Sulfur Sources of Orogenic Gold Deposits in the Bridge River-Bralorne Mining District, British Columbia, Canada

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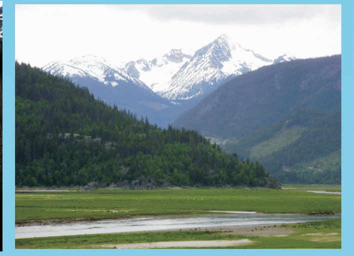
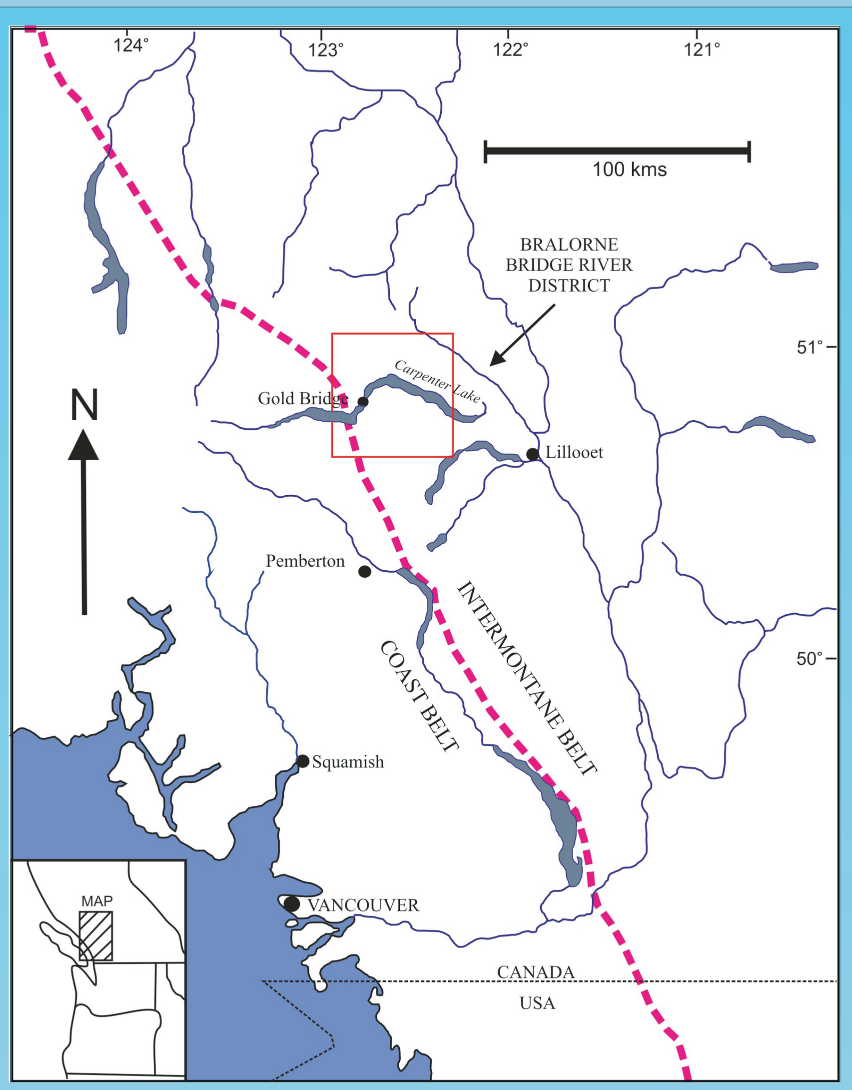
INTRODUCTION

The Bralorne Bridge-River mining district is the largest historical lode gold producer in British Columbia, collectibvely producing over 4 million ounces of gold between 1897 and 1971. Although dominated by orogenic gold occurrences, the district is characterised by three main metal associations; Au-dominant, Sb-dominant and Hg-dominant. These numerous deposits and mineral occurrences that make up this district form a spatial zonation, with Au in the southwest, Sb in the centre and Hg in the northeast.

Whilst orogenic gold deposits typically form district scale camps with numerous producers, only a small amount of gold was produced from three other mines (Congress, Wayside and Minto).
Explanations for this zonation are dominated by the consensus that the Au-dominant deposits and the rest of the occurrences and deposits are in no way related which has discouraged exploration in the district, with the exception of the veins immediately adjacent to the Bralorne-Pioneer mines.

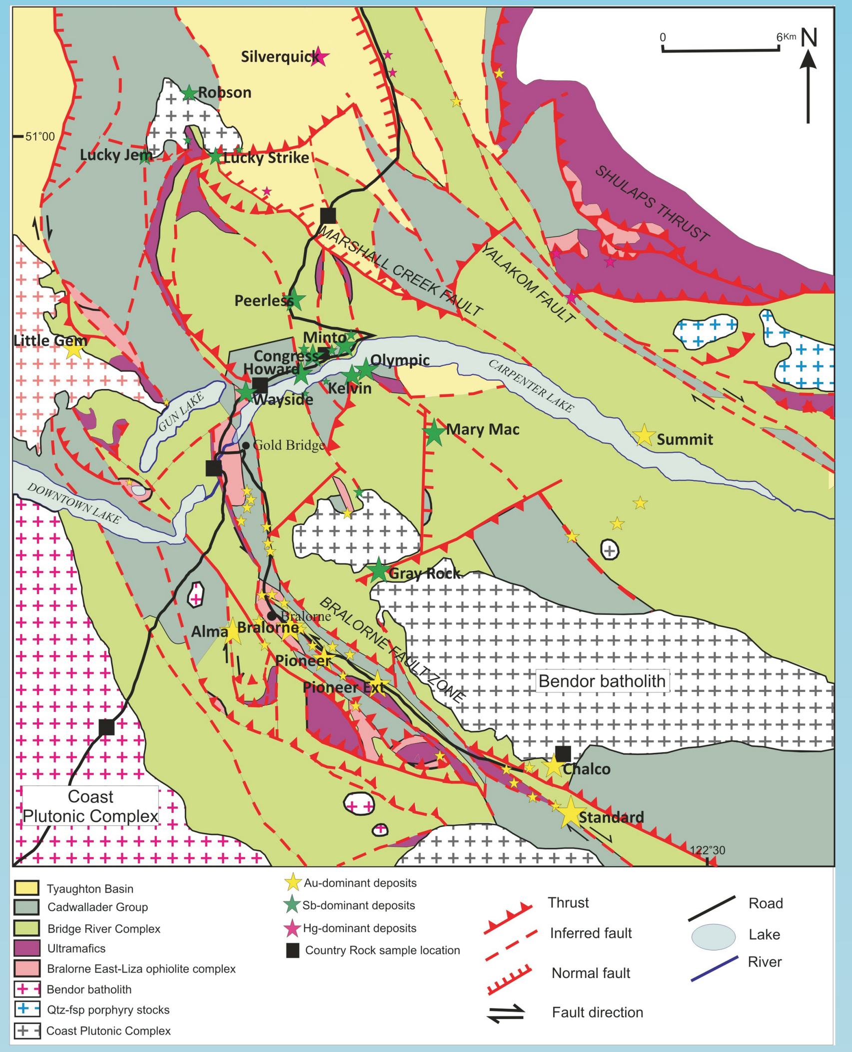

From left to right; path that continues down to the right towards the Chalco deposit; view looking back towards southwest, with Gold Bridge behind the first two ridges; view looking down gully at ruins of Pioneer mine dump.



Map of southwestern British Columbia showing district location and the main

REGIONAL GEOLOGY

The district straddles the boundary between the Middle Jurassic-Early Tertiary Coast Belt and the Late Paleozoic-Mesozoic Intermontane Belt that, together comprise this part of the southwestern Canadian Cordillera.
In the mid-lateJurassic, two main tectonic assemblages collided;
the oceanic back-arc basin Bridge River Complex (shown right) comprising basalt, gabbro, chert, shale, argillite and ultramafics was juxtaposed with the island arc Cadwallader Group, which consists of volcanics, marine and arc-marginal clastic strata. During and after terrane collision, late Jurassic-Cretaceous Tyaughton Basin, which consists mostly of clastic sediments and shales, were deposited on top.
Contractional deformation during the mid-Cretaceous resulted in a series of major structural systems. In the Bridge River district these are the Bralorne Fault Zone (Cadwallader Break), Eldorado Fault, Yalakom and Marshal Creek Faults and the Shulaps thrust. Dextral strike-slip movement re-activated these fault zones from 67Ma onwards.
The Coast Plutonic Complex (CPC) is the main component if the southwestern Coast Belt and the main granitic intrusion of this region. The Bendor Batholith is a younger consituent outlier pluton, east of the CPC, and is between the Bralorne Fault Zone and the Marshall Creek Fault.
What are considered to be the hypabyssal equivalents of the CPC intrude all of the units and comprise mafic to felsic dikes, hornblende porphyry (85.7Ma), albitite dikes (86-91Ma) and lamprophyre.



Regional geology of Bralorne Bridge-River mining district, showing deposits and occurrence types and locations.

METALLOGENY

Past producers of the district include the Bralorne and Pioneer gold mines, Wayside, Minto, Congress polymetalic gold-silver mines and the Silverquick mercury mine, with an additional 60 mineral occurrences throughout the district.

The Au-dominant deposits and occurrences are found along the Bralorne Fault Zone (see right), between the Bendor Batholoth and Coast Plutonic Complex. The zone is underlain by both the Bridge River Complex and Cadwallader Terrane sedimentary and volcanic units, as well as wedges of ultramafics and ophiolite. Gold-quartz veins are hosted in the diorite and gabbro of the Bralorne East-Liza ophiolite complex, bordered on one side by serpentinite and Bendor Batholith on the other.

The Sb-dominant veins are generally smaller than the gold deposits, and are discontinuous in the shear zones, have low gold-silver ratios and a large amount of mixed sulfides. Cairnes (1937) and Maheux (1989) identified two main styles of mineralisation; Sb-Au-Ag±Hg with a dominant stibnite phase and Ag-Au±Sb which is base metal enriched.

Hg-domiant deposits are characterised by cinnabar mineralisation, and occurs locally along the Yalakom and Relay Creek Fault systems. These deposits are typically hosted in sediments from the Tyaughton Basin and greenstone of the Bridge River Complex.

PREVIOUS MODELS AND SOURCES

Possible explanations for district scale zonation and sources for the sulfur and mineralising fluids include:
- Derivation from the magmas of the CPC or crustal fluids driven by heat from the CPC, sending out pulses of fluid in an easterly direction, resulting in the three zones of metal association (Leitch et al.1991a)
- Ophiolite from the Bralorne East-Liza ophiolite complex (Ash 2001)
- Bendor Batholith (Church 1996)
- Fluids pumped along re-activated faults in the structural belts (Bralorne Fault Zone, Marshall Creek and Castle Pass Faults and Yalakom Fault) (Schiarizza et al. 1997)

The age of mineralisation of the Bralorne-Pioneer gold veins as indicated by geochronology, is 67±2 Ma (Hart et al. 2008).
Therefore:
- Since the majority of CPC pluton emplacement occurred around 90Ma, it is evidently too old to provide heat and fluid sources
- The Bralorne East-Liza complex was thrust into the zone during the mid-Cretaceous deformation and is again too old.
- Recent geochronology of the Bendor Batholith placed it at 65±0.6 Ma, and is apparantly younger than mineralisation, but the dating is too close to be definite. This wouldn't explain the metal zonation as they are not aligned with respect to batholiths.
- However, the re-activation of the northwest trending faults occurred 67Ma and is therefore the same age as the mineralisation.

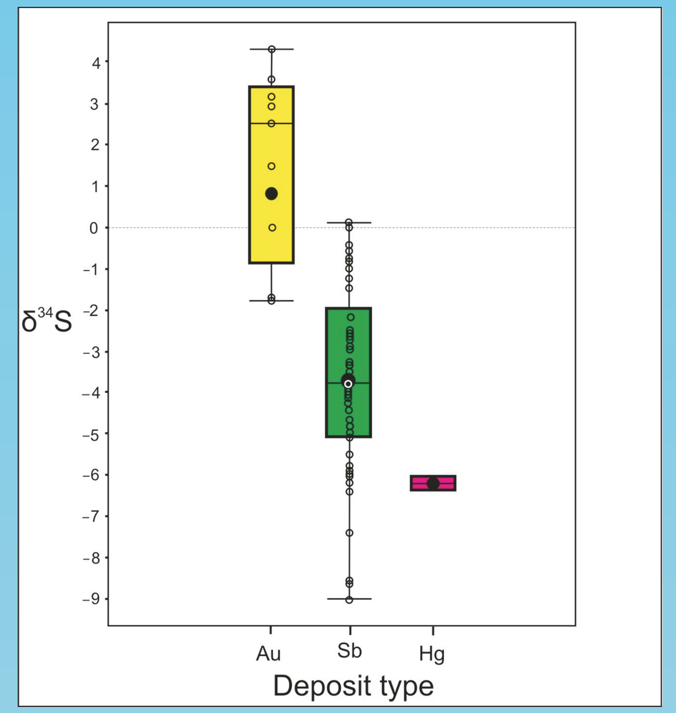
SULFUR ISOTOPES

Sulfur isotopes can be a powerful tool when identifying the processes and source(s) of sulfur in hydrothermal mineral systems.

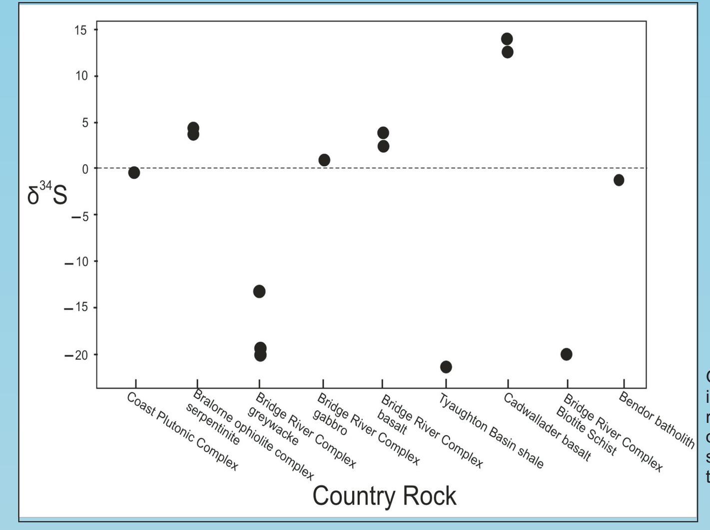
A sulfur isotopic study was conducted to determine the isotopic signatureof sulfur in sufhide minerals, from a wide range of 25 different deposits and mineral occurrences throughout the district. sulfur isotopic data from sulfide minerals are difficult to interpret. As a result, affitional efforts were made to obtain country rock samples of the main representative units, and these too were analyzed for their sulfur isotopic composition in order to provide a comparison point for the sulfide mineral isotope data. Nine samples of country rock were taken during the June 2008 field work. Samples include CPC, Bendor Batholith, biotite schist, basalt, gabbro and greywacke from the Bridge River Complex, basalt and albitite porphyry from the Cadwallader Group, serpentinite from the Bralorne-East Liza ophiolite complex and Silverquick Formation shaly sedimentary rocks from the Tyaughton Basin.

Results

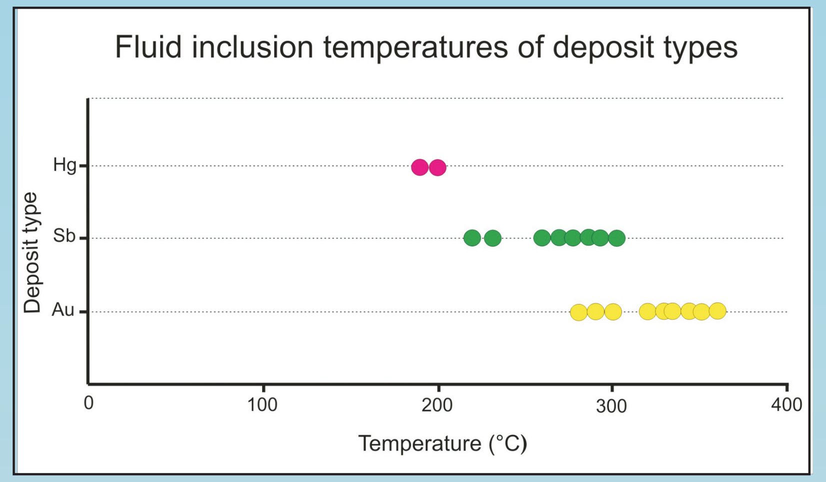
When separated according to deposit types (see below), the data show a clear pattern of a decrease in the heavier isotope, which is toward lighter ratios from Au, through Sb to Hg deposits. The distribution of the isotope patterns correlates with the deposit type distribution, thus showing a spatial zonation from west to east of a decrease in the heavier isotope (see right).This can be interpreted to mean that there is an increase in the amount of sedimentary sulfur as sedimentary sources are generally highly negative.



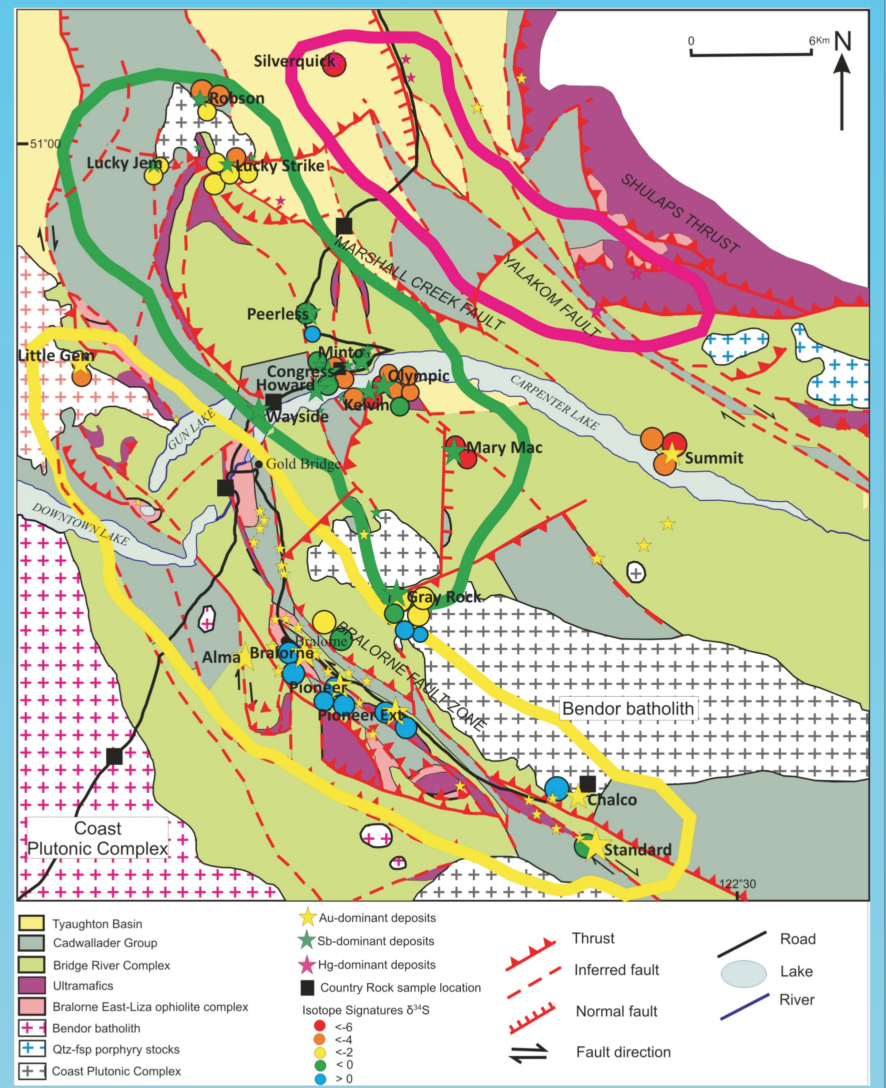
Graph displaying values for the sulfide minerals of deposits organised into metal-association type. It shows the relative decrease in $\delta^{34}S$ from west to east from Au-dominant, through Sb-dominant to Hg-dominant deposits and occurrences.



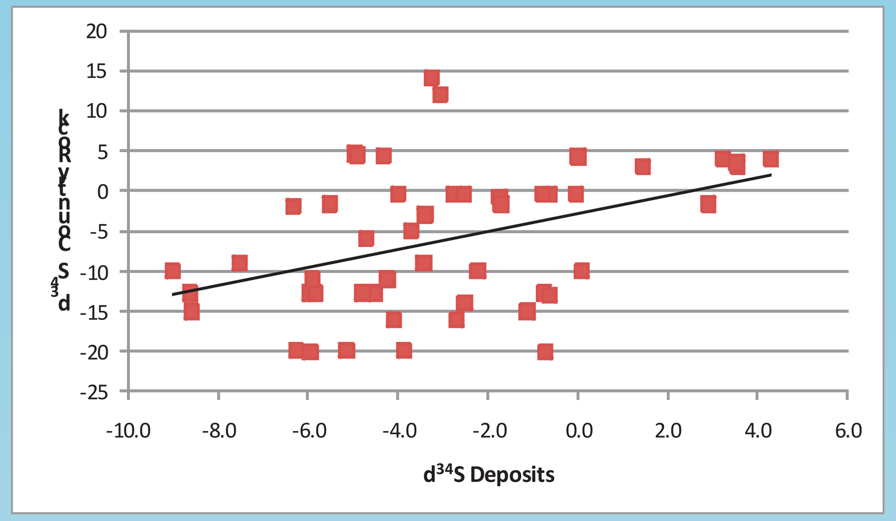
Graph showing ranges of sulfur isotopic values for the country rocks surrounding the deposit and occurrences. They are typical sulfur isotope ranges for their rock types (Ohmoto & Rye 1979).



Temperature data is from previously calculated fluid inclusion studies conducted by Leitch (1991) and Maheux (1989).
The gold deposits came from hot fluids, ranging from 280 to 365°C.
The antimony deposits are cooler with a range of 220 to 300°C.
The mercury deposits are the coolest with mineralising fluid temperatures around 190°C.
Note the cooling trend from Au (yellow) through Sb (green) to Hg (pink), thus cooling from west to east.



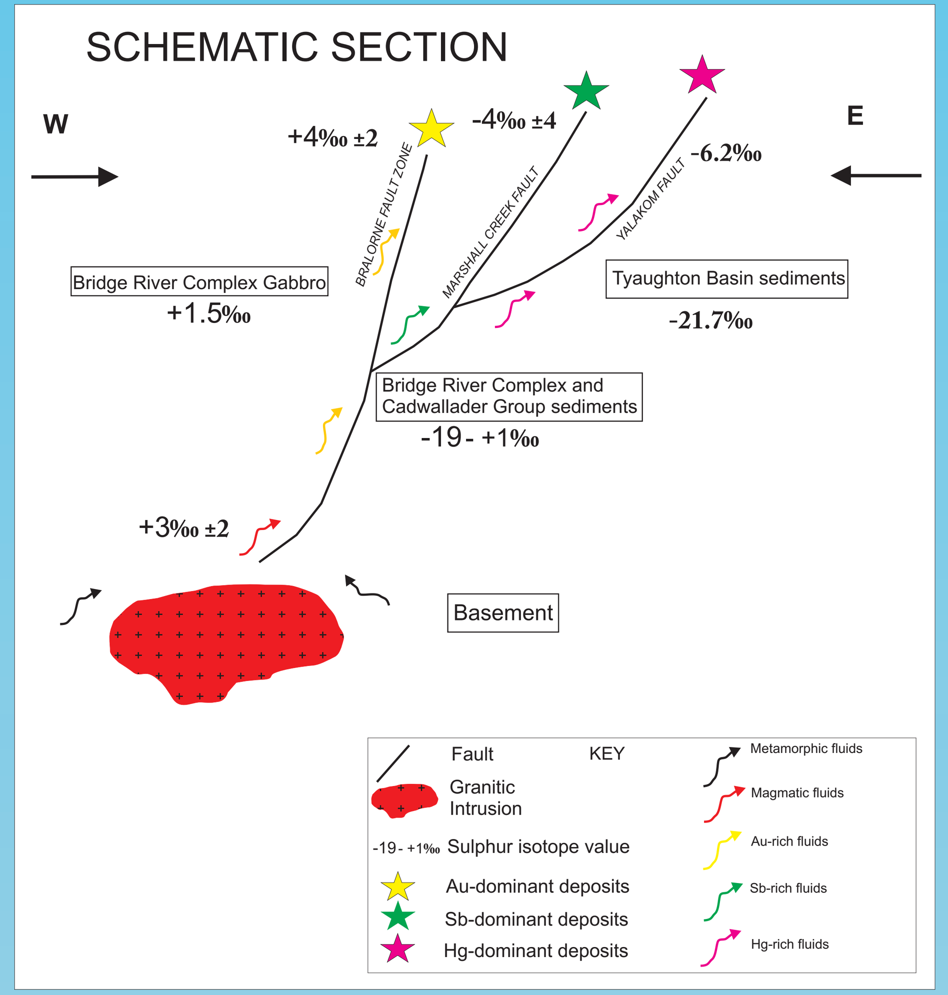
Regional geology mao showing spatial zonation of deposit-associations which correlate with a zonation of sulfur isotope values for the deposits.



As there are a variety of country rocks surrounding the mineralisation types, there are also a variety of sulfur sources, and as a result there would be mixing of the sulfur scavenged from the different sources, combining to produce a mixed sulfur isotope value. To explain the variable sulfur isotope values from the deposit sulfide minerals, the chart above was produced.

Deposit isotope values were assigned to their respective country rock host value. In the case where there was more than one country rock, a combine value was calculated based on the assumption that the accessible/soluble sulfur for each rock would be even.
It demonstrates there is a correlation between the sulfur of the country rocks and the sulfur of the surrounding deposits.

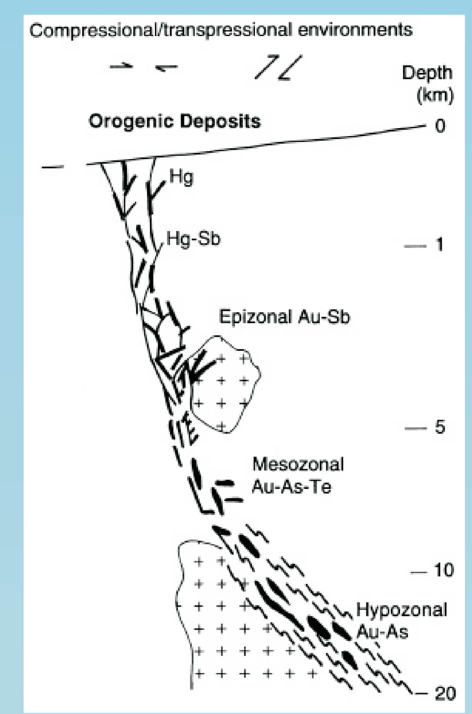
FLUID MODEL



This model shows the direction and flow of fluids up the re-activated fault zones, with fluids that originated from deep magmatic and metamorphic sources, evolved into the mineralising fluids which formed the deposits and occurrences. The sulfur was extracted along the fluid path from the surrounding country rocks.

This model is similar to Groves et al.(1998) crustal continuum model (see below) which states that the three orogenic dpeosit types share the same fluids and sulfur, which have all come from depper in the crust.

By this theory, the antimony and mercury dominant deposits are the shallower counterparts of deeper, high grade hypozonal gold deposits.



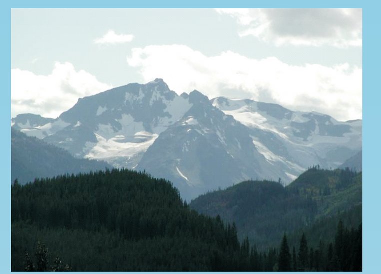
Crustal continuum model (Groves et al. 1998).

CONCLUSIONS

- Each metallogenic zone within the district displays a characteristic range of $\delta^{34}S$;

  Gold-dominant: **+4.3 to -2.7‰**
  Antimony-dominant: **+0.2 to -9‰**
  Mercury-dominant: **-6.2‰**

- The ranges decrease in $\delta^{34}S$ f rom west to east which means an increase of sulfur sourced from sedimentary rocks, or rocks with a more negative $\delta^{34}S$.
- A correlation between the deposit sulfide mineral $\delta^{34}S$ values and their respective host rock $\delta^{34}S$ values, which demonstrates an increasing reaction of country rock sulfur with the sulfur in the fluids and reflects the different types of host rocks.
- Temperature data from the district also display a pattern from west to east; one of cooling, which provides evidence for one fluid source for the three dominant types of mineralisation in the district.
- Sb and Hg deposits and occurrences represent the high level, lower temperature epizonal portions of an orogenic gold system.
- One deep crustal fluid source travelled up the re-activated dextral strike-slip faults, scavenging sulfur from the country rock as it went.
- Therefore different sources of sulfur for each deposit type.
- **Impact for regional exploration strategies**; the most prospective gold deposits will have a more positive $\delta^{34}S$, which can easily be determined through analysis.
- There is a distinct possibility for higher grade hypozonal gold deposits underneath the current deposits.



From left to right; view looking southeast from Peerless; view looking northeast along Carpenter Lake from Howard; view looking southwest from Chalco deposit vicinity.

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