Porphyry Integration Project: Bringing Together Geoscience and Exploration Datasets for British Columbia's Porphyry Districts

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Introduction

Understanding the geology of porphyry systems is necessary to focus exploration for porphyry mineralization. However, bridging the gap between conceptual ideas or focused scientific insights and practical exploration methods can be a challenge. Interpreting patterns, trends and features in geophysical and geochemical data from porphyry systems in the context of complex magmatic-hydrothermal systems can be difficult, particularly when data may be limited or restricted in aerial extent.

Geological models for porphyry systems have been developed over several decades by numerous researchers, providing guidance to explorers on both the regional and the more detailed levels of porphyry exploration (see Thompson, 1995). In BC, research related to porphyry systems has seen several periods of collaboration resulting in seminal volumes such as CIM Special Volume 15 (Sutherland Brown, 1976) and CIM Special Volume 46 (Schroeter, 1995), as well as integrated research projects on alkalic systems (e.g., research in the 1990s by the Mineral Deposit Research Unit [MDRU]; research in the 2000s by MDRU and the Centre for Ore Deposit Research [CODES], see Chamberlain et al., 2007; as well as research and mapping by the BC Geological Survey [BCGS], e.g., Preto et al., 2004; Logan et al., 2006, 2007). These projects have advanced the level of understanding of the tectonic and local magmatic-hydrothermal controls on BC's porphyry systems, as well as developed more detailed conceptual models for specific porphyry classes.

As explorers gain a better understanding of the details of porphyry systems, there is a need to review these models in the context of practical exploration methods. It is important not only to understand the variations within the models, but also to recognize what the variations within different porphyry systems look like in exploration datasets. Identifying which features of geological, geochemical and geophysical datasets are linked to mineralized porphyry centres is the key to successful exploration.

The porphyry integration project is working to develop integrated geological, geophysical and geochemical maps and datasets for thirteen important porphyry districts in BC. The exploration data are drawn from public and, where possible, private company contributions. The goal is to develop an integrated model for porphyry discovery that links conceptual geological models with practical field exploration.

Porphyry Integration Project

Some of BC's more advanced porphyry districts have exploration datasets that span decades, and full compilation of these data has not yet been completed. Integrating the data and then interpreting the geological, geophysical and geochemical context for known mineralization in these districts, some of which have developed mines, will provide an excellent resource to aid in the development of focused exploration strategies for other porphyry occurrences in BC. Compiling examples of how porphyry system features manifest in exploration datasets and explaining the significance of the findings in the context of the current understanding of porphyry systems, is fundamental to strong science-based exploration and is the concept for the porphyry integration project. The porphyry integration project was outlined in detail in Devine (2011) and the following article is intended to provide a brief update on the progress to date.

Selected BC Porphyry Districts

The districts chosen for evaluation during this project reflect the variety in porphyry systems in BC (Figure 1). Porphyry deposits in BC may be grouped into 'pre-accretion' and 'post-accretion' settings, based on the timing of their emplacement relative to tectonic accretion to the North American continental margin (e.g., McMillan et al., 1995; Figure 1). The calcalkalic and alkalic classification is also reflected in this grouping by the direct links between tectonic processes and magma series. The pre-accretion porphyries are those developed in the Stikine and Quesnel arc terranes; they include both calcalkalic Cu-Mo-(Au) and alkalic Cu-Au systems, commonly found to occur within coeval magmatic and volcanic host rocks. The porphyry

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districts in Quesnel and Stikine terrane include many of BC's richest Cu-porphyry deposits. The post-accretion deposits are more widespread across terrane boundaries and occur in magmatic suites emplaced into older rocks, inboard of the continental margin. They are calcalkalic Cu-Mo and Mo dominant systems formed from more evolved magmatic systems.

Variation within porphyry systems is also reflected in the earlier divisions of classic, volcanic and plutonic (McMillan and Panteleyev, 1988), which reflect the variety of emplacement settings for porphyry systems. The dominant controls include hostrock variation and resultant reactivity of hostrocks, as well as variable degrees of structural control, either pre-emplacement, synemplacement or post-

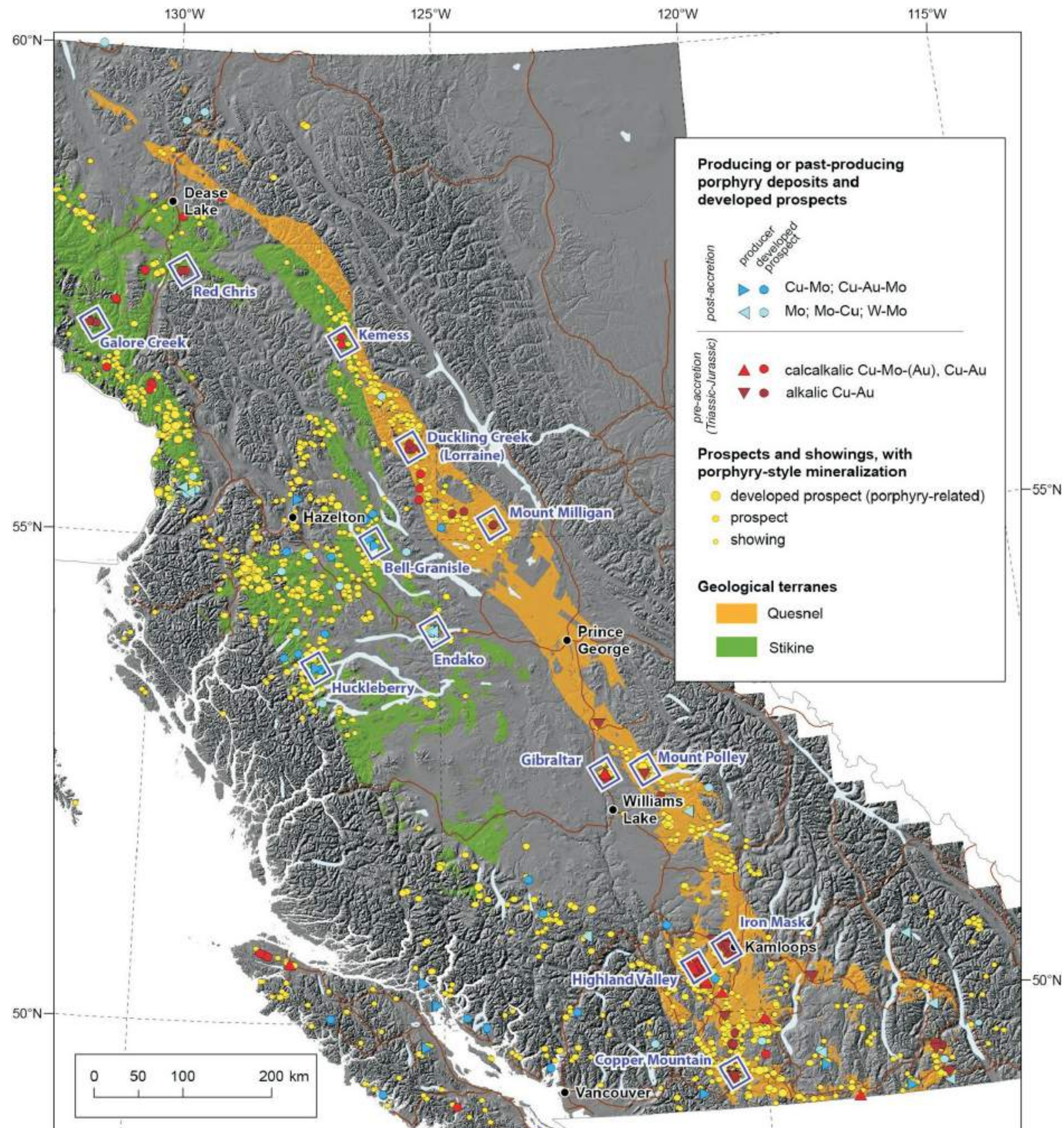


Figure 1. Locations of porphyry districts in British Columbia identified for compilation and integration by the Porphyry Integration Project (blue rectangles); digital elevation model developed by the Canadian Council on Geomatics (2004). The locations of porphyry showings, prospects and developed prospects are from the MINFILE database (BC Geological Survey, 2011).

emplacement. Together with the variations in magmatic and hydrothermal character of calcalkalic and alkalic systems these controls may lead to a variety of porphyry mineralization settings and styles.

The districts chosen for evaluation in the project represent these porphyry system variations within BC (Figure 1). Data availability, quality and quantity were also taken into consideration, and the result is a working list of 13 BC porphyry districts. They include Triassic and Jurassic alkalic and calcalkalic districts within the Stikine and Quesnel terranes, represented by Copper Mountain, Iron Mask, Mount Polley, Mount Milligan, Duckling Creek (Lorraine), Galore Creek, Red Chris, Kemess and Highland Valley. Post-accretion districts are represented by Endako, Huckleberry and Bell-Granisle. The list is somewhat weighted toward the alkalic class due to the high level of exploration interest in these gold-rich, potentially high-grade, although smaller footprint deposits. This interest in alkalic systems has been reflected in the recent research by the MDRU-CODES collaboration (Chamberlain et al., 2007), BCGS initiatives (e.g., Logan et al., 2006, 2007), as well as recent Geoscience BC Quesnellia Exploration Strategy (QUEST) initiatives to develop datasets over the Quesnel and Stikine terranes to encourage new exploration.

District-Scale Approach

The 'district-scale' approach is fundamental to the focus of the project. Encouragement for developing strong district-scale understanding of porphyry systems comes from the recognition that porphyry deposits commonly occur in clusters associated with certain magmatic suites and that deposits of different ages, mineralization styles and metal ratios may occur within a single district (e.g., Cadia Ridgeway, Wilson et al., 2003). Mineralization occurring peripheral to the main porphyry centres may also be economically significant and warrant inclusion in any district-scale model for porphyry exploration. The idea of adopting a porphyry 'footprints' approach to research and exploration recognizes that the alteration and hydrothermal manifestations of a porphyry systems may extend much farther outwards than the mineralized zones and provide a larger target area for exploration.

While deposit-scale variations within a district are important to understanding the intricacies of porphyry systems, the variations can be quite complex and dependent on a number of specific local factors. Significant effort has been put into understanding the geological details of many BC porphyry deposits (e.g., Sutherland Brown, 1976; Schroeter, 1995). The district-scale controls are certainly dependent on local characteristics; however, the step back in scale allows for the recognition of other magmatic and structural features that may be controlling porphyry mineralization within a wider region.

This district-scale challenge is familiar to explorers who commonly rely on broad aeromagnetic, electromagnetic, induced polarization (IP) and geochemistry surveys to focus their efforts. Insight into the manifestation of the more subtle features of porphyry systems within these data, at the district-scale, is highly useful to field exploration.

Development of Data Layers and Presentation

The approach for data collection and integration over the selected districts has been systematic and has followed the general order listed below:

1) collection of available public geochemical and geological data
2) review of assessment reports for historic soil geochemistry data, and digitizing when of value to the project
3) engagement with companies in the district of interest following a review of historic work
4) development of consistent maps and digital datasets by the project team
5) integration of spatial data and geological evaluation

Stage 1 compilation includes regional public data: BC regional geochemical survey (RGS), aeromagnetic surveys, QUEST electromagnetic and gravity data. Figure 2 is an example of a set of regional data presented in a consistent format at the district-scale for the Mount Polley area. The BC Geological Survey geological compilation for Mount Polley can be compared with the regional magnetic, radiometric (K-Th) and stream-sediment geochemistry data. By comparing these integrated data at a similar scale and format it is possible to develop interpretations of trends.

Stage 2 compilation includes more detailed, district-specific data such as ground geophysical surveys, for example local ground magnetic and IP surveys. Soil geochemistry surveys are also included in this compilation, many of which have been filed in historic assessment reports. The distribution and availability of these district-specific data is more limited than the government-developed regional datasets. Compilation of these data is on-going and will result in several new digital products.

Where possible, companies have been contributing digital data, such as detailed geophysical surveys or historic soil geochemistry data, to complete certain district datasets (stage 3 compilation).

During the course of the project, maps of the data are being produced in-house by the Geoscience BC project team. Figures 2 and 3 are examples of some of the GIS-based maps that are being used to organize and view the multi-layered, multi-disciplinary data. The concept of scale consistency between districts is important in the development of data layers. Not only are maps being used to evaluate datasets within the districts, but also to compare and con-

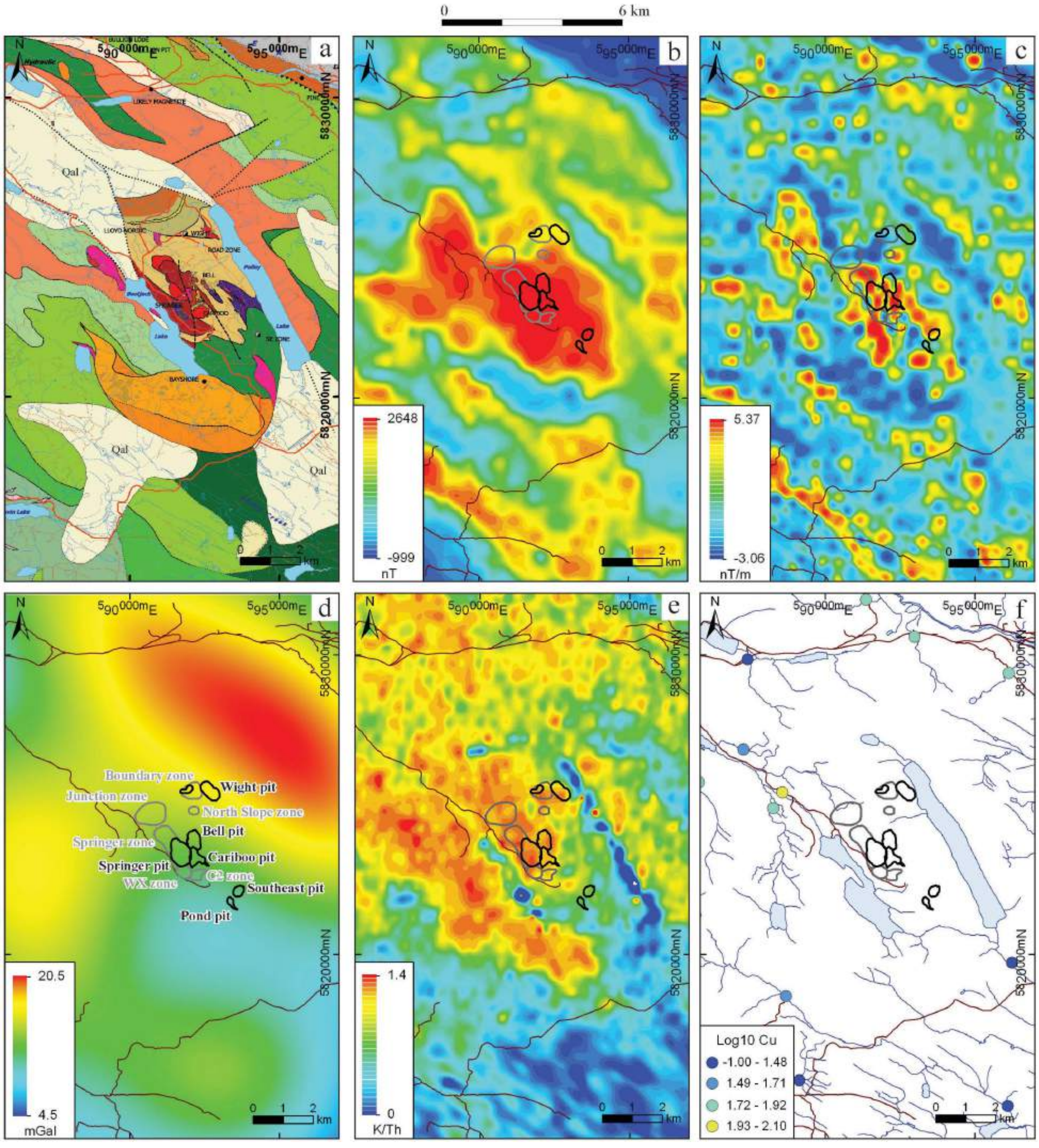
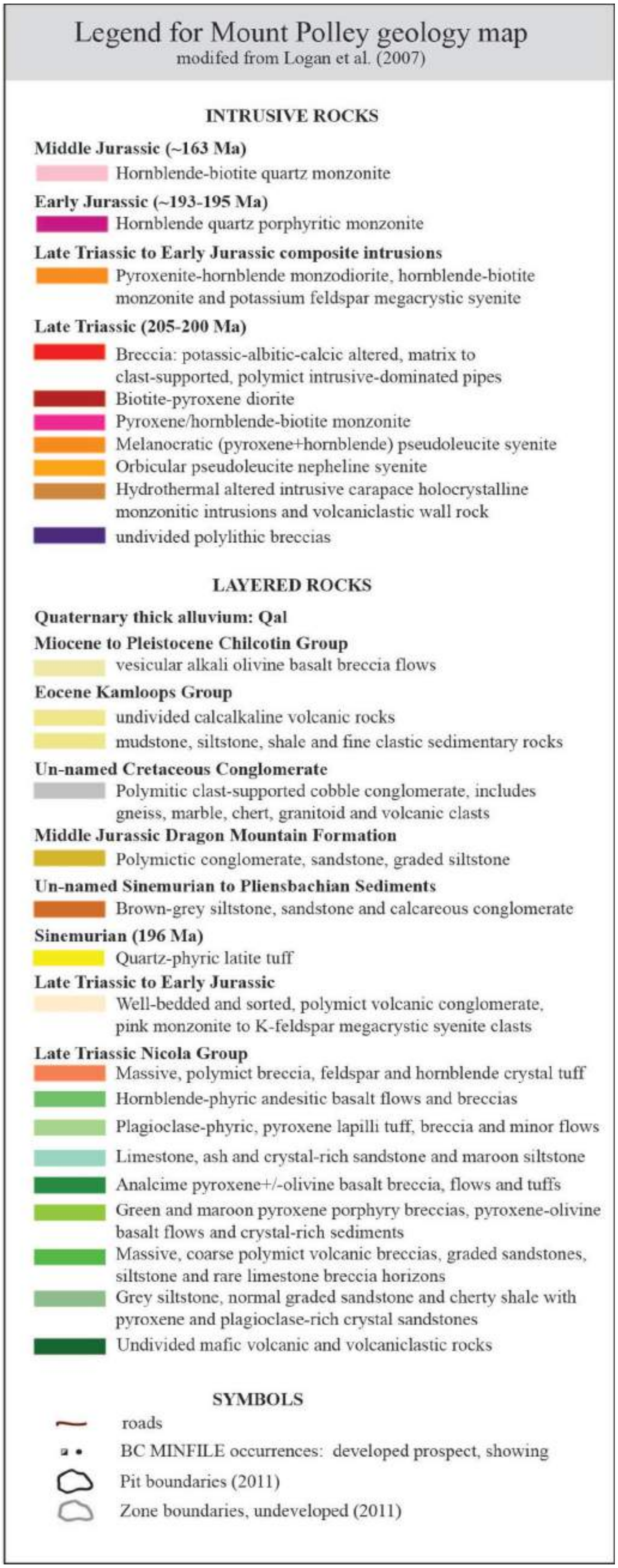


Figure 2. Examples of layers of regional data over the Mount Polley alkalic Cu-Au porphyry district, British Columbia; the locations of developed pits are shown in black outlines, and the locations of undeveloped mineralized zones are shown in grey outlines (taken from Imperial Metals Corporation (2011): **a)** geological map of Logan et al. (2007); the intrusive complex between Polley and Bootjack lakes is host to the mineralized zones that comprise the district; **b)** total magnetic field map generated by Geoscience BC (GBC) from the 2005 Geological Survey of Canada Hydraulic Survey (Carson et al., 2006); a more detailed magnetic survey of the Mount Polley area was undertaken by Shives et al. (2003); **c)** first vertical derivative of the total magnetic intensity (TMI) image generated by GBC from Carson et al. (2006); **d)** isostatic Bouguer gravity image from the Quesnellia Exploration Strategy (QUEST) project data (Sander Geophysics, 2008); **e)** radiometric image generated by GBC from Carson et al. (2006); **f)** compilation of Cu values in regional stream-sediment data (Jackaman, 2008). All geophysical data layers are produced by P. Kowalcyzk on behalf of Geoscience BC; the regional stream-sediment data compilation is by D. Heberlein for Geoscience BC. All maps are in UTM NAD83 projection, Zone 10.


Legend for Mount Polley geology map
modifed from Logan et al. (2007)
INTRUSIVE ROCKS
Middle Jurassic (~163 Ma)
Hornblende-biotite quartz monzonite
Early Jurassic (~193-195 Ma)
Hornblende quartz porphyritic monzonite
Late Triassic to Early Jurassic composite intrusions
Pyroxenite-hornblende monzodiorite, hornblende-biotite monzonite and potassium feldspar megacrystic syenite
Late Triassic (205-200 Ma)
Breccia: potassic-albitic-calcic altered, matrix to clast-supported, polymict intrusive-dominated pipes
Biotite-pyroxene diorite
Pyroxene/hornblende-biotite monzonite
Melanocratic (pyroxene+hornblende) pseudoleucite syenite
Orbicular pseudoleucite nepheline syenite
Hydrothermal altered intrusive carapace holocrystalline monzonitic intrusions and volcaniclastic wall rock
undivided polylithic breccias
LAYERED ROCKS
Quaternary thick alluvium: Qal
Miocene to Pleistocene Chilcotin Group
vesicular alkali olivine basalt breccia flows
Eocene Kamloops Group
undivided calcalkaline volcanic rocks
mudstone, siltstone, shale and fine clastic sedimentary rocks
Un-named Cretaceous Conglomerate
Polymitic clast-supported cobble conglomerate, includes gneiss, marble, chert, granitoid and volcanic clasts
Middle Jurassic Dragon Mountain Formation
Polymictic conglomerate, sandstone, graded siltstone
Un-named Sinemurian to Pliensbachian Sediments
Brown-grey siltstone, sandstone and calcareous conglomerate
Sinemurian (196 Ma)
Quartz-phyric latite tuff
Late Triassic to Early Jurassic
Well-bedded and sorted, polymict volcanic conglomerate, pink monzonite to K-feldspar megacrystic syenite clasts
Late Triassic Nicola Group
Massive, polymict breccia, feldspar and hornblende crystal tuff
Hornblende-phyric andesitic basalt flows and breccias
Plagioclase-phyric, pyroxene lapilli tuff, breccia and minor flows
Limestone, ash and crystal-rich sandstone and maroon siltstone
Analcime pyroxene+/-olivine basalt breccia, flows and tuffs
Green and maroon pyroxene porphyry breccias, pyroxene-olivine basalt flows and crystal-rich sediments
Massive, coarse polymict volcanic breccias, graded sandstones, siltstone and rare limestone breccia horizons
Grey siltstone, normal graded sandstone and cherty shale with pyroxene and plagioclase-rich crystal sandstones
Undivided mafic volcanic and volcaniclastic rocks
SYMBOLS
roads
BC MINFILE occurrences: developed prospect, showing
Pit boundaries (2011)
Zone boundaries, undeveloped (2011)

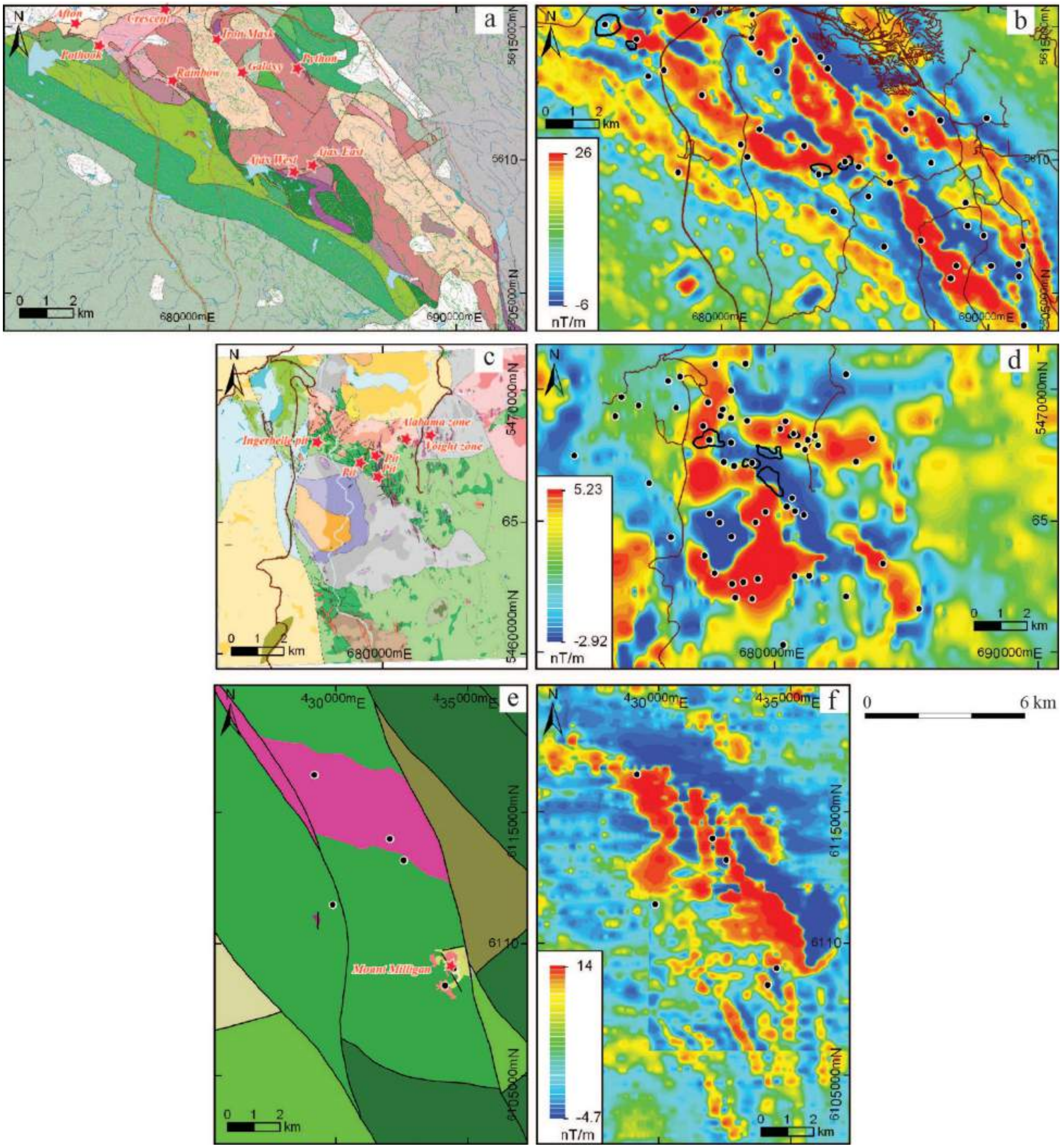


Figure 3. Examples of 1:50 000 scale compilation maps of geology and first-vertical derivative magnetic survey images generated from regional data over several alkalic Cu-Au districts in British Columbia. Maps are produced to the same scale using consistent colour ramps and legends to allow for comparing and contrasting data between districts: **a)** and **b)** geology map of Iron Mask batholith, compilation by Logan, et al. (2006), first vertical derivative magnetic survey map generated from the 1995 Iron Mask geophysical survey (Shives and Carson, 1995); **c)** and **d)** Copper Mountain geology compilation of Preto et al. (2004), first vertical derivative magnetic data generated from the 1971 Geological Survey of Canada aeromagnetic survey (Natural Resources Canada, 2011); **e)** and **f)** geology of the Mount Milligan area from the BC Digital Geology compilation (Massey et al., 2005), with more detailed geology in the vicinity of the deposit developed by Placer Dome Inc., published in Jago and Tosdal (2009), first vertical derivative magnetic survey map is generated from the 2005 Mount Milligan geophysical survey (Shives, 2005) and the 2008 Z-Axis Tipper Electromagnetic (ZTEM) survey test block over the Mt. Milligan area (Geotech Ltd., 2009). All levelled first vertical derivative products were produced by P. Kowalczyk for Geoscience BC.

Legend for Iron Mask geology map
modifed from Logan et al. (2006)

INTRUSIVE ROCKS

Latest Triassic Iron Mask batholith

- Sugarloaf: porphyritic hornblende diorite
- Cherry Creek: biotite monzonite to monzodiorite
- Pothook: corase biotite pyroxene diorite
- Hybrid: xenolith-rich Pothook or Sugarloaf phase

LAYERED ROCKS

Un-named Miocene volcanic rocks

- vesicular basalt flows and tuff

Eocence Kamloops Group

- undivided alkaline volcanic rocks

Late Triassic Nicola Group

- undivided volcanic and sedimentary rocks
- augite porphyry and polylithic breccia
- feldspar>pyroxene-porphyritic lapilli tuff
- polylithic lahar, including mineralized clasts
- picrite flow, breccia
- coarse augite porphyry
- feldspar>pyroxene volcaniclastic
- sediments with augite porphyry source
- Nicola sedimentary facies: mainly siltstone, lesser basalt, chert, minor limestone and ultramafite

Legend for Mount Milligan map

INTRUSIVE ROCKS

- hornblende-biotite monzonite
- diorite, lesser monzonite, syenite
- monzonite

LAYERED ROCKS

sedimentary rocks

- Nechako Plateau Group
- un-named

TAKLA GROUP volcanic rocks

- trachyte
- latite
- Witch Lake formation
- undivided andesitic rocks

- roads
- BC MINFILE occurrences
- *Afton* Mines and developed prospects

Legend for Copper Mountain geology map
modifed from Preto et al. (2004)

INTRUSIVE ROCKS

Post-Lower Cretaceous

- grey andesite feldspar porphyry dikes
- 'mine dikes': light grey and buff felsite, and quartz, quartz-feldspar and feldspar porphyry dikes

Late Lower Cretaceous

Verde Creek Quartz Monzonite

- porphyritic biotite-hornblende quartz monzonite and/or granite

Late Triassic

COPPER MOUNTAIN INTRUSIONS

Lost Horse Intrusions

- porphyritic augite and biotite-augite microdiorite, micromonzonite and microsyenite

Copper Mounatin, Voigt, Smelter Lake stocks

- microdiorite and latite porphyry dikes
- pegmatite, syenite, and perthitic alkali feldspar syenite ("perthosite")
- monzonite
- gabbro and/or pyroxenite
- diorite

STRATIFIED ROCKS

Tertiary (Middle Eocene)

PRINCETON GROUP

Allenby Formation

- dacite tuff, breccia

Lower volcanic formation

- undivided basalts

Late Triassic

NICOLA GROUP

Sedimentary rocks

- conglomerates, minor sandstone
- calcareous siltstone, clastic limestone

Volcanic and volcaniclastic rocks

- massive andesite, pillow lava, volaniclastic breccia
- Wolf Creek formation -massive andesite, minor basalt, volcaniclastic breccia

trast between districts (Figure 3). The development of consistent legends and scales is paramount to the value of the maps for further interpretation of the relationships of exploration data within and between districts.

Looking Forward

The porphyry integration project is ongoing and has made steady progress over the past year. The data compilation component of the project has taken longer than anticipated and is scheduled for completion over the winter of 2012. Data interrogation and interpretation has started and will ramp-up once the data compilation phase is complete. Maps and digital products developed during the course of the project will be made available publically through Geoscience BC's website (http://www.geosciencebc.com/s/DataReleases.asp) in 2012.

Acknowledgments

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