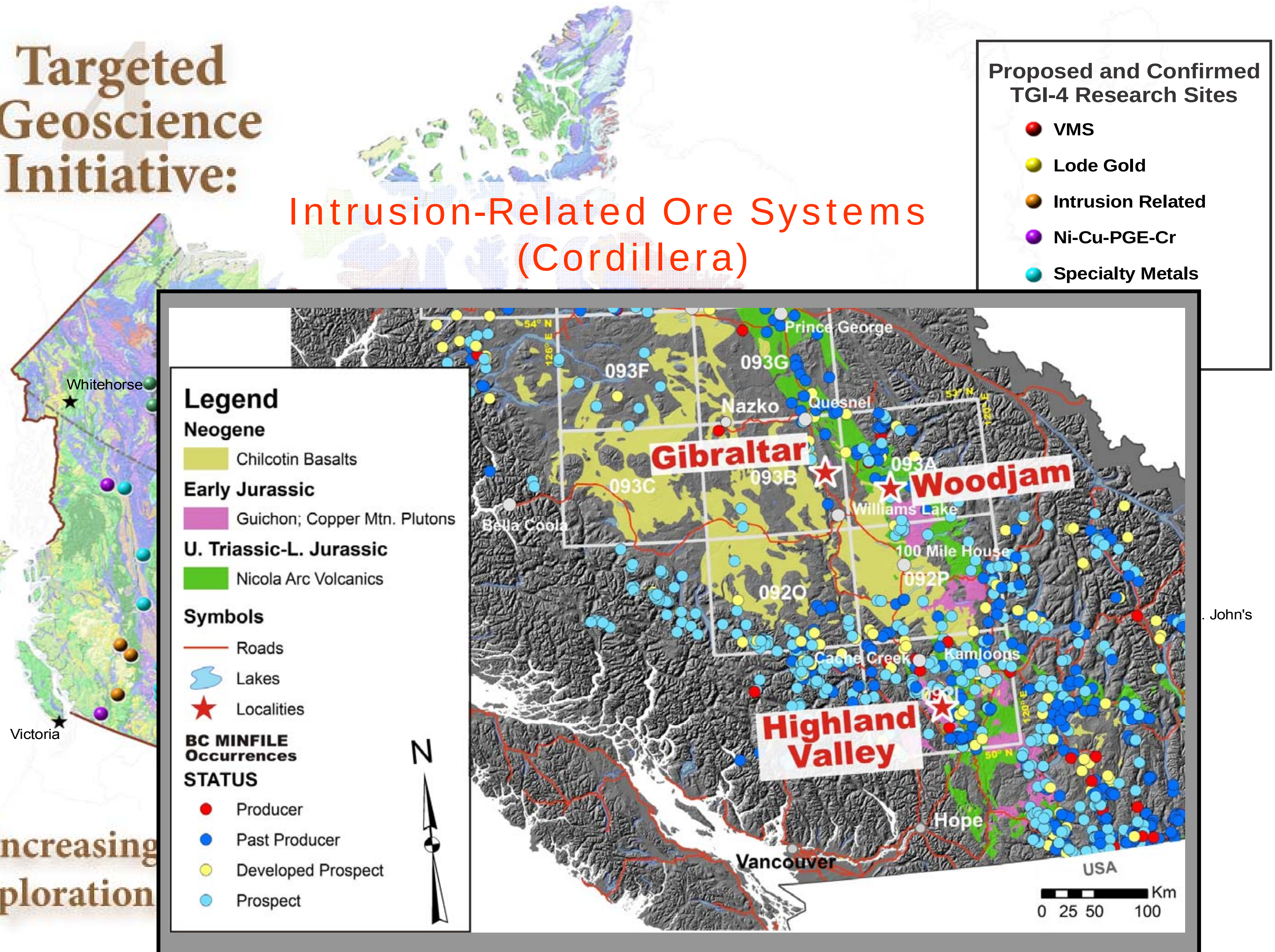
Distinctive geological, mineralogical and geochemical characteristics exist that can ***differentiate*** not only ***deposit sub-types*** but also the ***degree of fertility of hidden/deep mineralization***

...Increasing Deep Exploration Effectiveness

Canada

Targeted Geoscience Initiative:

Intrusion-Related Ore Systems (Cordillera)

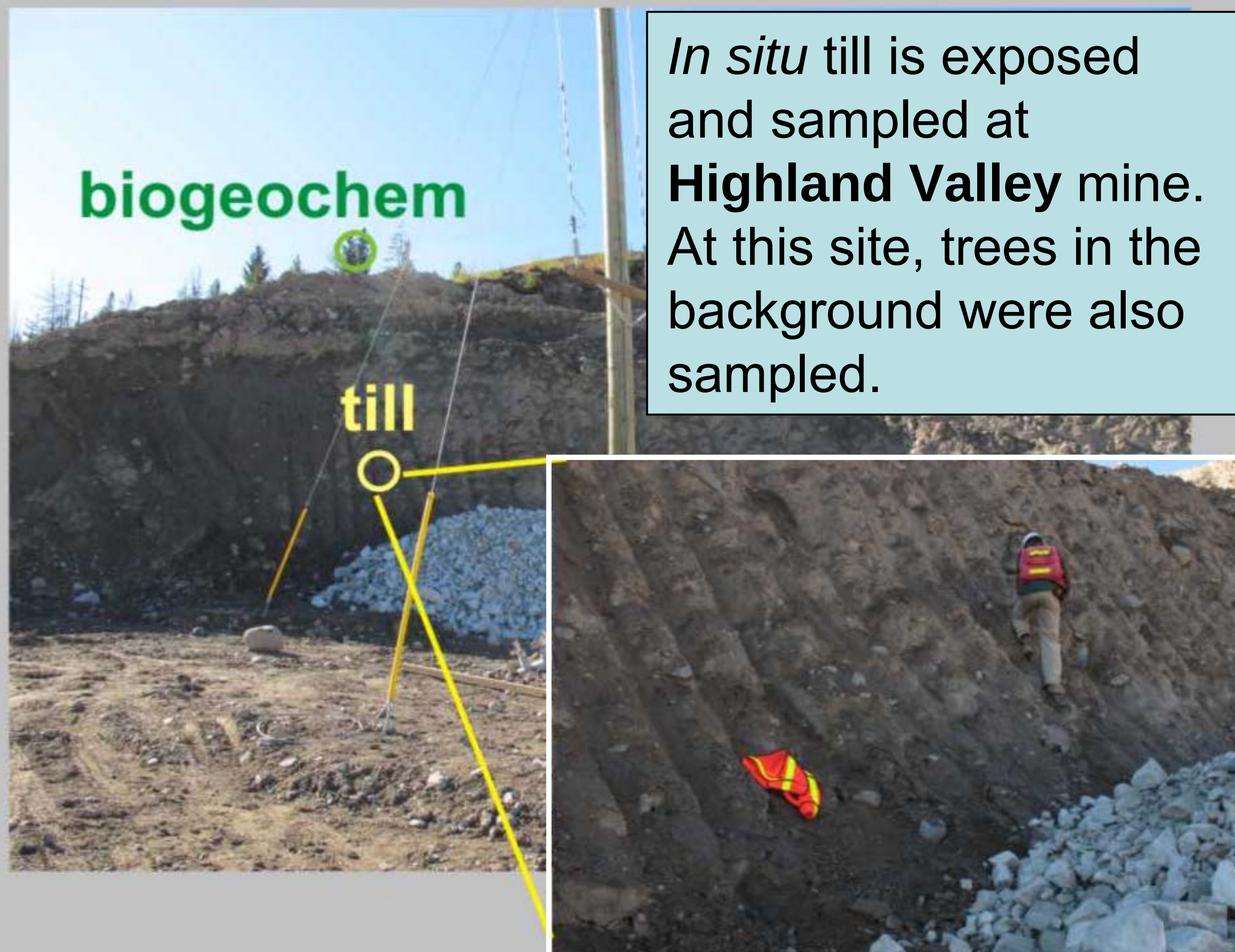


...Increasing Exploration

Canada

Intrusion Related Ore Systems -- Cordillera

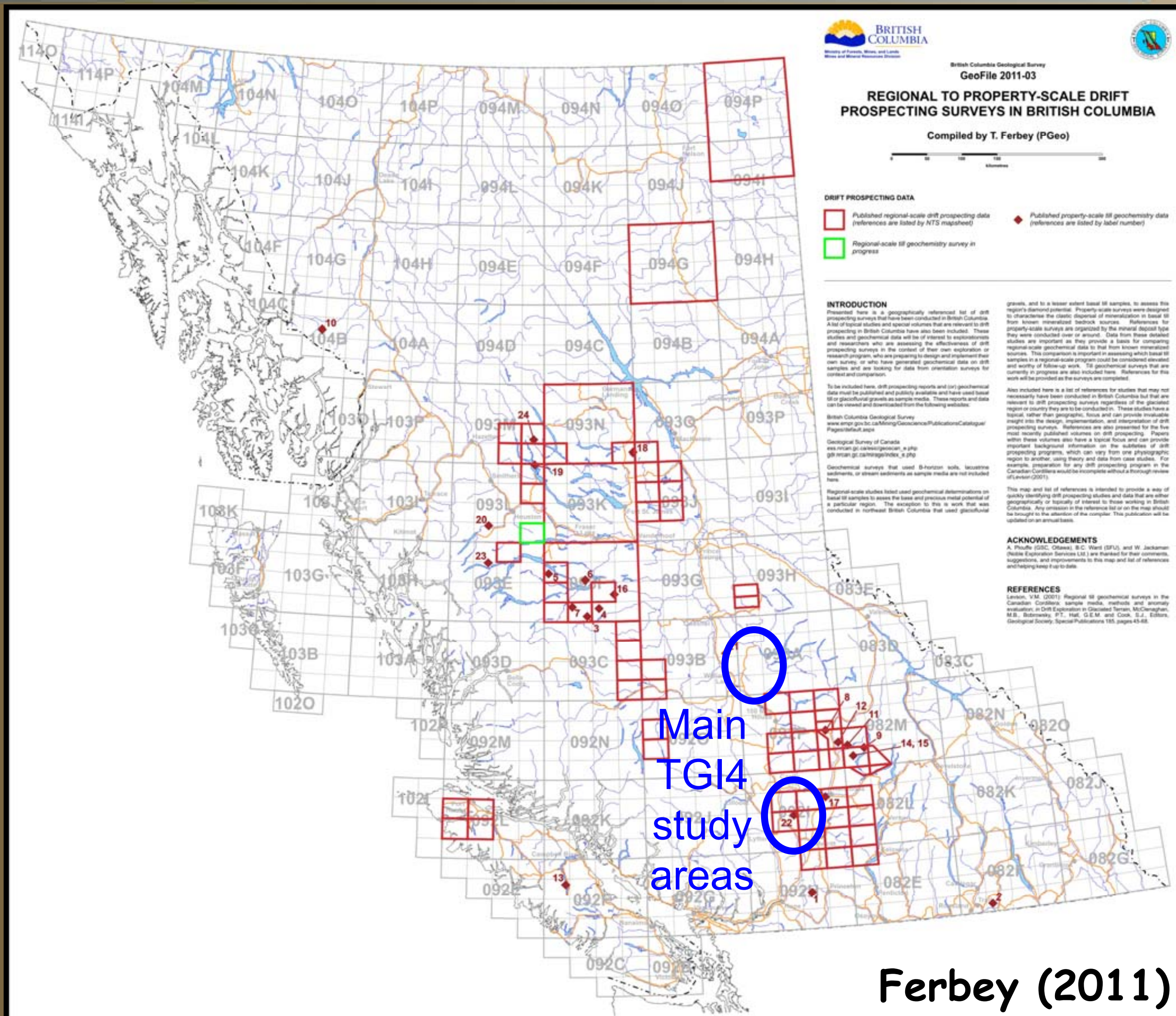
- **Identifying the signature of buried deposits (Highland Valley, Woodjam, Gibraltar)**



In situ till is exposed and sampled at **Highland Valley** mine. At this site, trees in the background were also sampled.

Glacial Processes -- Lessons from Previous Drift-Prospecting Studies in the Cordillera

Drift Prospecting Studies and Maps, B.C.



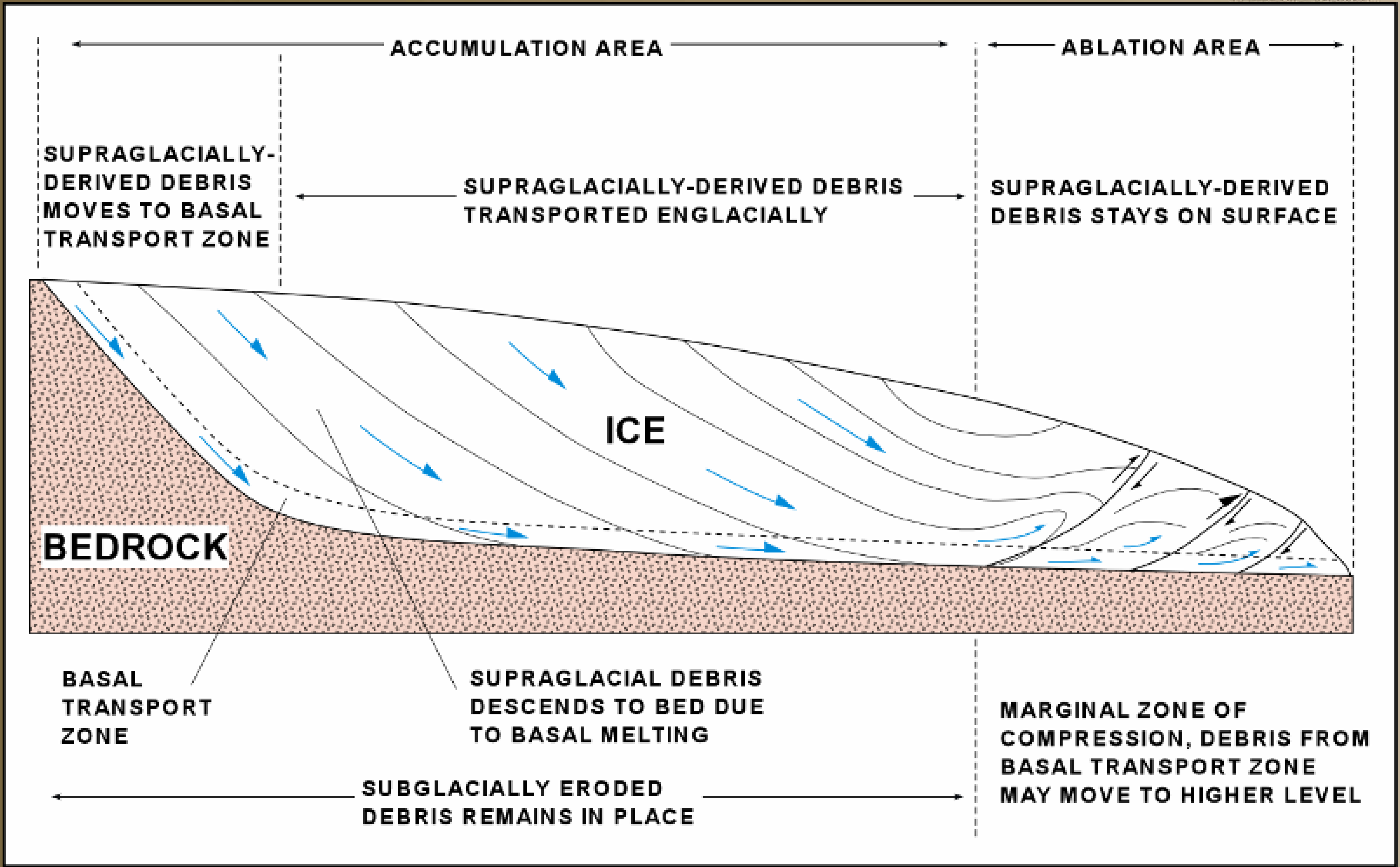
Canada

Drift Prospecting -- Mineral discoveries:

BRITISH COLUMBIA:

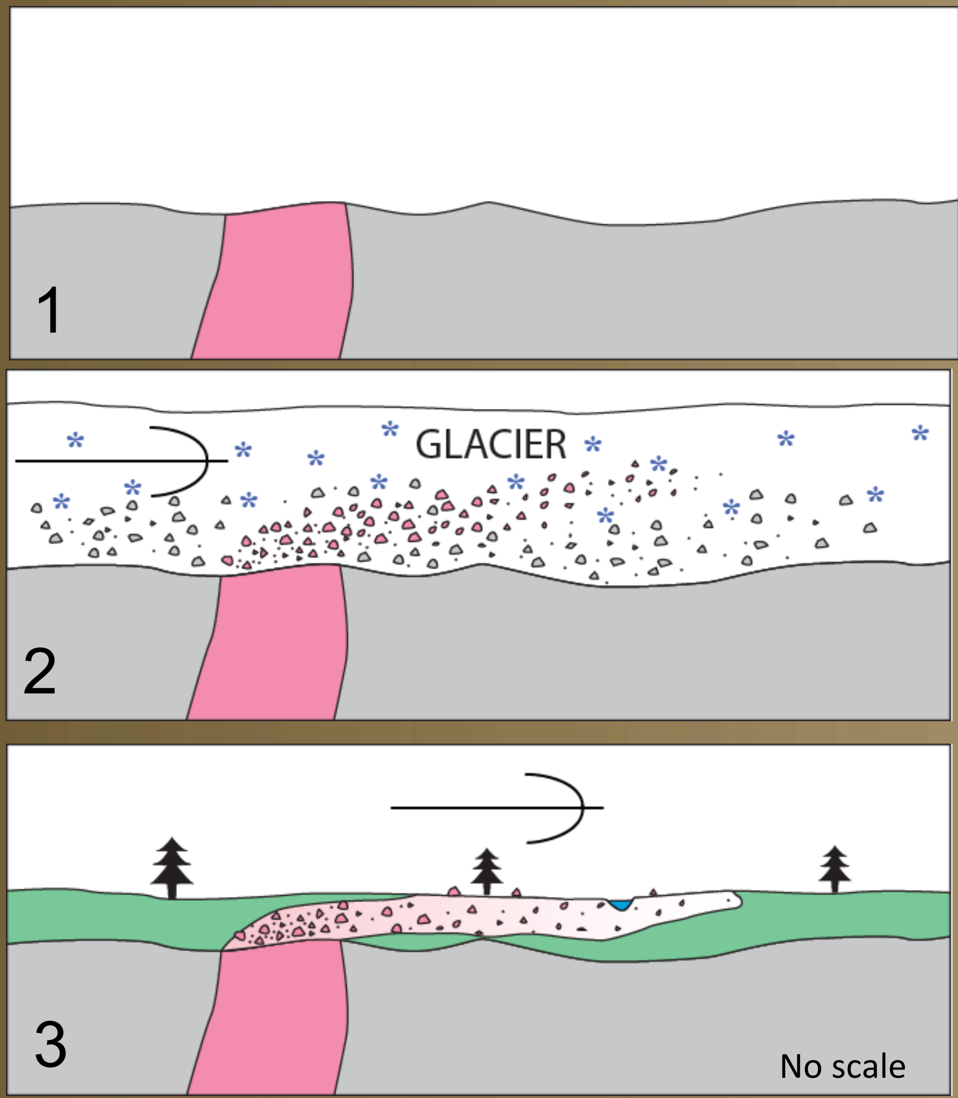
- Boulder tracing of gold mineralization (Plouffe et al. 2011a; CJES)
- Evidence of subglacial mineralization in the region of Windy Craggy (Day et al. 1987; CJES)
- Chappell Gold Silver deposit (Barr 1978; CIMM Bulletin)
- Sullivan Mine (Burchett 1944; Western Miner)
- Island Copper Deposit, Vancouver Island (Witherly 1979)
- 3Ts and Cigar anomalies (Levson et al. 1994; Levson, 2001; Cook et al., 1995)
- Red Sky property (Ferbey, 2010)

Glacial Processes -- Profile of a glacier



Boulton (1996)

Glacial transport: dispersal train (cross-section)



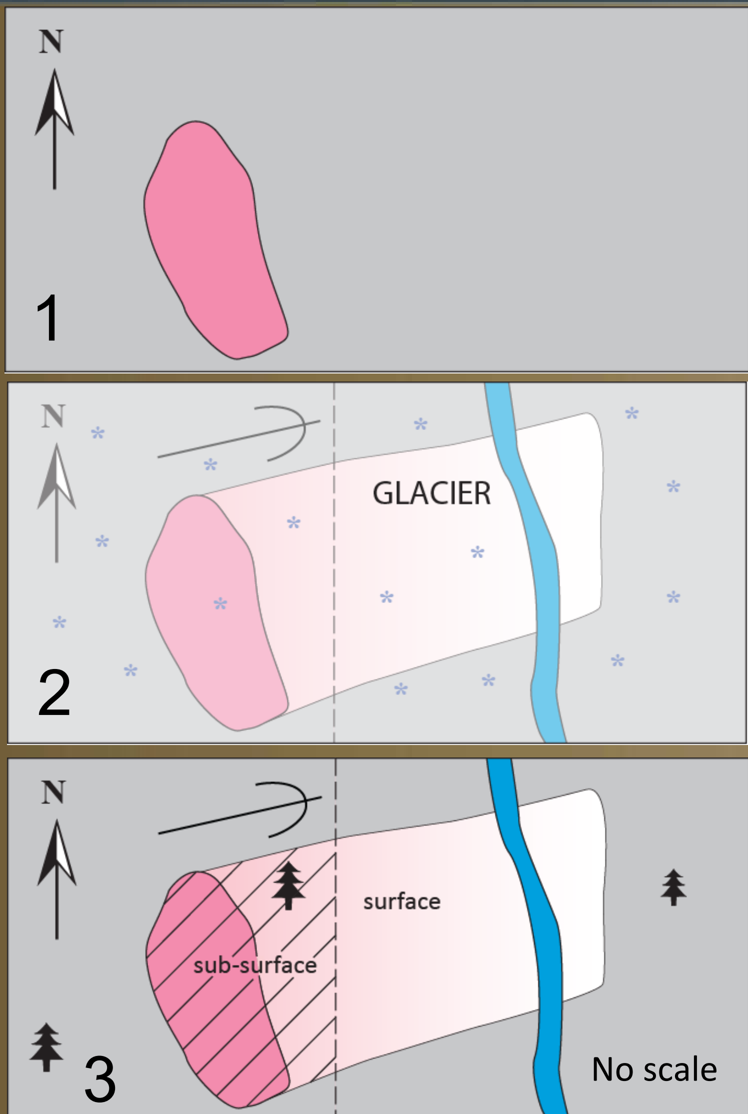
Mineralized zone (in pink) exposed at surface prior to a glaciation

Mineralized zone eroded by a glacier during a glaciation and mineralized debris transported in the direction of glacier flow (down-ice direction)

After glaciation, resulting glacial dispersal train (graded pink zone) in till (green). No scale on this diagram because scale of dispersal train depends on numerous factors: size of mineralized zone, contrast between mineralized zone and host rock, till thickness, topography and position of source rock, etc.

Modified from Drake (1983), Miller (1984), McClenaghan and Kjarsgaard (2007)

Glacial transport: dispersal train (plan view)



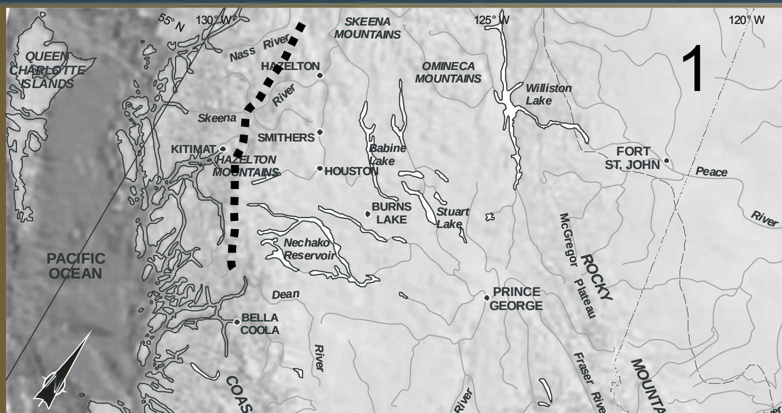
Same as previous figure but in plan view; mineralized zone exposed at surface prior to a glaciation

Mineralized zone eroded by a glacier during a glaciation and mineralized debris transported in the direction of glacier flow (down-ice direction)

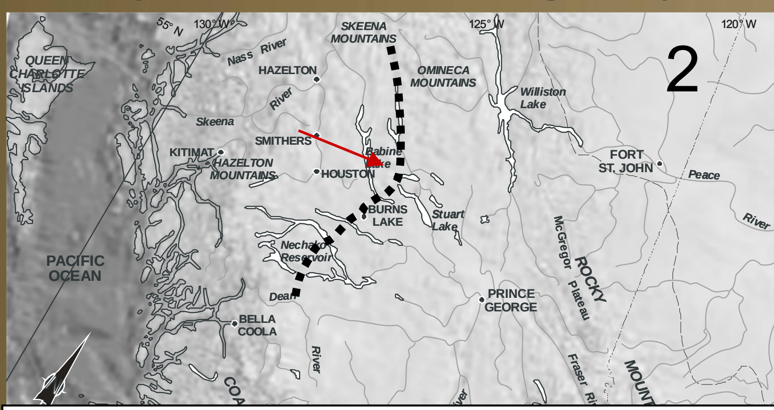
After glaciation, resulting glacial dispersal train (pink zone) is in the sub-surface close to the source and at surface at some distance. As in previous diagram, no scale is provided. Debris from the dispersal train can be reworked by streams and affect stream sediment composition

Modified from Drake (1983), Miller (1984), McClenaghan and Kjarsgaard (2007)

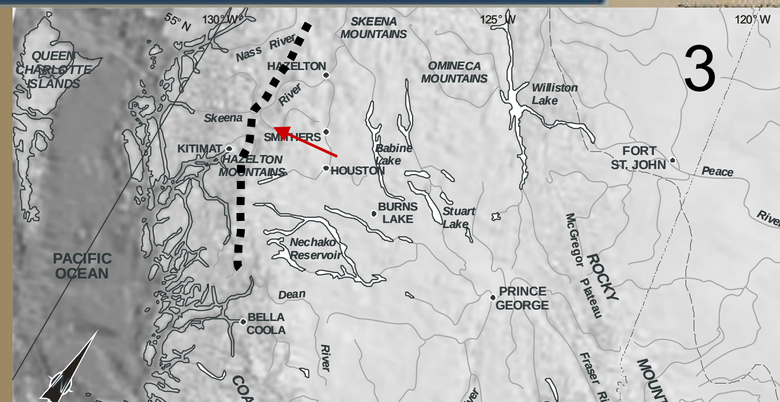
Glacial transport: the effect of ice divides



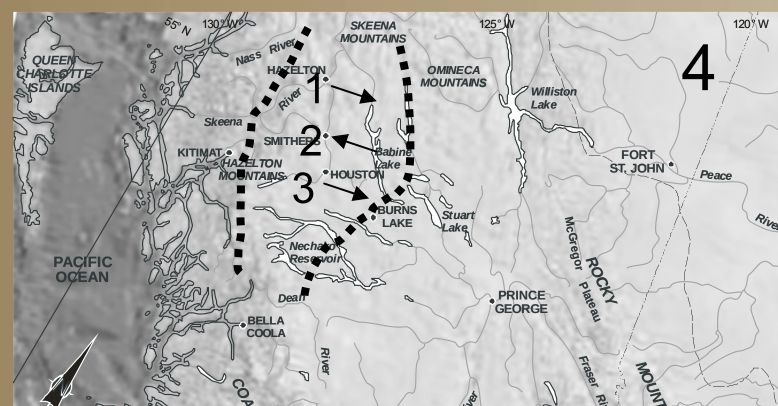
Ice divide (dotted line) above the Coast Mountains at the onset of the last glaciation



Migration of ice divide (dotted line) easterly (red arrow) above the Interior Plateau at glacial maximum



Ice divide (dotted line) migrated westerly (red arrow) during deglaciation.

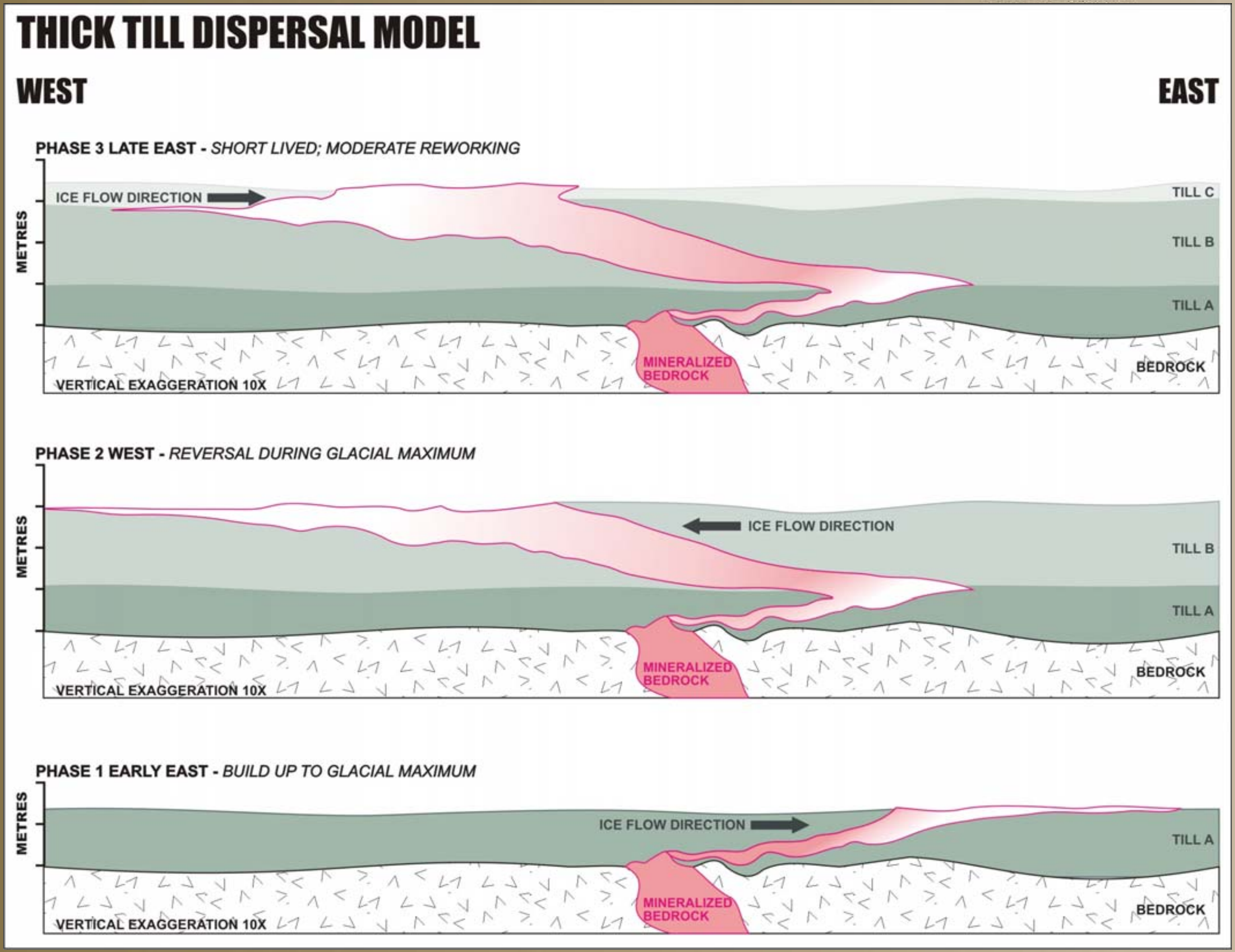


Major changes in ice-flow direction within the zone of ice divide migration

Stumpf et al. (2000)

Glacial Processes -- Ice-divide Migration and effect on glacial dispersal

Based on dispersal at Huckleberry Mine



Ferbey et al. (2012; BCGS Open File 2012-02)

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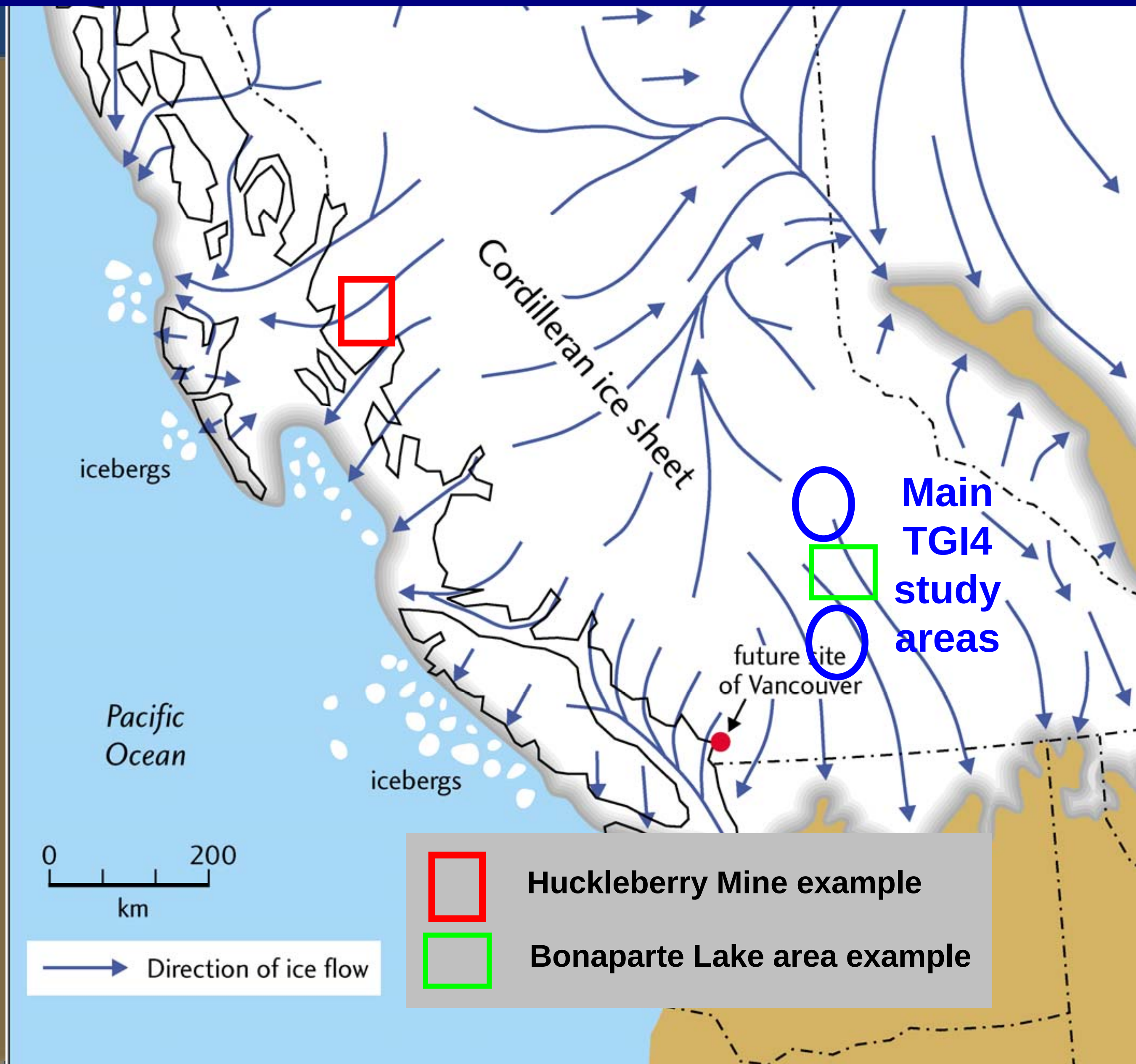
Glacial Processes -- Glacial transport in Bonaparte Lake area



TGI4 Ore Systems

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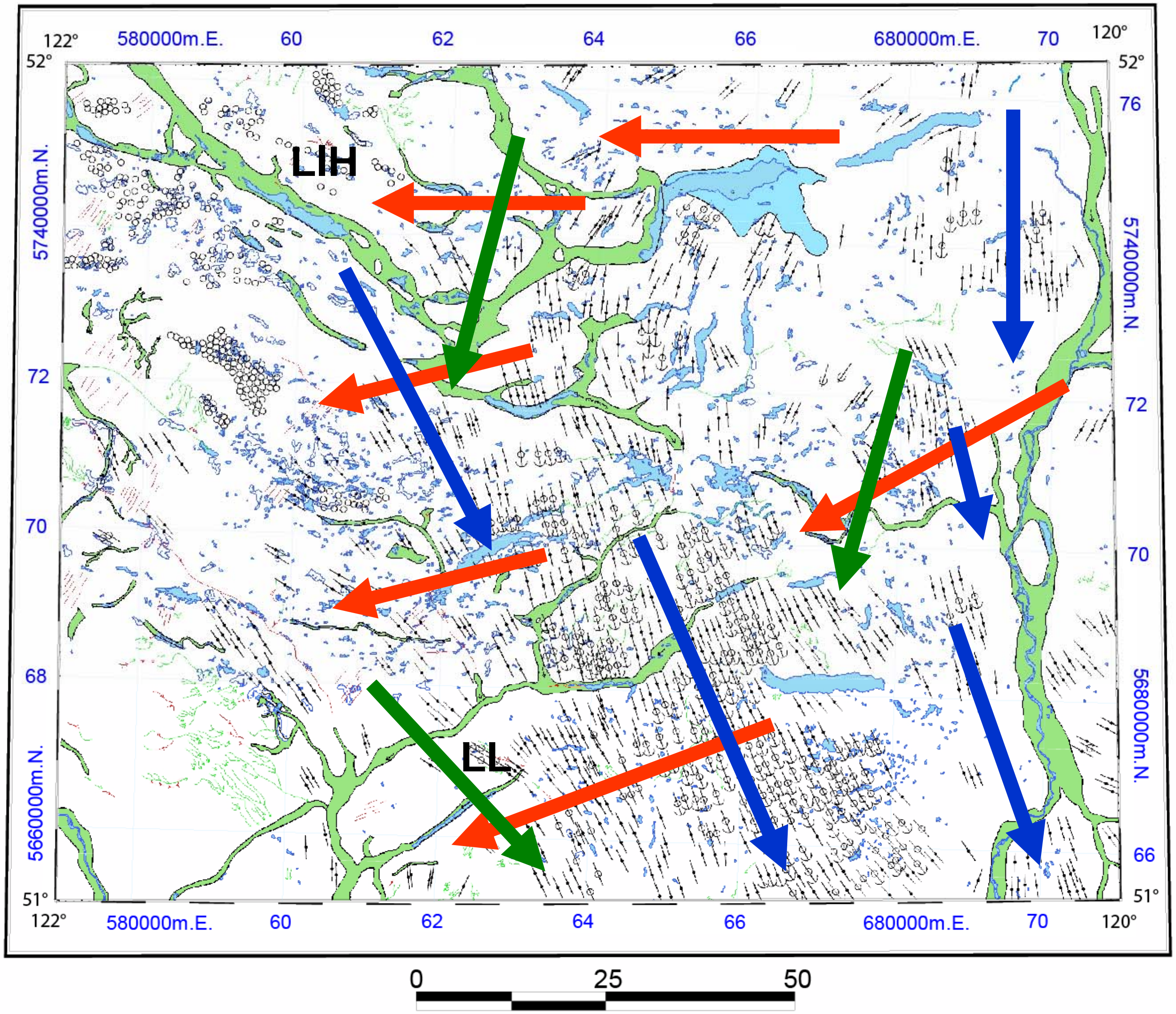
Glacial Processes -- Glacial transport in Bonaparte Lake area

Ice-flow history: south central British Columbia



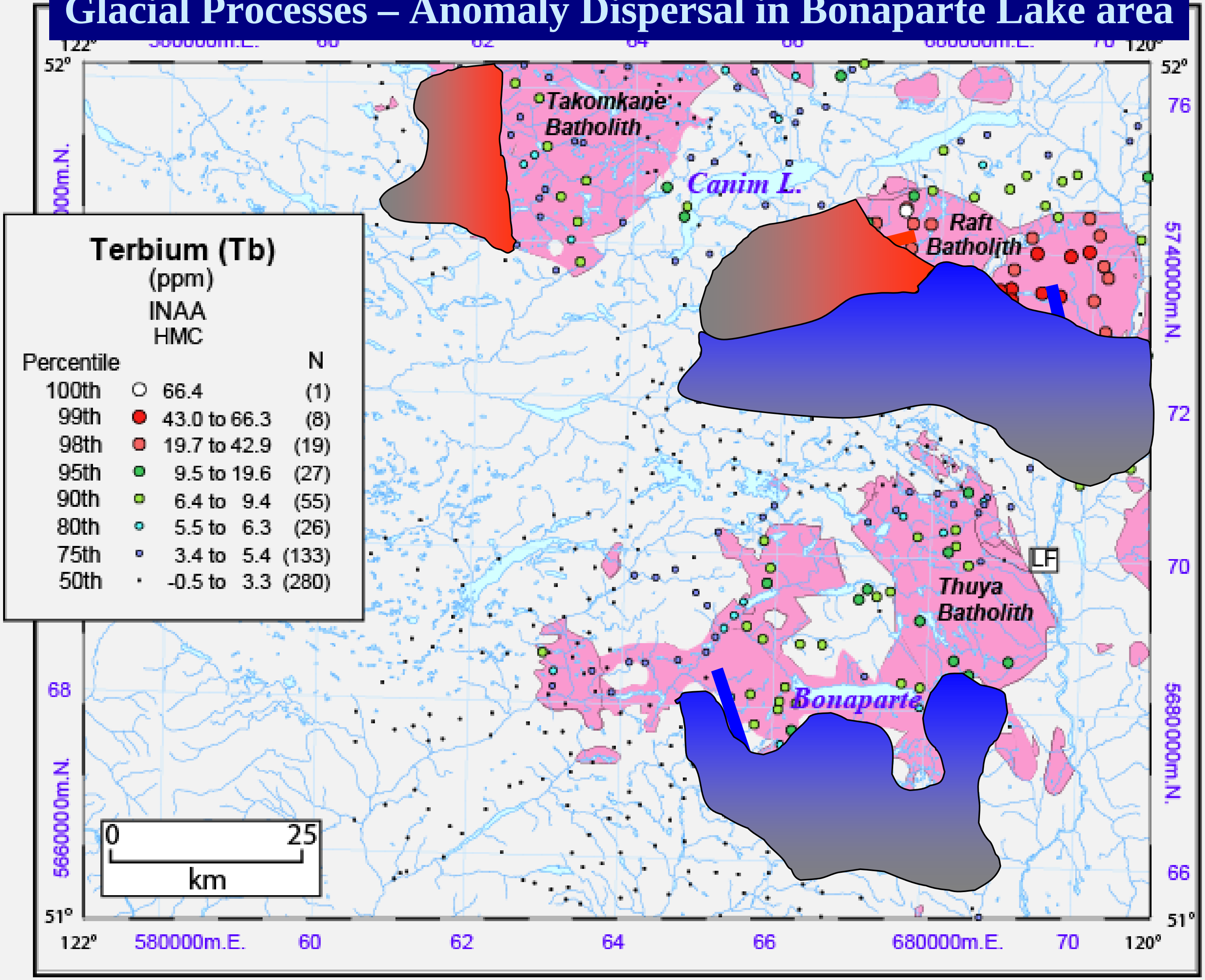
Regions

LIH -- Lac la Hache

LL -- Loon Lake

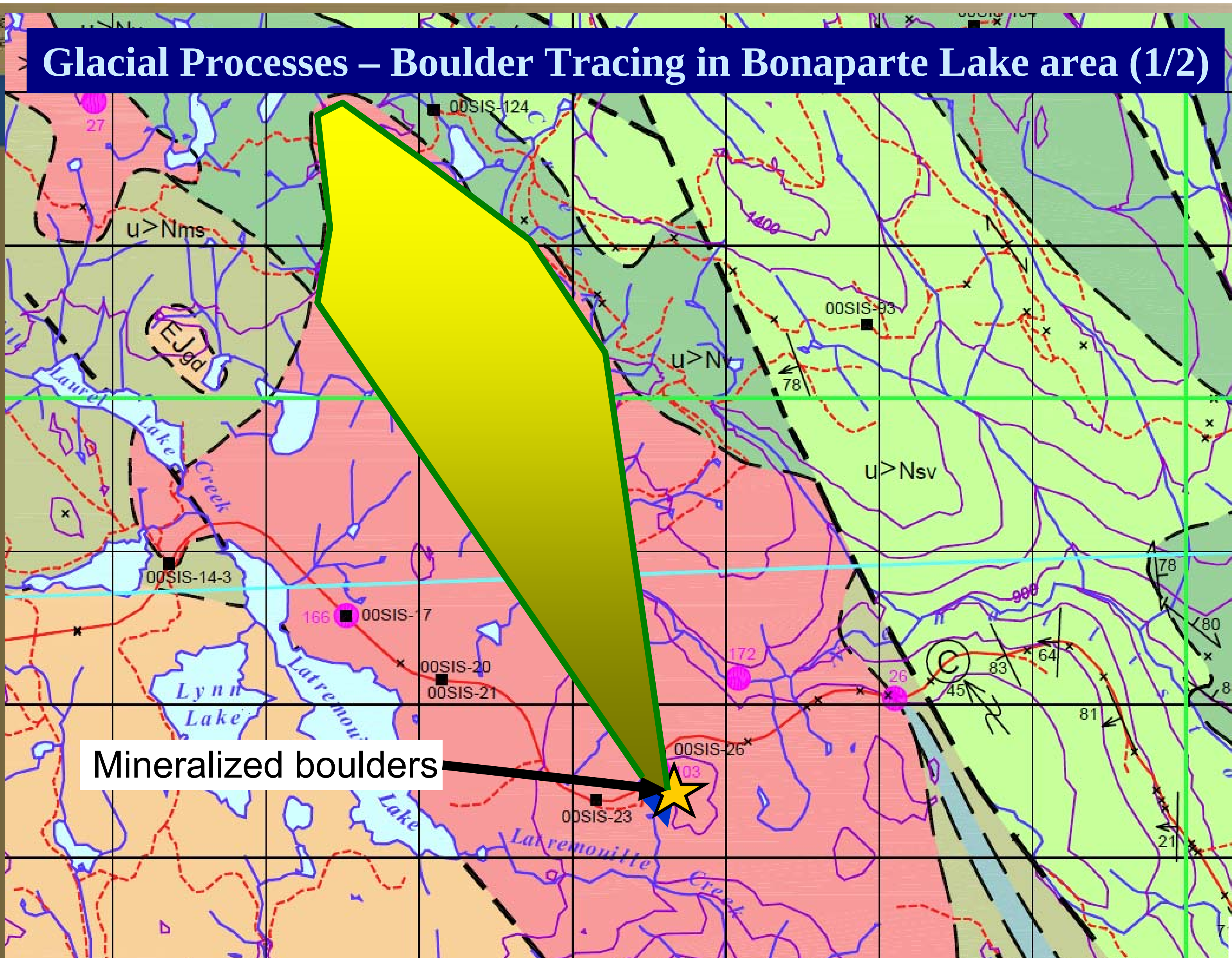
(Plouffe et al., 2011c; Tipper 1971a, b, c)

Glacial Processes – Anomaly Dispersal in Bonaparte Lake area



(Plouffe et al., 2010, 2011c)

Glacial Processes – Boulder Tracing in Bonaparte Lake area (1/2)



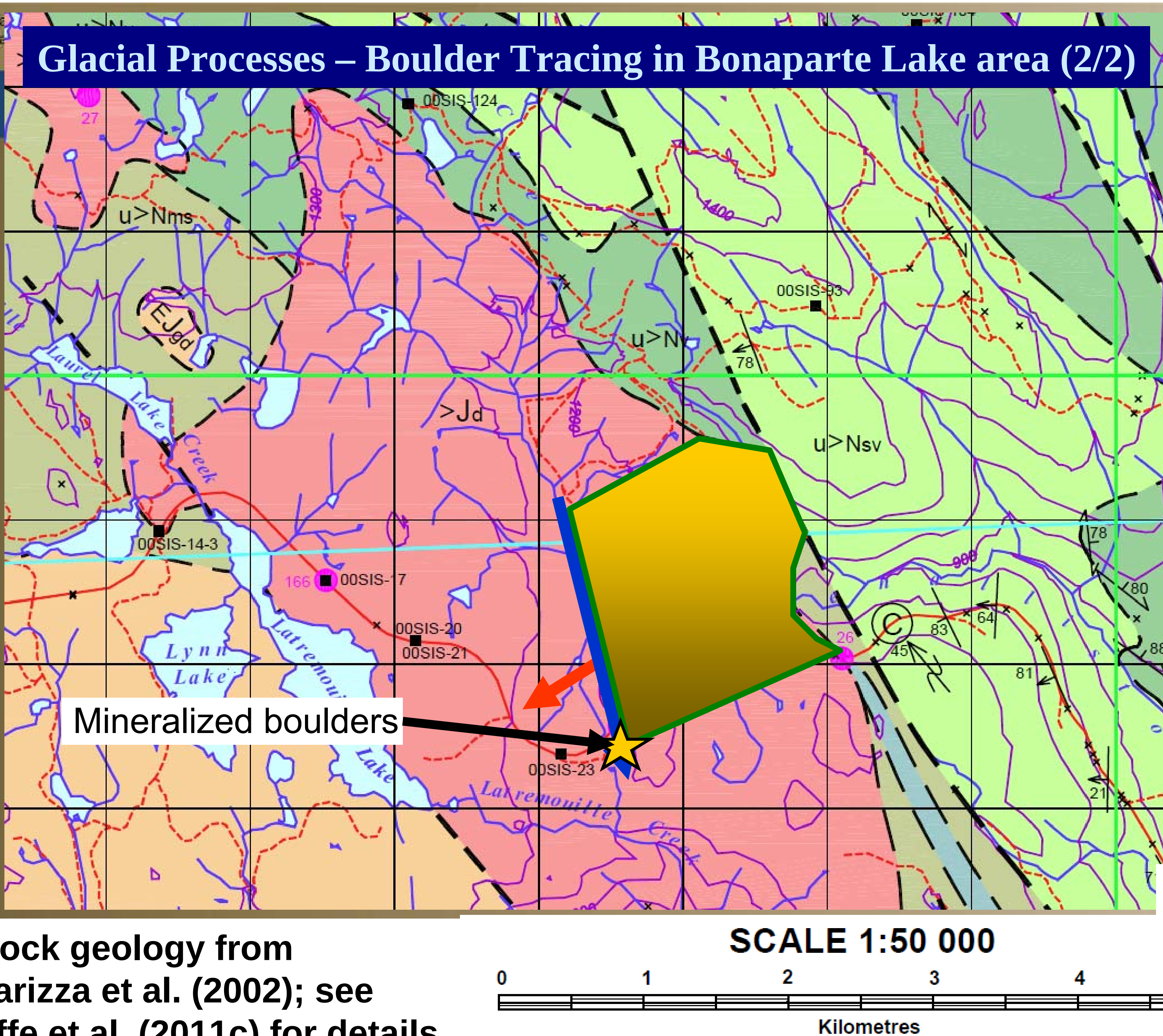
Bedrock geology from Schiarizza et al. (2002); see Plouffe et al. (2011a) for details.

SCALE 1:50 000

0 1 2 3 4 5

Kilometres

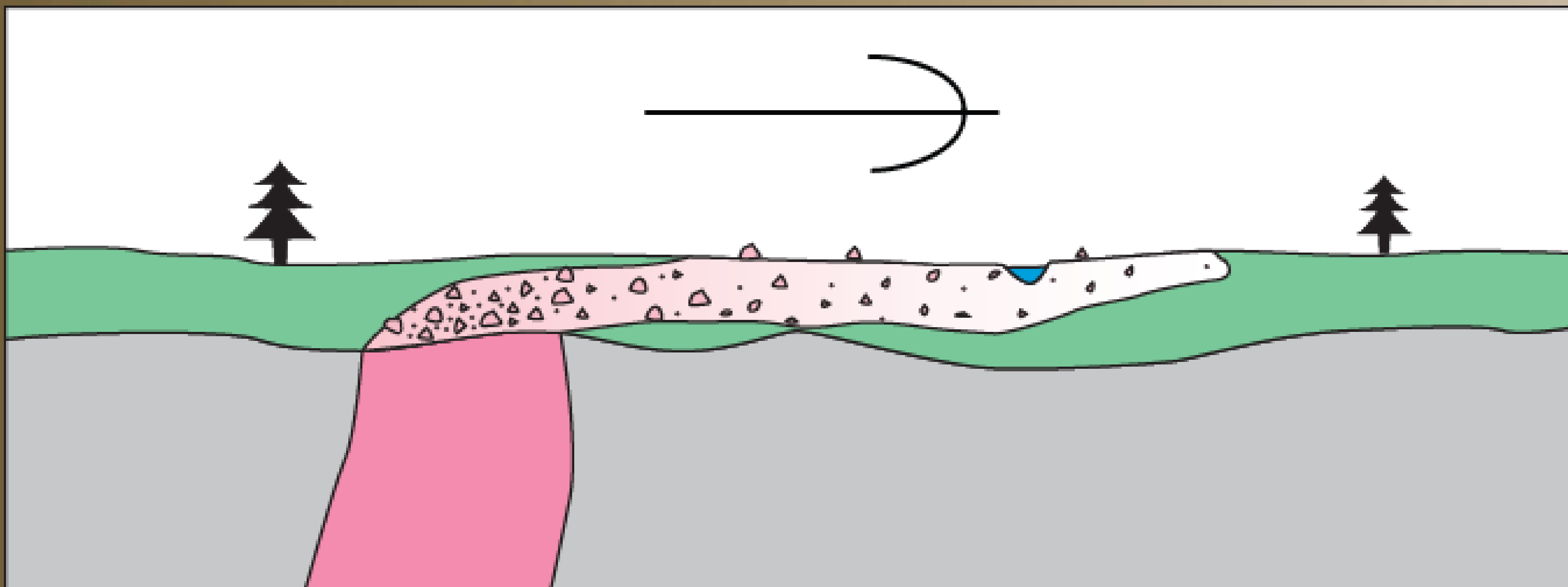
Glacial Processes – Boulder Tracing in Bonaparte Lake area (2/2)



Bedrock geology from Schiarizza et al. (2002); see Plouffe et al. (2011c) for details.

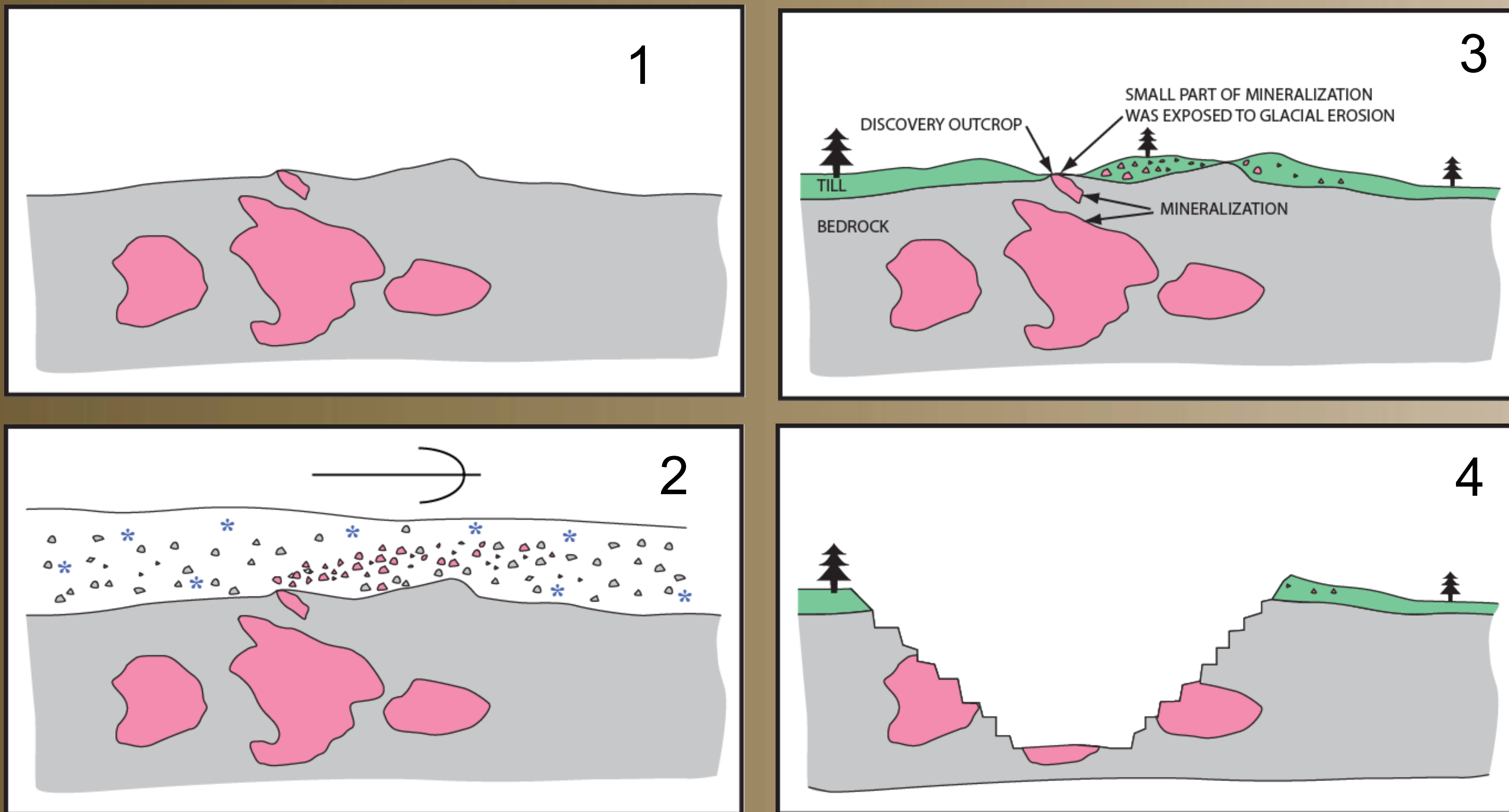
Glacial Processes – Source area and dispersal; present *NOT* the key to the past?

Mineralization exposed to glacial erosion;
single till sheet



Modified from Drake (1983), Miller (1984), McClenaghan and Kjarsgaard (2007)

Glacial Processes – Source area and dispersal; present *NOT* the key to the past?



e.g. Gibraltar Mine

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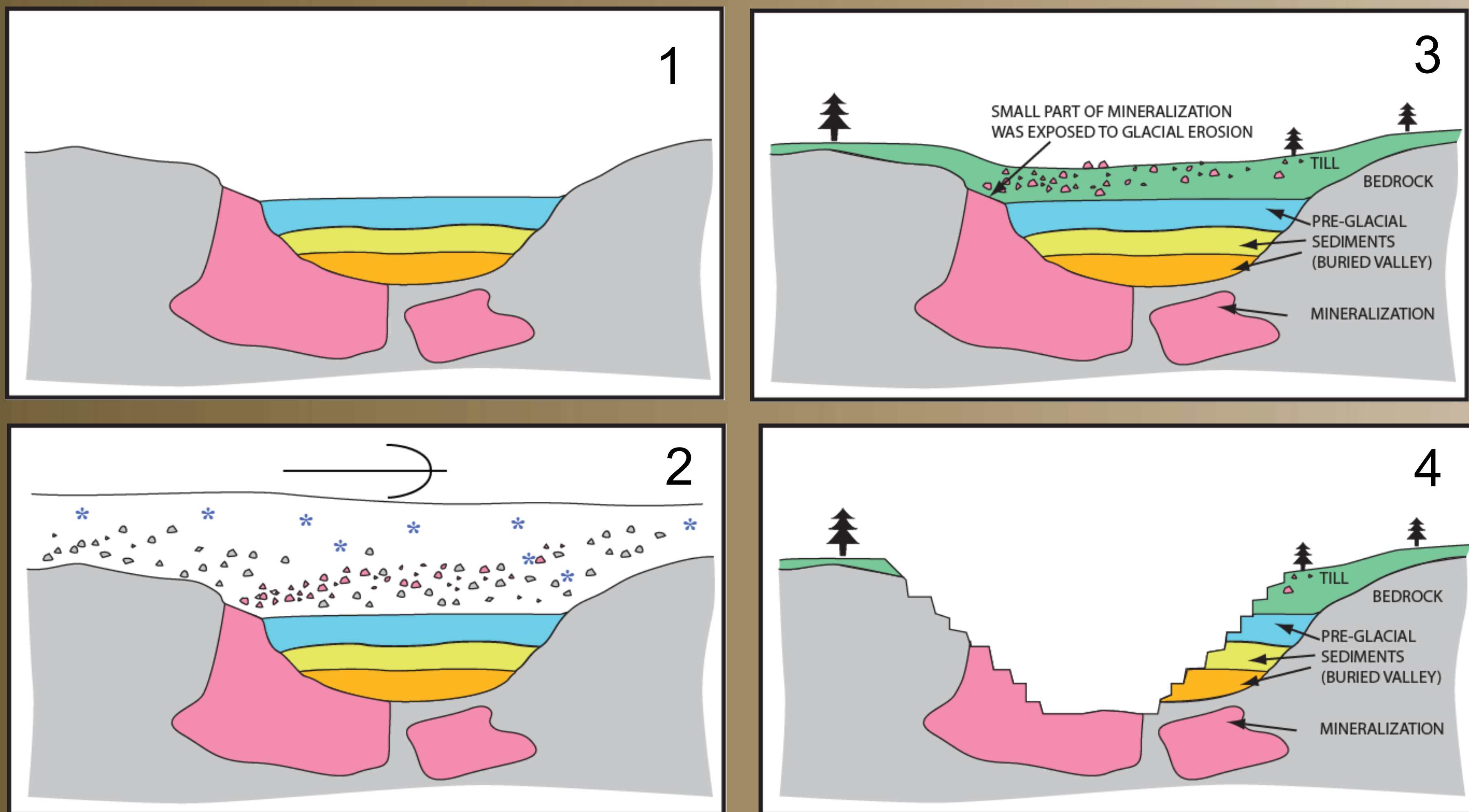
Gibraltar Mine -- Gibraltar Pit

Canada

Glacial Processes – Source area and dispersal; present *NOT* the key to the past?

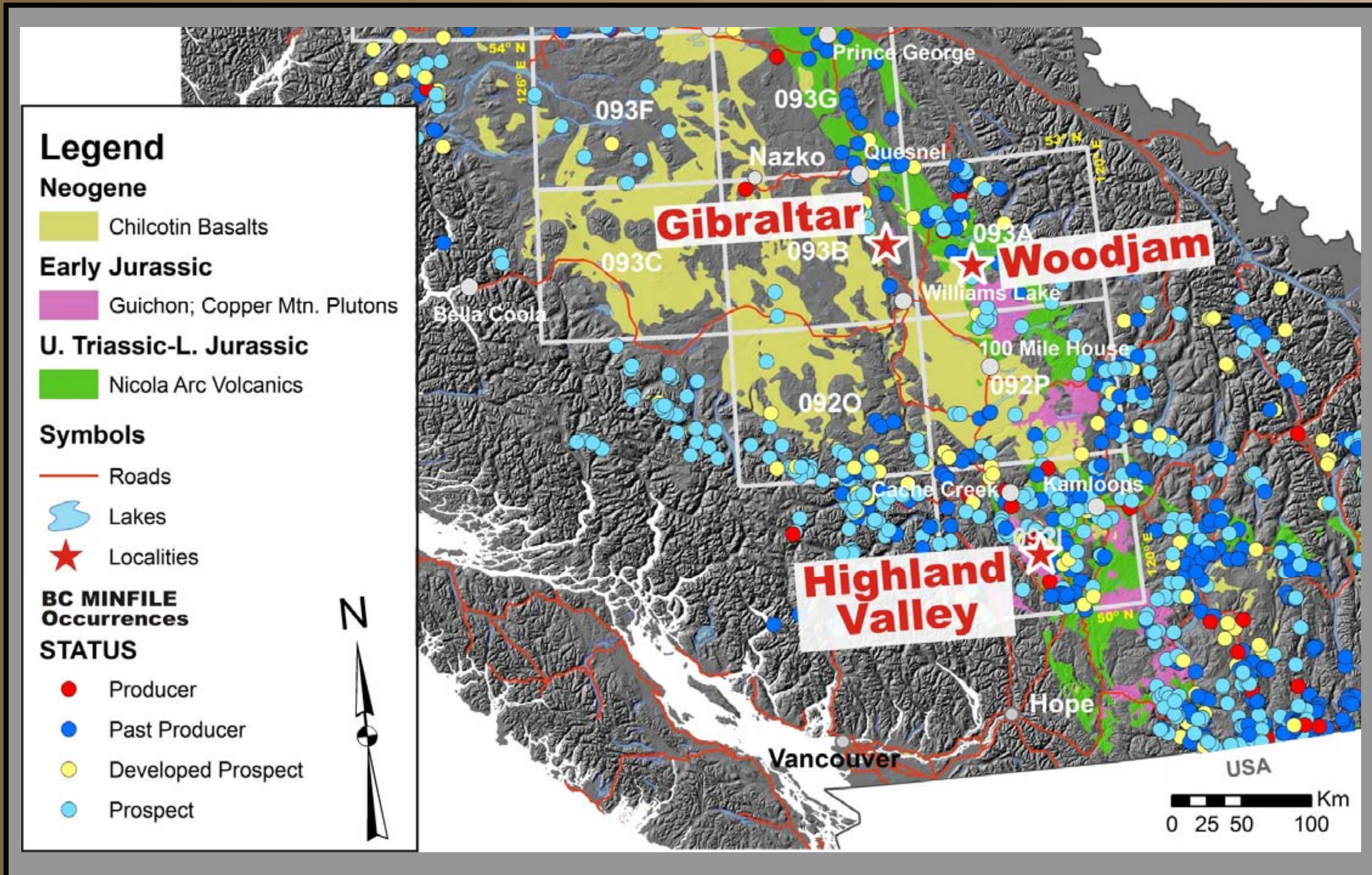


e.g. Highland Valley Mine

Highland Valley Mine: Valley Pit and pre-glacial sediments cover

View W to Valley Pit, Highland Valley District (July 2011)

Scoping Study 1 – Gibraltar: Bedrock Geology



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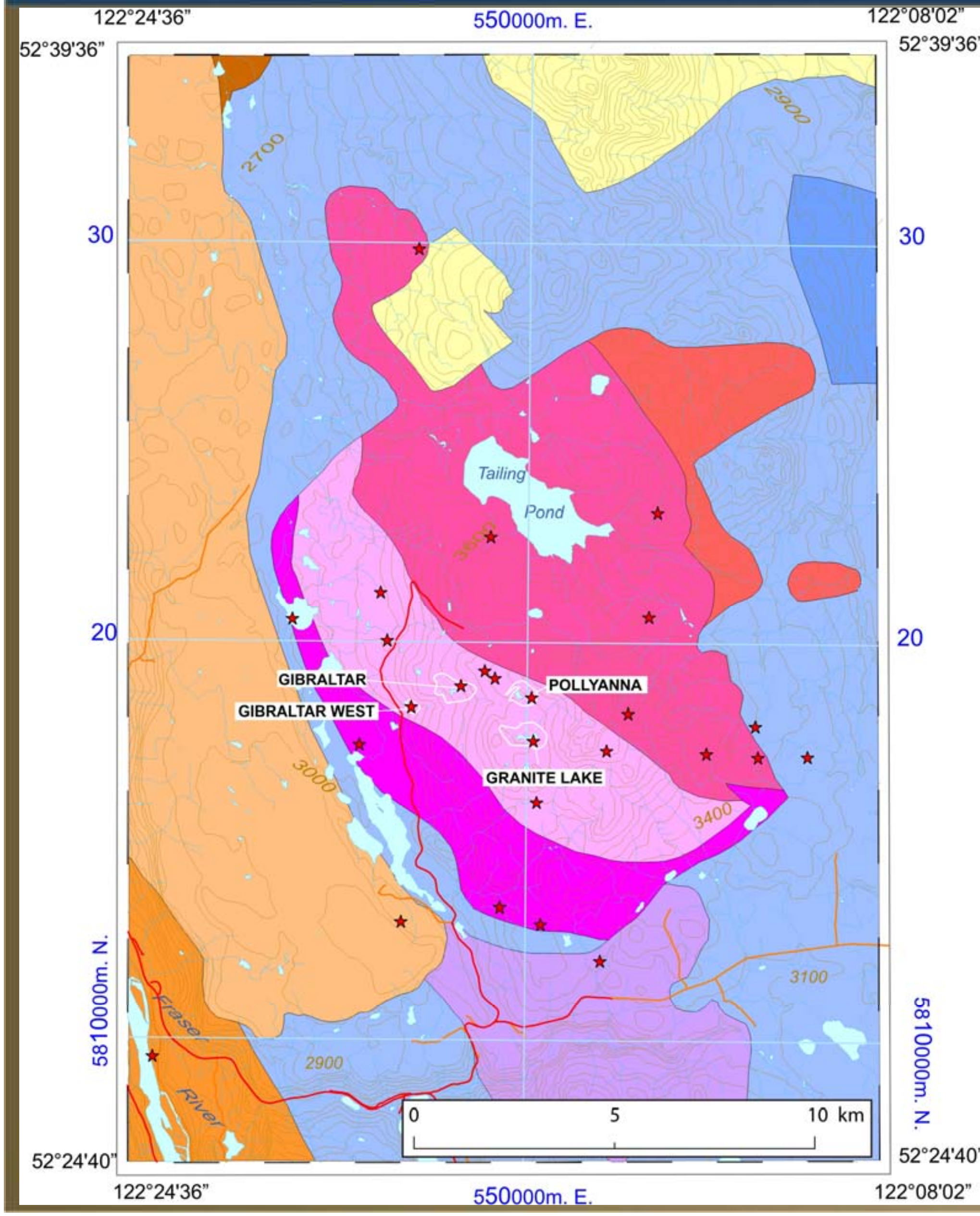
Scoping Study 1 – Gibraltar: Bedrock Geology



LEGEND

STRATIFIED ROCKS

Neogene
Chilcotin Group
- Basaltic volcanic rocks with lesser sedimentary rocks

Oligocene to Pliocene
- Conglomerate

Eocene to Oligocene
Endako Group
- Basaltic volcanic rocks with lesser sedimentary rocks

Quesnel Terrane
Upper Triassic and Lower Jurassic
Nicola Group
- Volcanic sandstone and siltstone

Cache Creek Terrane
Carboniferous - Lower Jurassic
Cache Creek Complex
- Undivided marine sedimentary and volcanic rocks
- Limestone, minor greenstone, chert, and argillite

INTRUSIVE ROCKS

Mid-Cretaceous
Sheridan stock (ca. 108 Ma)
- Quartz monzonite, granodiorite, granite, quartz diorite

Middle Jurassic
Ste. Marie Plutonic Suite
- Quartz monzonite

Late Triassic
Granite Mountain Batholith (ca. 215 Ma)
Granite Mountain phase
- Leucocratic quartz diorite

Mine and northern border phase
- Quartz diorite

Southern border phase
- Diorite

★ Minfile occurrence

Geology from: Ash et al., 1999a

Canada

Scoping Study 1 – Gibraltar: Bedrock Geology

View approximately east to poly-deformed, altered tonalite in Gibraltar pit (rock hammer is 30 cm long).

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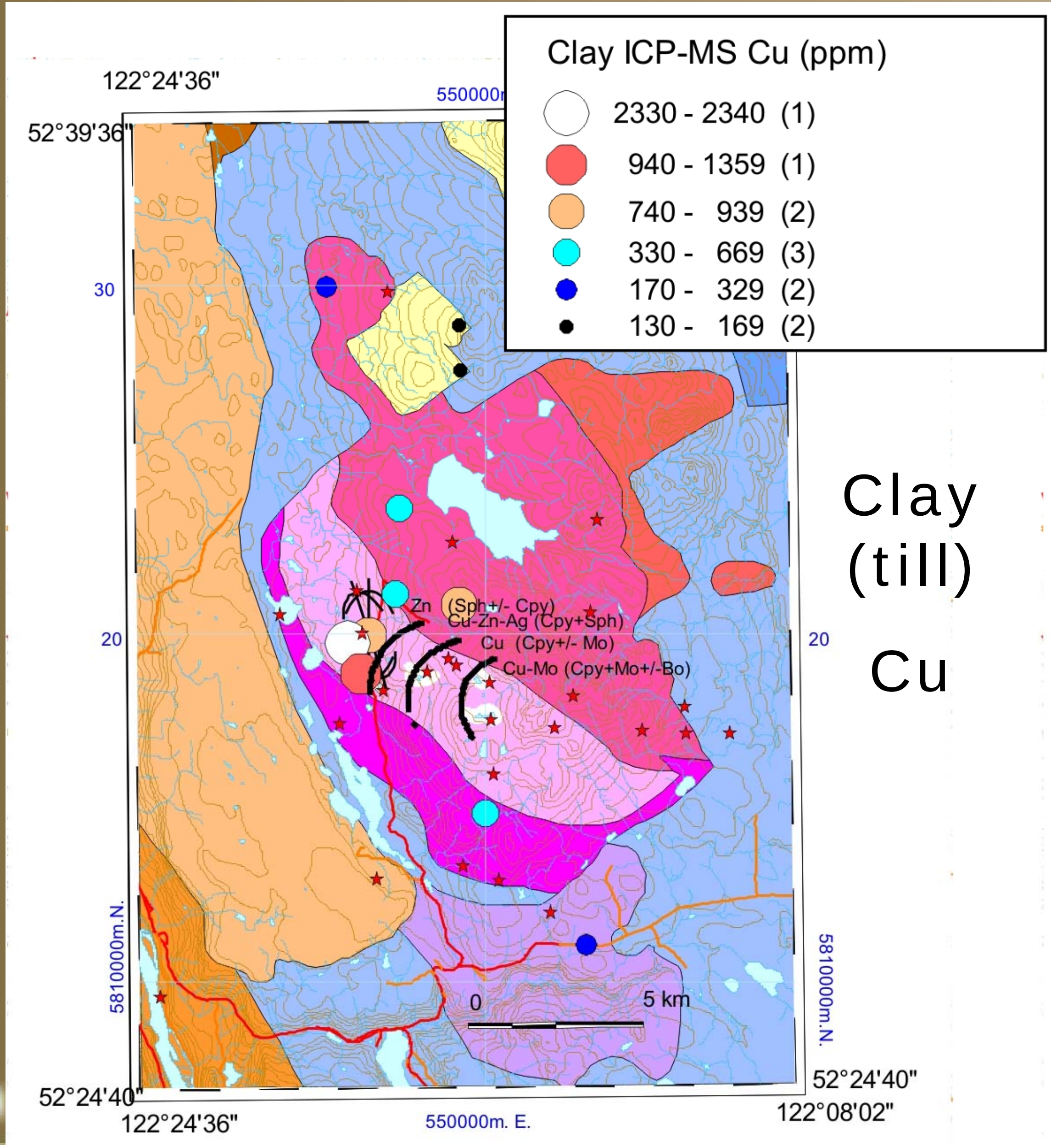
Scoping Study 1 – Gibraltar: Previous Work – till geochemistry



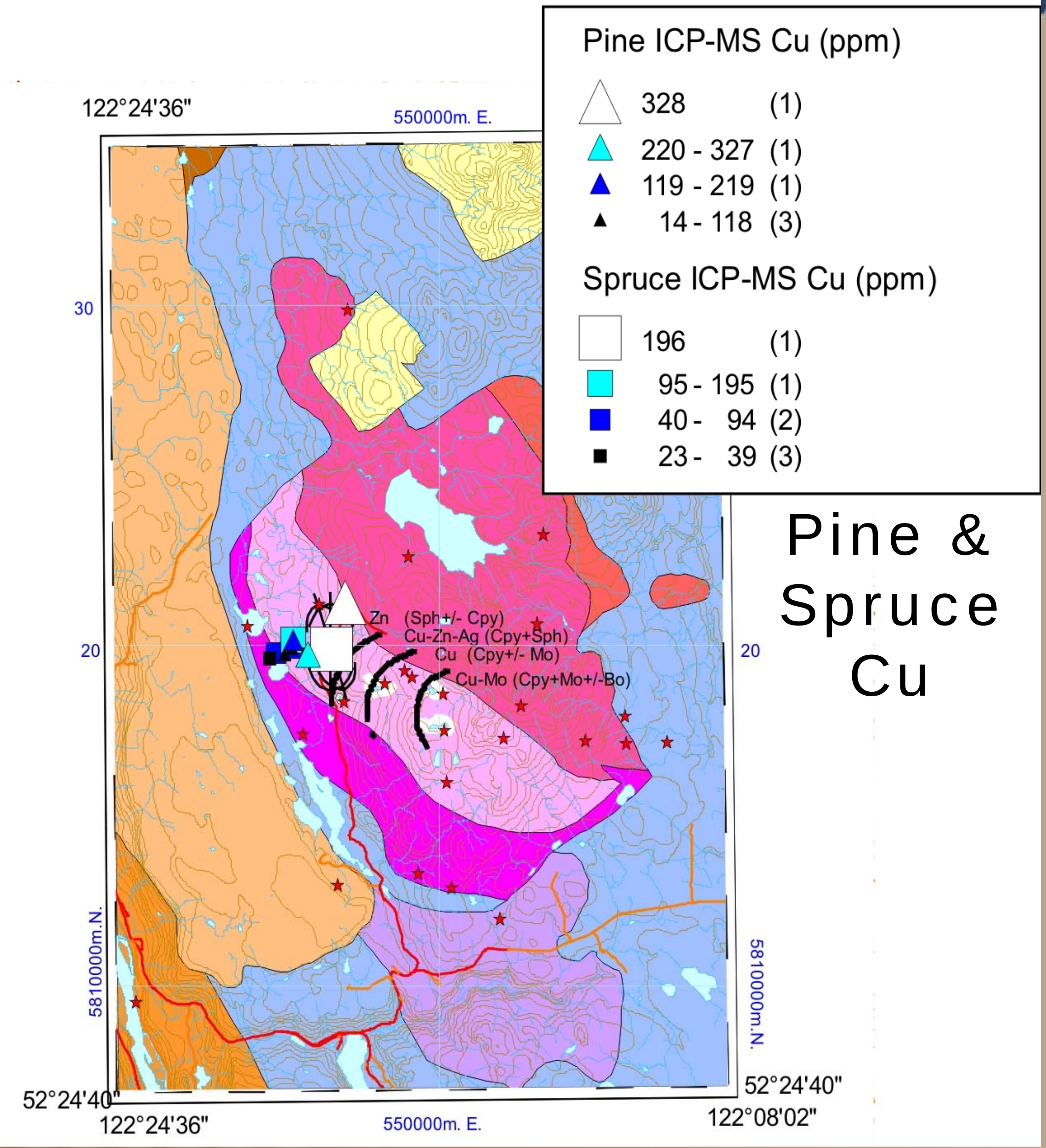
Clay (till)

Cu

Preliminary results -- Plouffe et al. (2011b)

Canada

Scoping Study 1 – Gibraltar: Previous Work –biogeochemistry

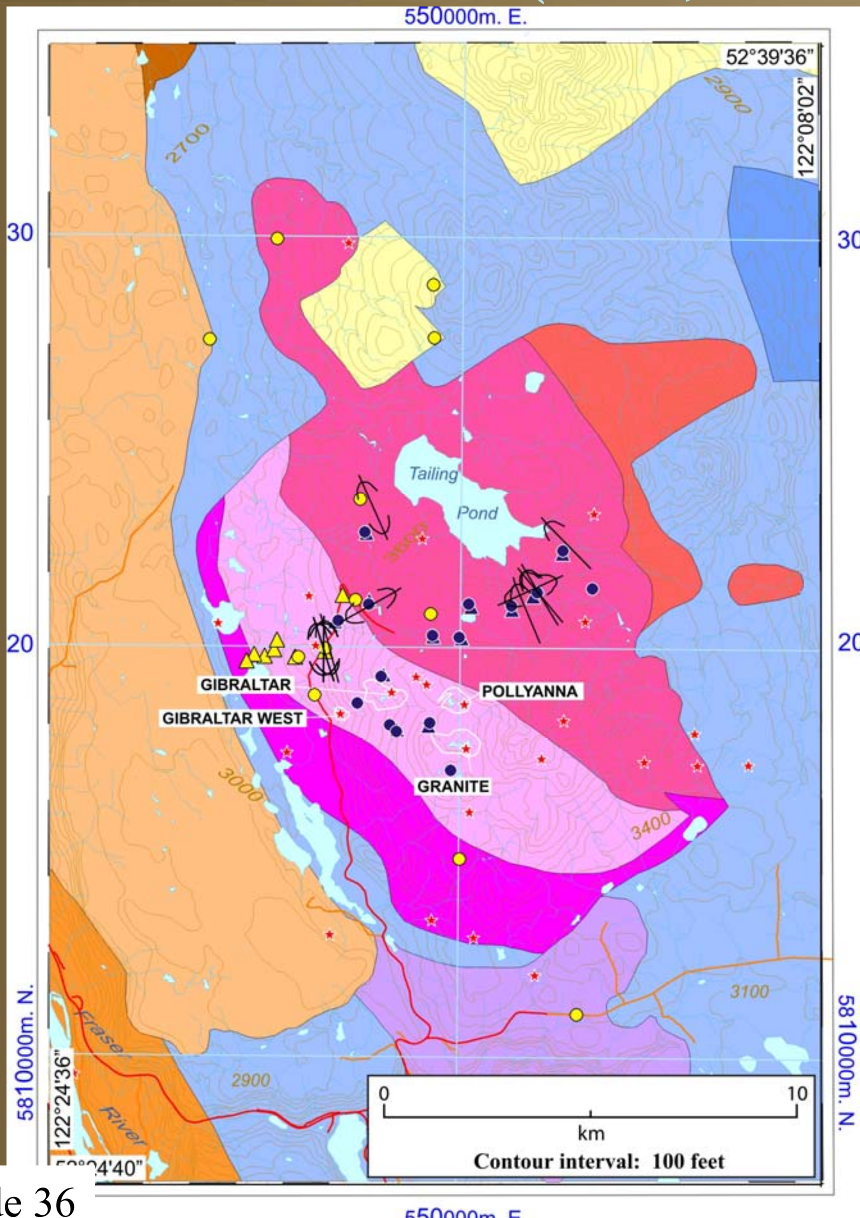


Pine & Spruce Cu

Preliminary results -- Plouffe et al. (2011b)

Canada

Scoping Study 1 – Gibraltar: Ice Movement Indicators and 2011 Sampling Sites (till = 19; bark = 21)



LEGEND

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Late Triassic
Granite Mountain Batholith (ca. 215 Ma)
Granite Mountain phase
- Leucocratic quartz diorite

Mine and northern border phase
- Quartz diorite

Southern border phase
- Diorite

Open pit
Glacial striations (movement direction: known, unknown)

2008 samples (GSC OF 6755)
- tree bark
- till

2011 samples
- tree bark
- till

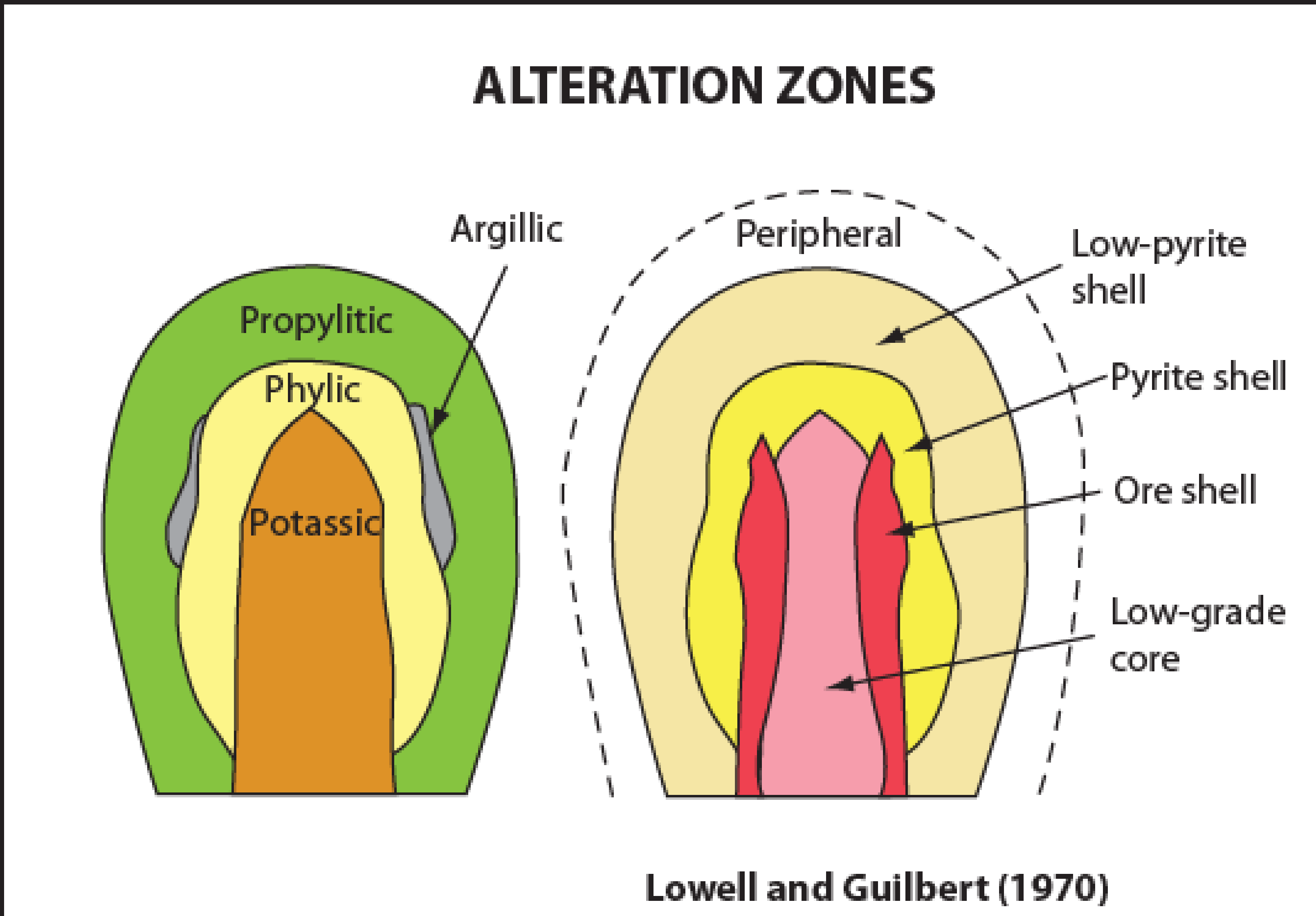
Minfile occurrence

Geology from: Ash et al., 1999a

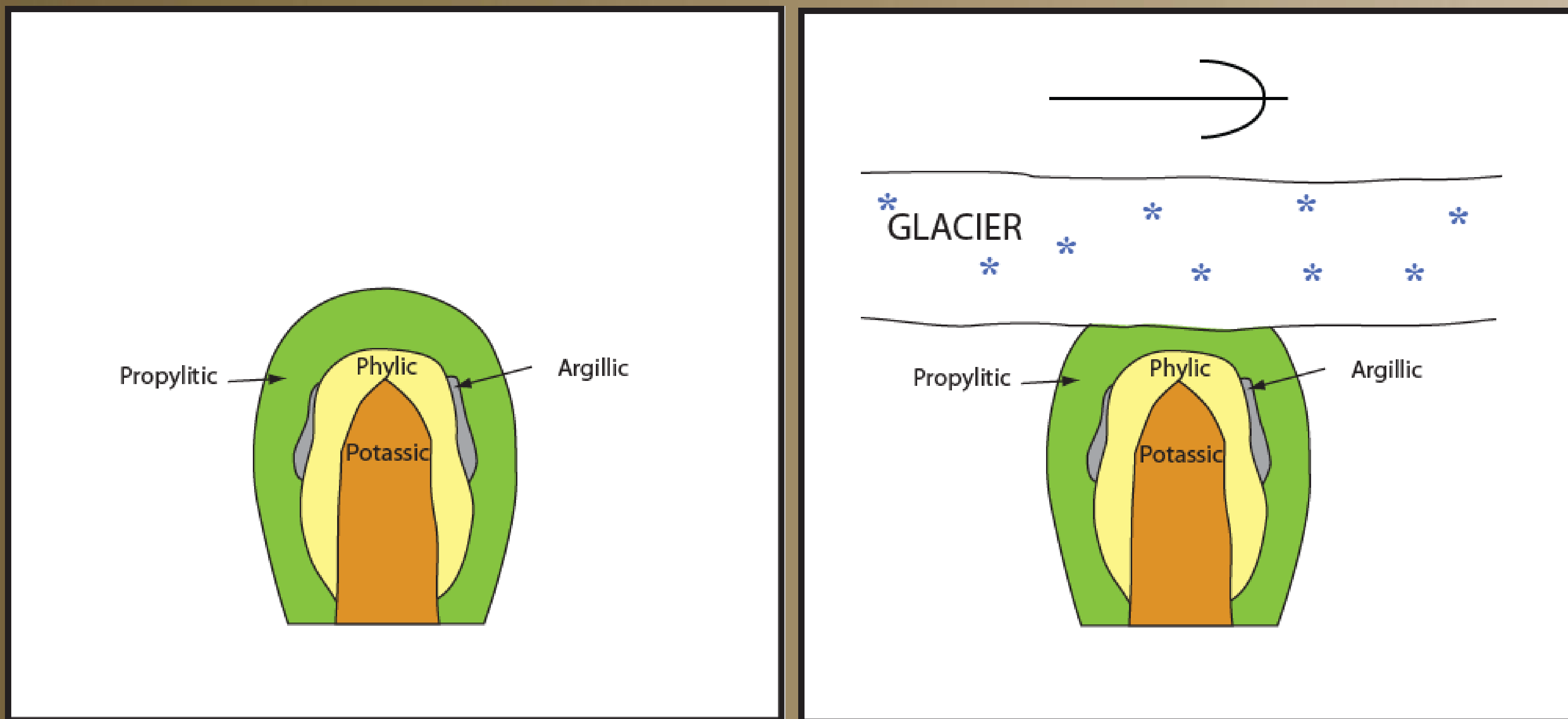
Scoping Study 1 – Gibraltar: 2011 Sampling Sites

Sampling sites in the pits, such as at Gibraltar pit, were chosen where the sediment succession was *in situ* and tree cover had survived.

Alteration zones and Porphyry Indicator Minerals (PIM)



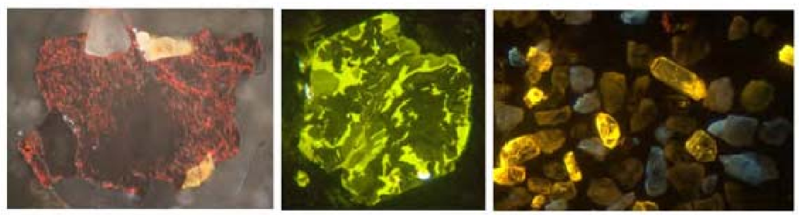
Glacial erosion of porphyry system alteration zones



Porphyry Indicator Minerals (PIM) – Mineral Deposit Research Unit

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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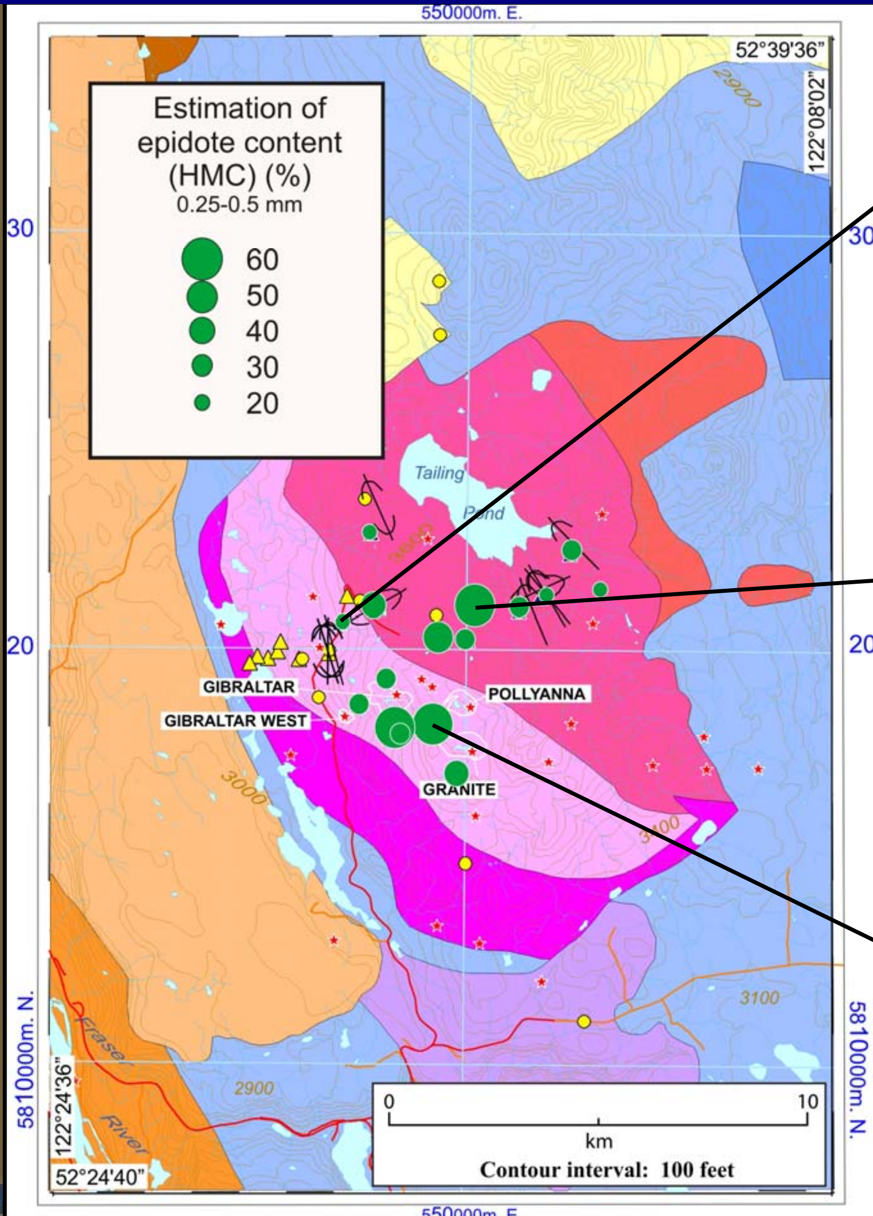
Mineral Deposit Research Unit
UBC

Canada

Heavy Mineral Concentrates and Porphyry Indicator Minerals (PIM) – modal estimates of epidote at Gibraltar



Sample 11PMA-038A-1

20% Epidote

(0.25-0.50 mm)

Sample 11PMA-018A-1

60% Epidote

(0.25-0.50 mm)

Sample 11PMA-029A-1

60% Epidote

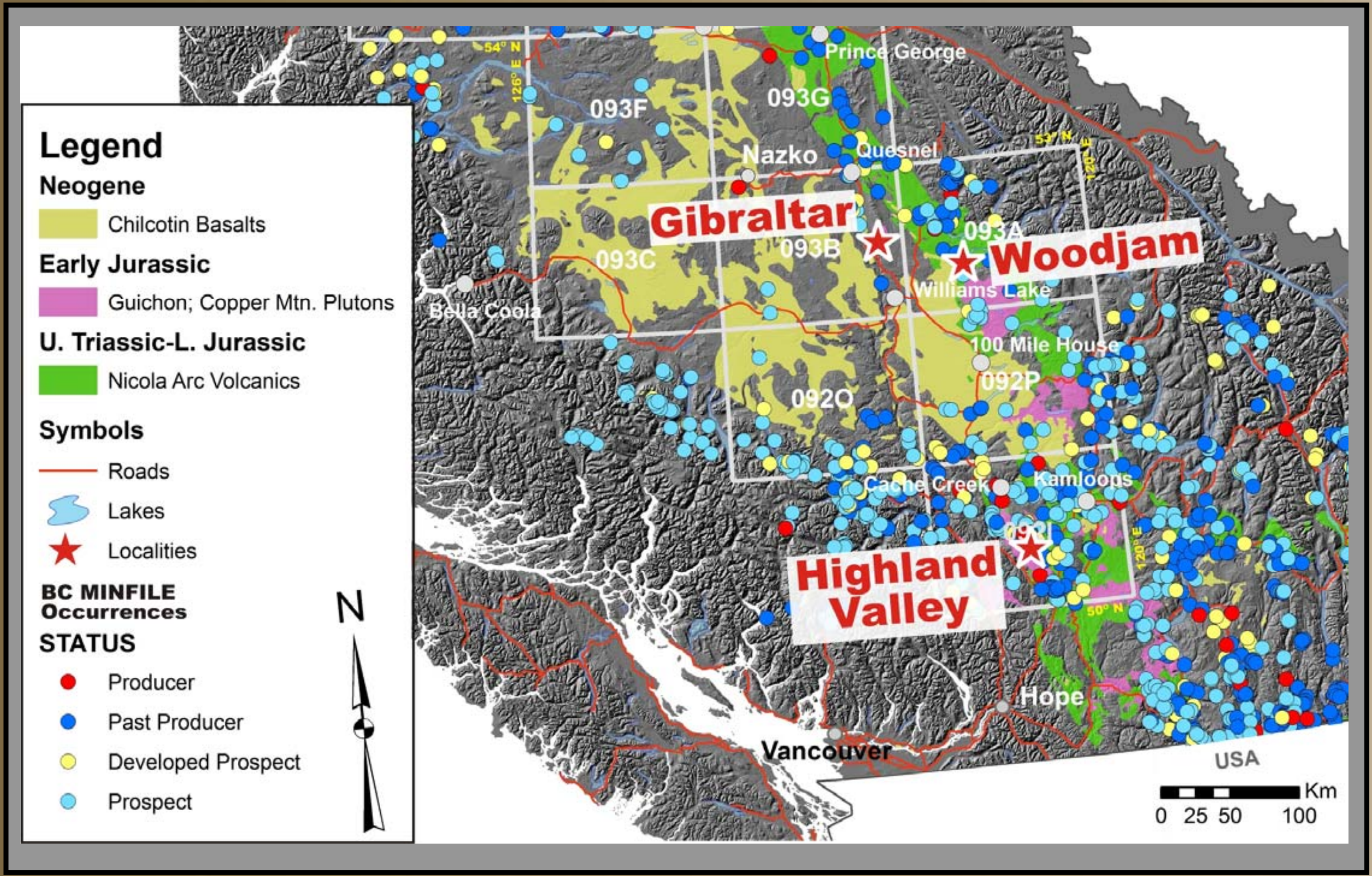
(0.25-0.50 mm)

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

<u>NB</u> – photos are representative of mineral assemblage but not necessarily the modal abundance of epidote indicated in estimates

Canada

Scoping Study 2 – Woodjam: Bedrock Geology



Canada

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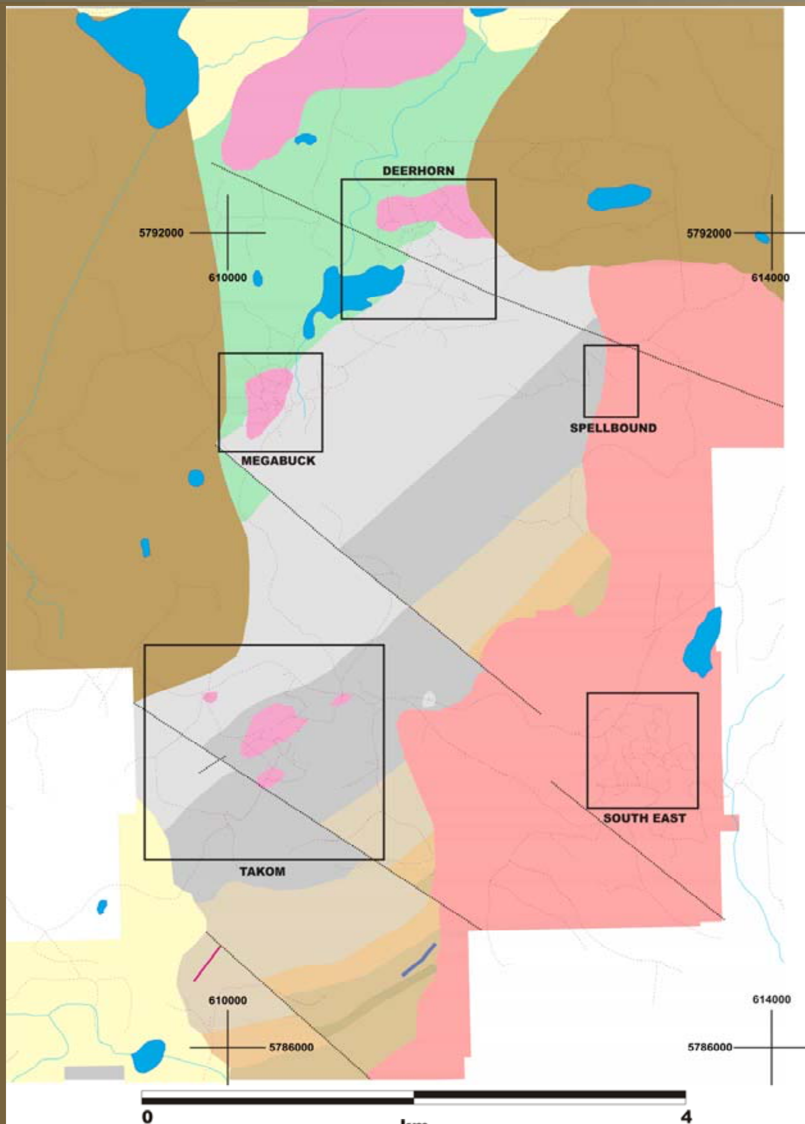


LEGEND

Quaternary cover

MIOCENE

Chilcotin Group

vesicular, olivine-plagioclase-phyric basalt

EARLY JURASSIC

Takomkane Batholith

medium-grained, equigranular to weakly megacrystic hornblende quartz monzonite

fine-grained hornblende-pyroxene diorite

medium-grained, plagioclase-hornblende-phyric monzonite with a variably-altered aphanitic groundmass.

UPPER TRIASSIC

Nicola Group

hornblende-pyroxene-plagioclase porphyry andesite with sharp upper and lower contacts with volcanic sandstone to mudstone units; local monomictic breccia sub-units

locally bedded and laminated plagioclase-rich sandstone to mudstone

matrix- to clast-supported polymictic breccia to plagioclase- and pyroxene-rich sandstone containing angular to subround clasts of plagioclase- and pyroxene-phyric andesite, basalt, and rare mudstone, sandstone and hornblende-phyric dacite; locally interbedded with laminated mudstone to sandstone

pyroxene-plagioclase porphyry andesite dyke

coarse-grained plagioclase porphyry andesite (a.k.a. "turkey track unit"); trachytic texture defined by an alignment of plagioclase crystals; local chlorite filled amygdales; peperite facies at the upper and lower contacts of unit

medium-grained plagioclase-pyroxene porphyritic andesite; local chlorite-filled amygdales; peperite facies at the upper and lower contacts of unit

coarse-grained plagioclase-pyroxene porphyritic andesite; peperite facies at the upper contacts of unit

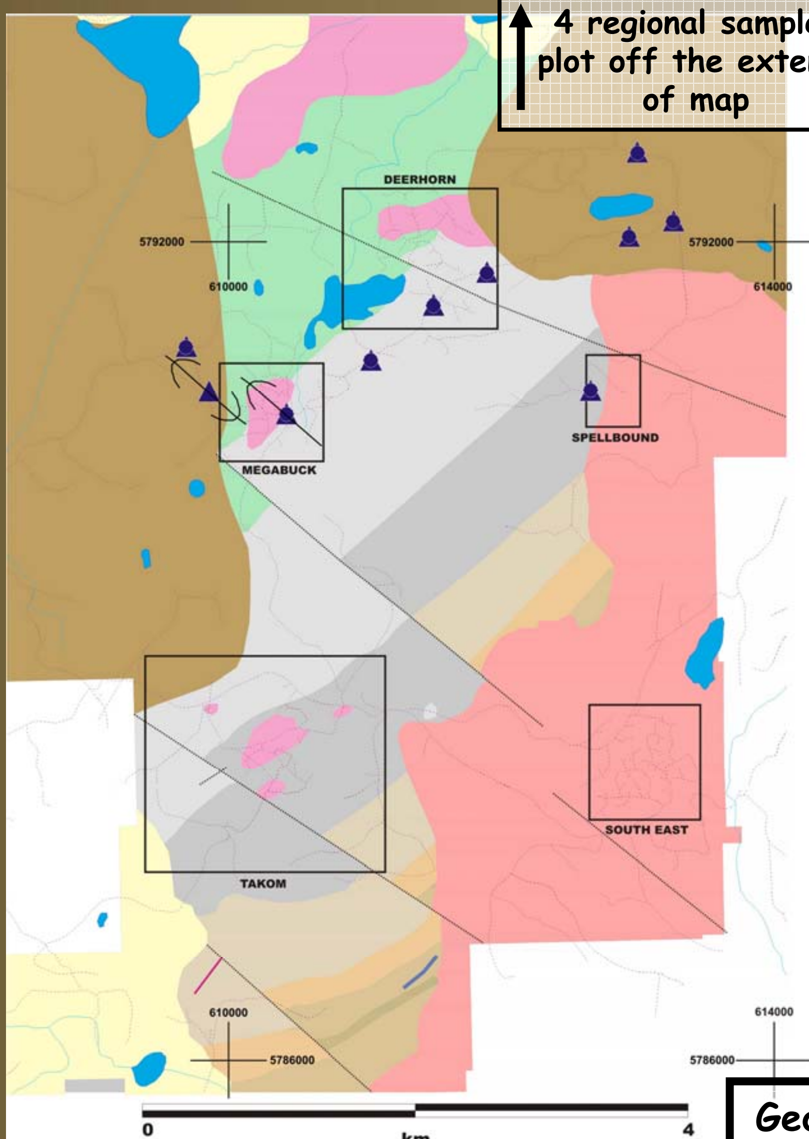
matrix-supported polymictic breccia to sandstone; contains angular to subround clasts of fine-grained plagioclase porphyry andesite unit and of plagioclase- and pyroxene porphyry andesite and basalt; thin- to thick-bedded; locally interbedded with mudstone

inferred fault

Geology after Blackwell et al. (2010)

Natural Resources Canada | Ressources naturelles Canada

Scoping Study 2 – Woodjam: Ice Movement Indicators and 2011 Sampling Sites (till = 18; bark = 27)



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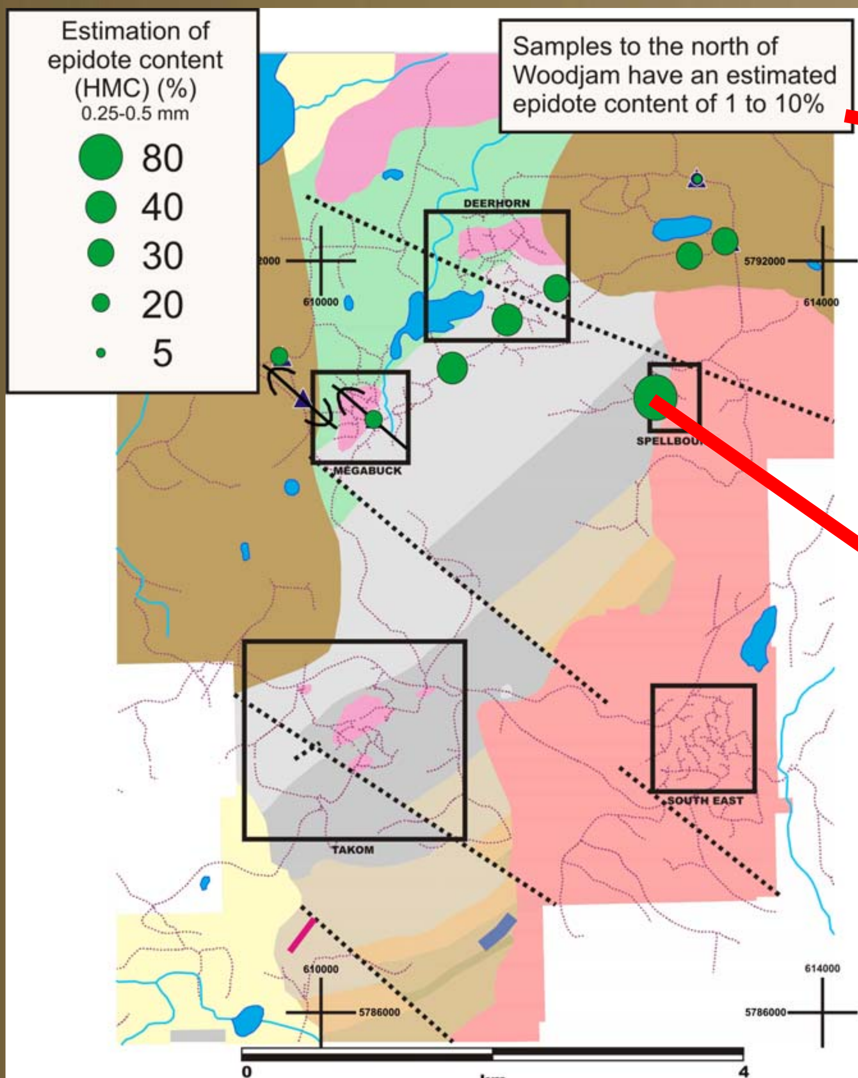
inferred fault

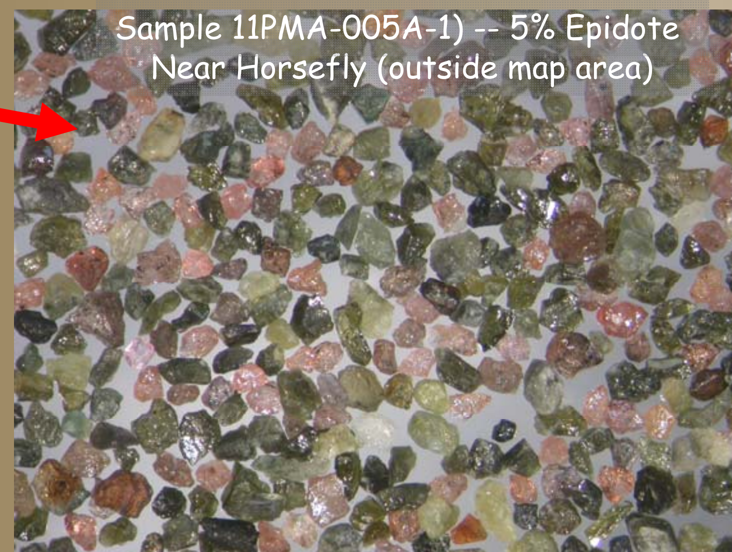
2011 samples
- ▲ tree bark
- ● till

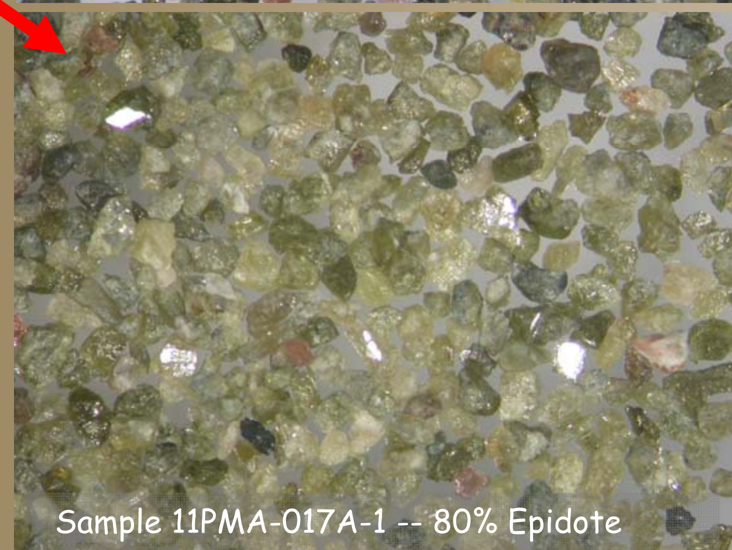
Geology after Blackwell et al. (2010)

Canada

Heavy Mineral Concentrates (HMC) and Porphyry Indicator Minerals (PIM) – modal estimates of epidote at Woodjam





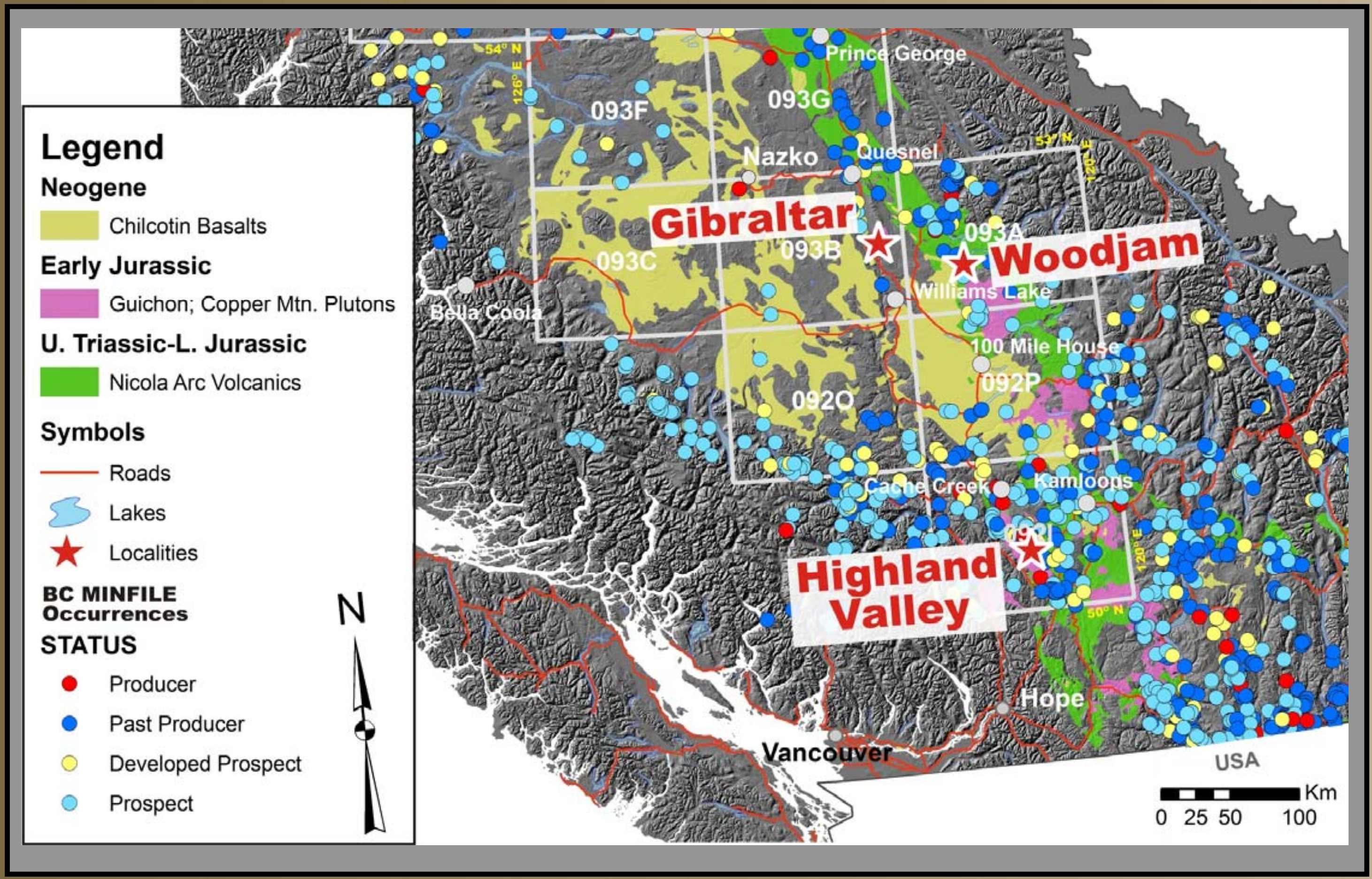


***NB* – photos are representative of mineral assemblage but not necessarily the modal abundance of epidote indicated in estimates**

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

Canada

Scoping Study 3 – Highland Valley District: Bedrock Geology



Canada

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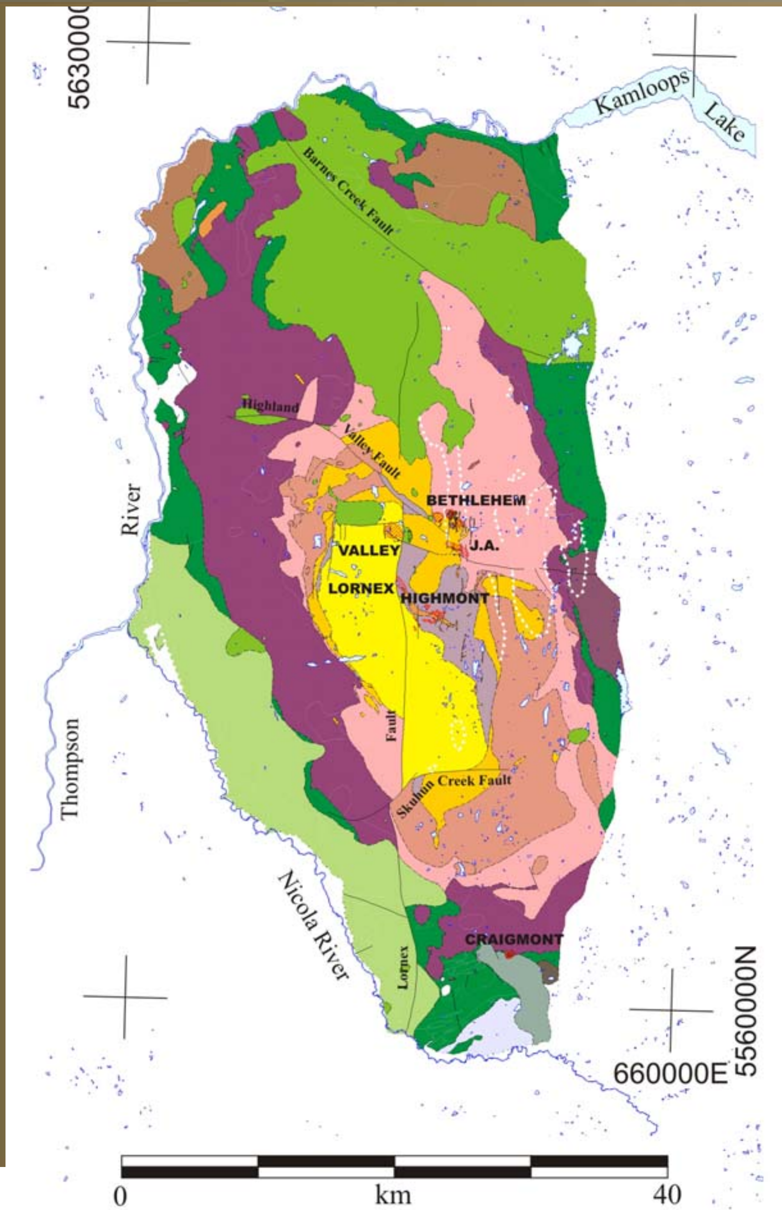
Scoping Study 3 – Highland Valley District: Bedrock Geology



LEGEND

EOCENE AND YOUNGER?
Kamloops Group
mafic and felsic volcanic flows and associated intrusive rocks; breccia and sedimentary rocks

EOCENE?
Coldwater Formation
sedimentary rocks

Kingsvale Group
basalt and intermediate to felsic porphyry; breccia and sedimentary rocks

CRETACEOUS
Spences Bridge Group
felsic, intermediate and minor mafic lavas and associated intrusive rocks; breccia, tuff, and sedimentary rocks

JURASSIC
Ashcroft Formation
shale, siltstone, sandstone, conglomerate and minor limestone

LATE TRIASSIC
Gump Lake Phase
granodiorite to quartz monzonite; includes post-Gump Lake phase mafic dykes

GUICHON CREEK BATHOLITH

Bethlehem Suite

post-Bethsaida phase quartz porphyry and aplitic dykes (includes Gnawed Mountain phase)

Bethsaida Phase: quartz monzonite to granodiorite

Skeena Sub-phase: intermediate in composition and texture between Bethsaida and Bethlehem phases

Bethlehem Phase: granodiorite

Highland Valley Suite

Chataway Phase: granodiorite

Guichon Phase: fine- and medium-grained granodiorite

Border Phase: mafic quartz diorite to granodiorite

UNASSIGNED INTRUSIONS

Coyle Stock: diorite to quartz monzonite, local alaskite

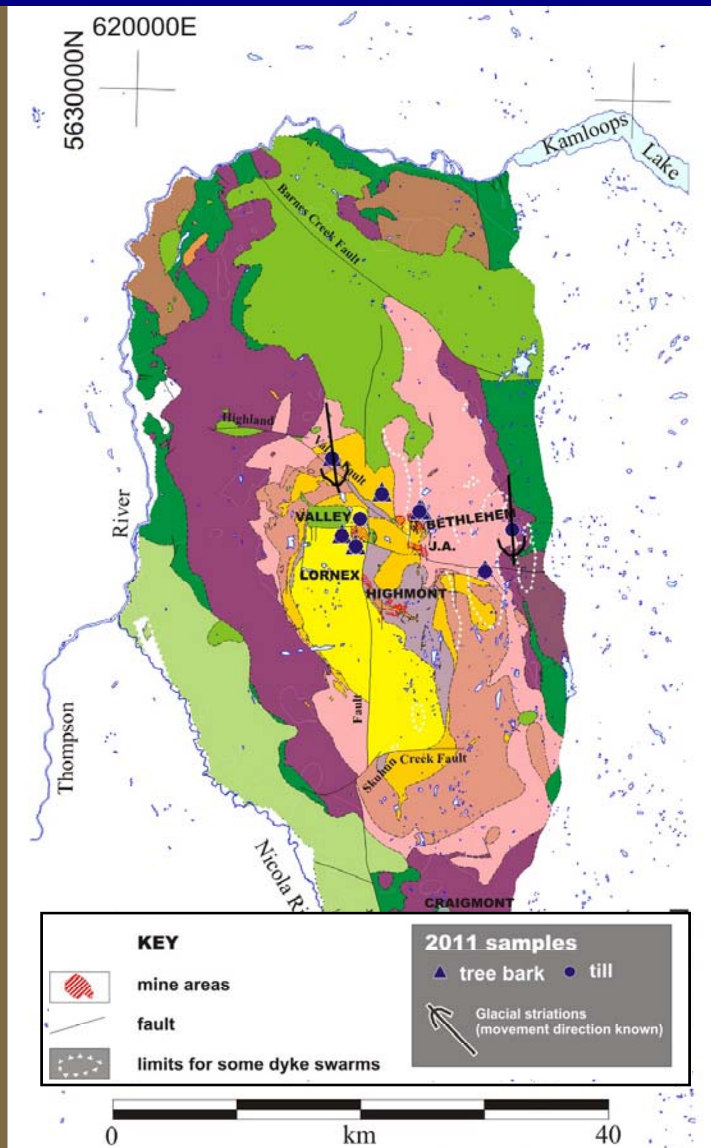
NICOLA GROUP
mafic, intermediate and uncommon felsic flow rocks and breccia; associated volcano-sedimentary rocks and minor limestone

Bedrock geology from: McMillan et al., 2009)

Canada

Natural Resources Canada Ressources naturelles Canada

Scoping Study 3 – Highland Valley District: Ice Movement Indicators and 2011 Sampling Sites (till = 9; bark = 18)



LEGEND

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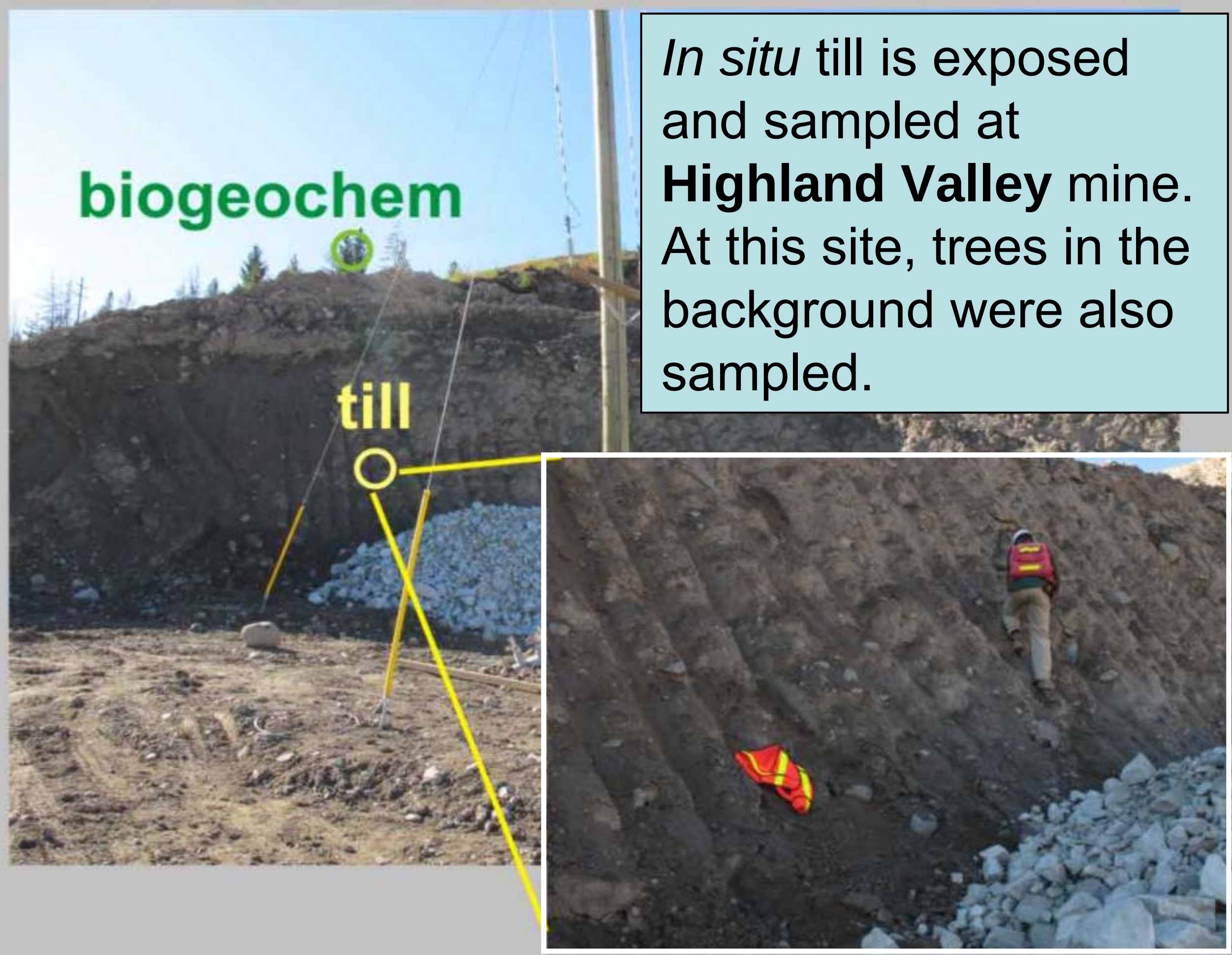
Bedrock geology from: McMillan et al., 2009)

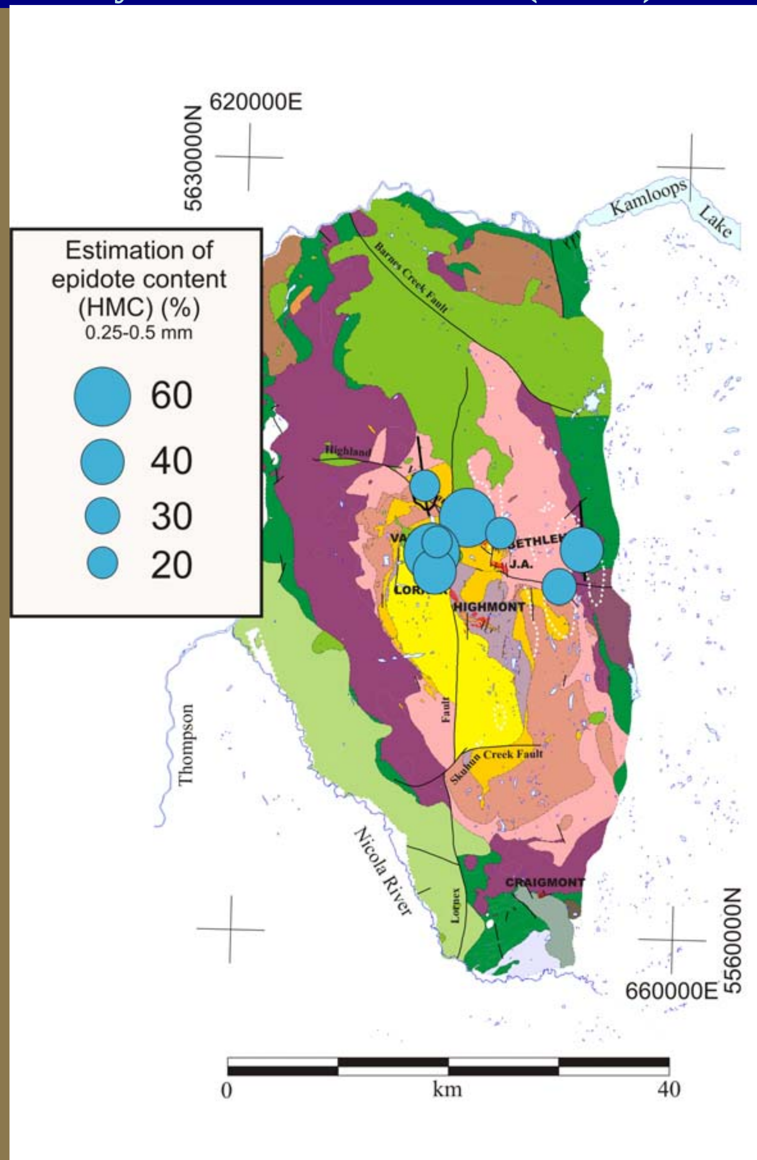
Canada

Scoping Study 3 – Highland Valley District: example of 2011 Sampling Site



In situ till is exposed and sampled at **Highland Valley** mine. At this site, trees in the background were also sampled.

Porphyry Indicator Minerals (PIM) at Highland Valley District – modal estimate of epidote from heavy mineral concentrate (HMC)



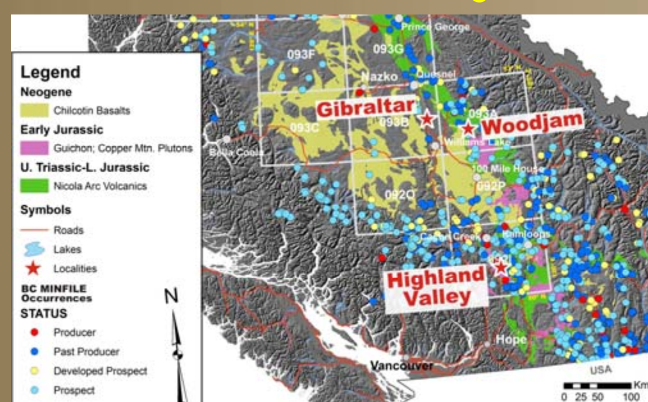
Bedrock geology from: McMillan et al., 2009)

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

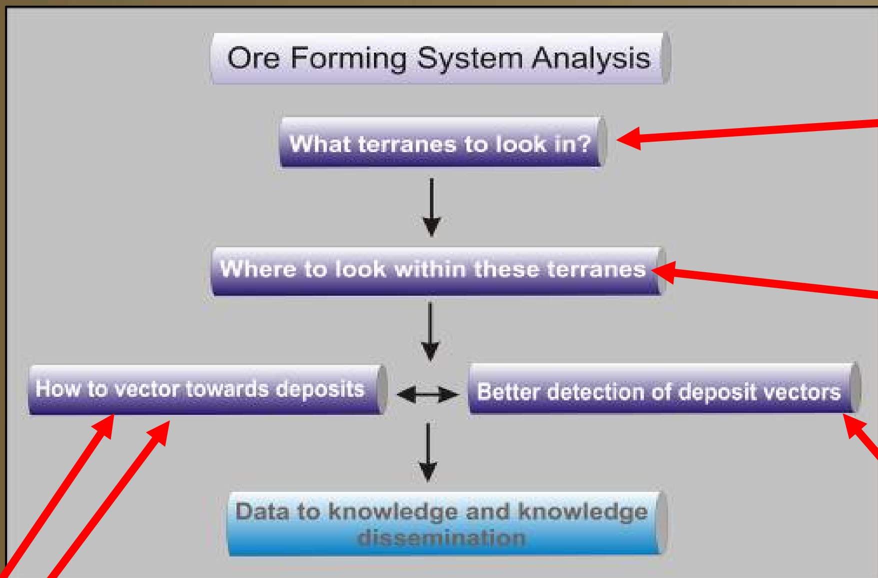
Conclusions and proposed future studies

"Geoscience knowledge to support enhanced effectiveness of deep exploration"

- What is TGI-4 [5 yrs; 2010-2015]?
- What is the focus in the S. Canadian Cordillera?
- Glacial processes: Lessons learned for drift prospecting
- 3 scoping studies: Gibraltar, Woodjam, Highland Valley District
- What's next?



TGI4 Intrusion-related Ore System – What's Next in Can. Cordillera



Tectonics, structural setting and development of Gibraltar

Role of basement structures in localizing GCB (HVD)

PIMS as vectors and fertility indicators

Till composition and biogeochemical signals and vectors

Ice movement(s) and glacial processes

2012 & 2013 Field Seasons – HQP training

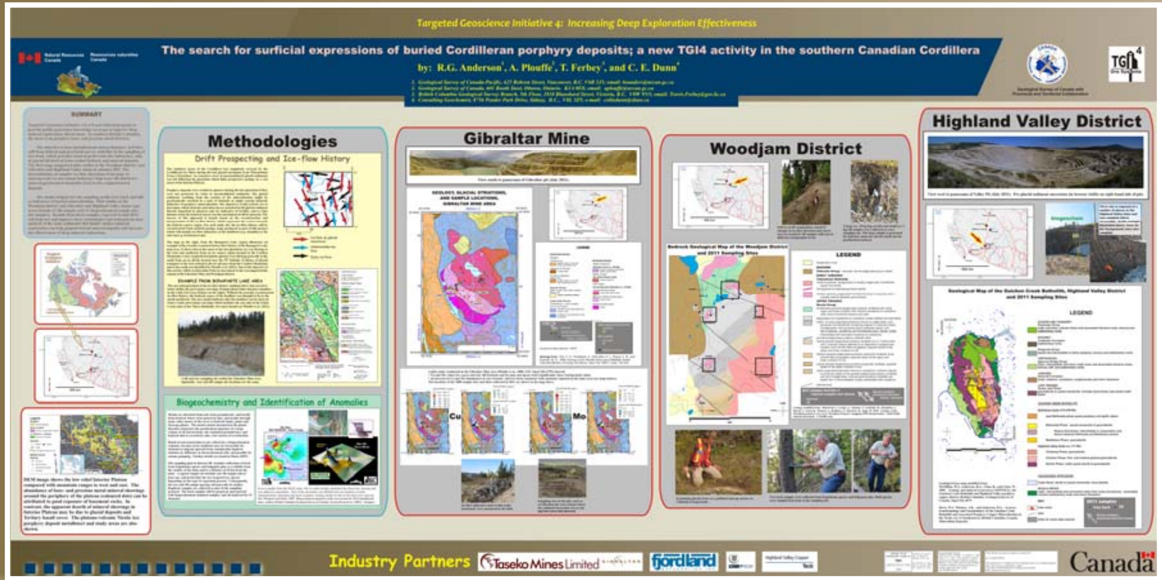
Further Information related to Cordilleran activities in Intrusion-related Ore System Project:

Current Research paper:

Anderson, R.G., Plouffe, A., Ferbey, T., Dunn, C.E., 2012. The search for surficial expressions of buried Cordilleran porphyry deposits; background and progress in a new Targeted Geoscience Initiative 4 activity in the southern Canadian Cordillera, British Columbia; Geological Survey of Canada, Current Research (Online), no. 2012-7, 19 pages, doi:10.4095/290295

Open File:

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, 1 sheet. doi:10.4095/289918.



Canada