Big Salmon Complex versus Iberian pyrite Belt: lithologic, geochemical and tectonic comparisons

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BRITISH COLUMBIA GEOLOGICAL SURVEY
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Introduction

More than 1700 Mt of volcanogenic massive sulphide has accumulated in over 80 known deposits within the Iberian Pyrite Belt (IPB) representing the largest sulphide accumulation on Earth Polydeformed Late Devonian to Middle Mississippian shale and felsic volcanic rocks constituting the IPB extends for 250 km from southern Portugal to southwest Spain. Mineral extraction from the belt dates back to the Chalcolithic era (4500-3000 BC) . The belt is a well studied and well understood mining camp.

In contrast to the IPB, no massive sulphide deposits are known from the Big Salmon Complex and related rocks in remote, virtually uninhabited northern B.C. Indeed, almost no written history exists for the area prior to the last century. Geologic study is limited mainly to reconnaissance mapping by Gabrielse (1969) and revision mapping by Mihalynuk et al. (1998, 2000), Nelson et al. (1998, 2000) and Roots et al. (2000). Our recent work has permitted correlation with the Yukon-Tanana Terrane, including rocks in the Finlayson Lake area to the north, in which VMS deposits have been discovered within the last six years.

A comparison between the well known IPB and the relatively poorly understood Big Salmon Complex was undertaken in order the help evaluate the Big Salmon Complex for its potential as a host for VMS deposits such as those discovered in the Finlayson Lake area.

Similarities between the Big Salmon Complex and IPB are surprising:

- Both are Late Devonian arc and clastic successions
- Both are built on allochthonous continental margin strata
- Both volcanic successions are geochemically best described as continental arcBoth might show a change to alkaline volcanics along strike
- Both successions contain exhalite markers at the sites of mineralization
- Both IPB mineralization and BSC exhalites are of latest Devonian age (within error)

Key differences are:

- Big Salmon Complex has not been explored for 6000 years
- Big Salmon Complex contains proportionally fewer felsic volcanic rocks
- Big Salmon Complex is relatively poorly exposed -covered by colluvium, swamp and forest

Location

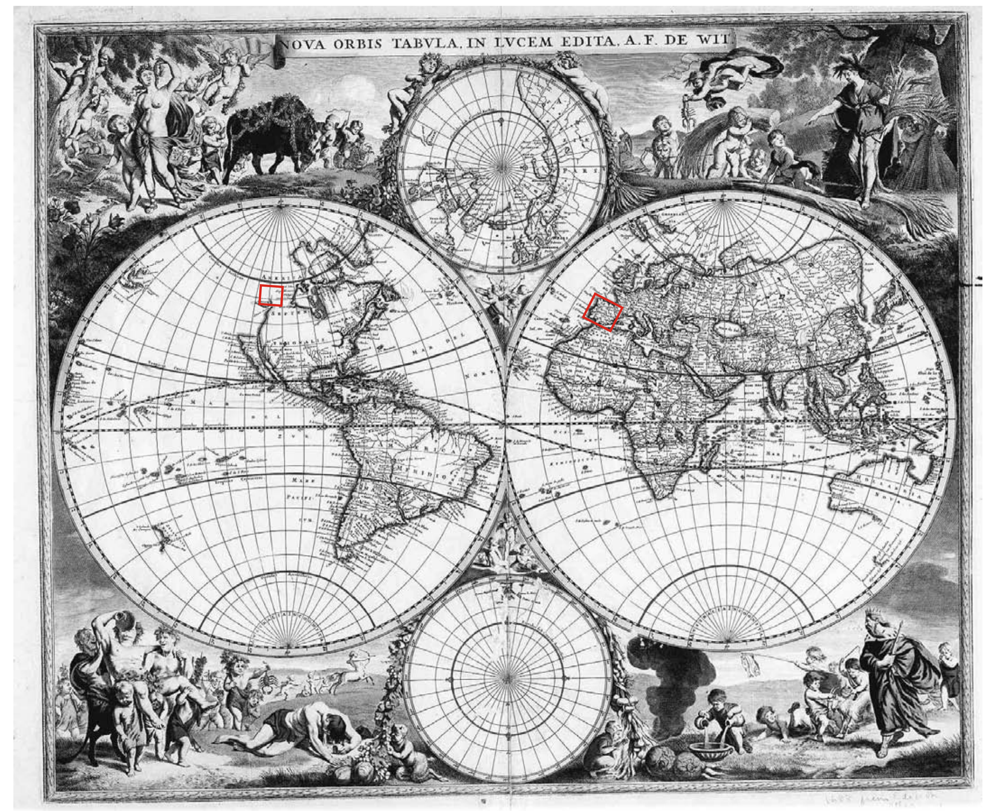


Figure 1

One striking difference between the Big Salmon Complex and the Iberian Pyrite Belt is displayed by this map by De Wit (1688). The Iberian peninsula was well explored at this time and mineral deposits of the Pyrite Belt had been exploited for 4000 years. Meanwhile, basic geographic elements of northwestern North America had not been established and mineral exploitation was unknown.

Additional Sources:

Barriga, F.J.A.S. (1990): Metallogenesis in the Iberian Pyrite Belt; *in* Pre-Mesozoic geology of Iberia, edited by R.D. Dallmeyer and M. Garcia, *Springer-Verlag*, Berlin, pages 369-379.

British Columbia, *BC Ministry of Energy and Mines*, Bulletin 105, 217 pages.

Mihalynuk, M.G., Nelson, J. and Friedman, R.M. (1998): Regional Geology and Mineralization of the Big Salmon Complex

Regional Geology

Figure 2

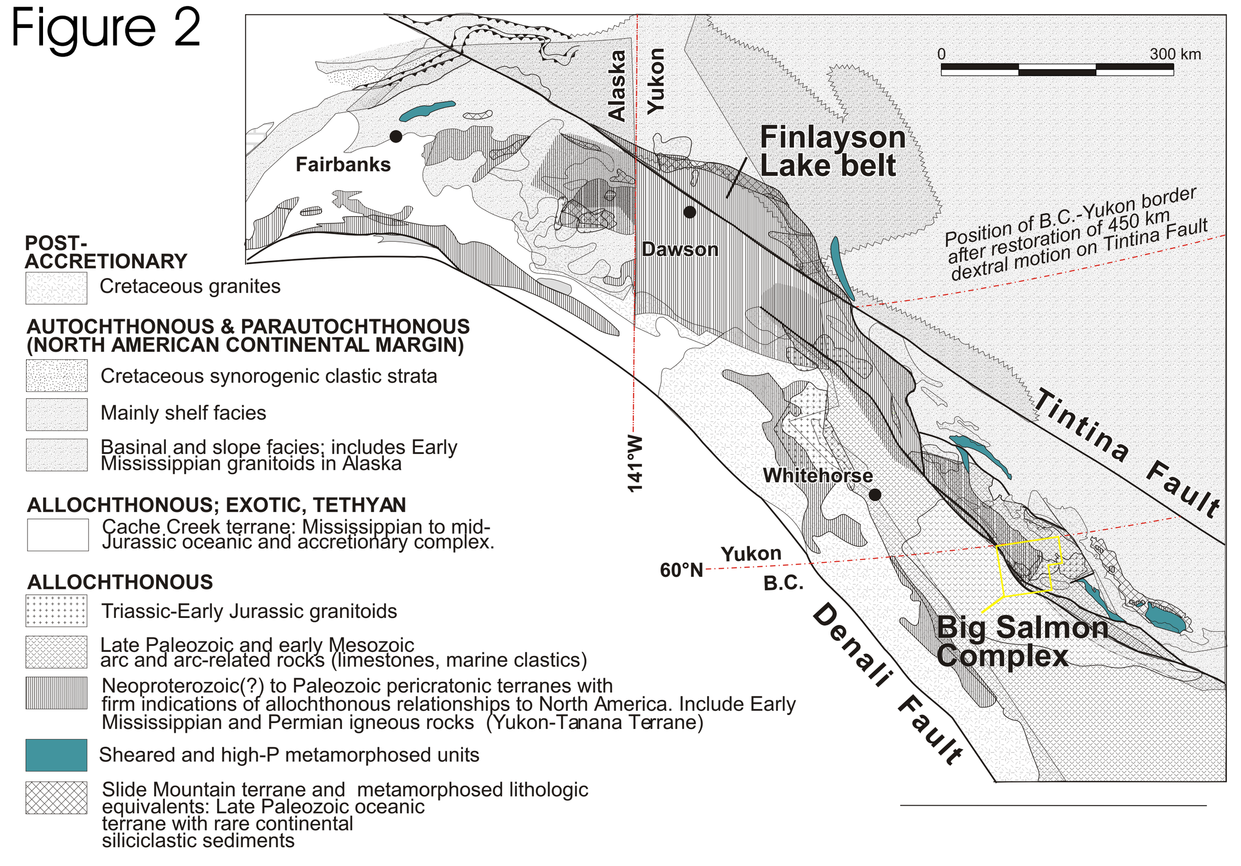


Figure 2, Above: location of the Big Salmon Complex within the Yukon-Tanana Terrane of northern British Columbia, southern Yukon and Eastern Alaska (geological map simplified from Mihalynuk et al., 1999). East of the Tintina Fault, the bedrock geology and the British Columbia Yukon border has been translated 450 km northward to restore Cretaceous offset.

Figure 3, Below: geological belts of the Iberian Penninsula (after Quesada, 1991); CZ = Cantabrian Zone, WALZ = West Austrian-Leonese Zone, GTZ = Galacia Tras-os-Montes Zone, CIZ = Central Iberian Zone, BCSZ = Badajoz=Córdoba Shear Zone, OMZ = Ossa-Morena Zone, PTSZ = Porto Tomar Shear Zone, PL = Pulo do Lobo, SPZ = South Portuguese Zone. Both maps are approximately the same scale.

Figure 3

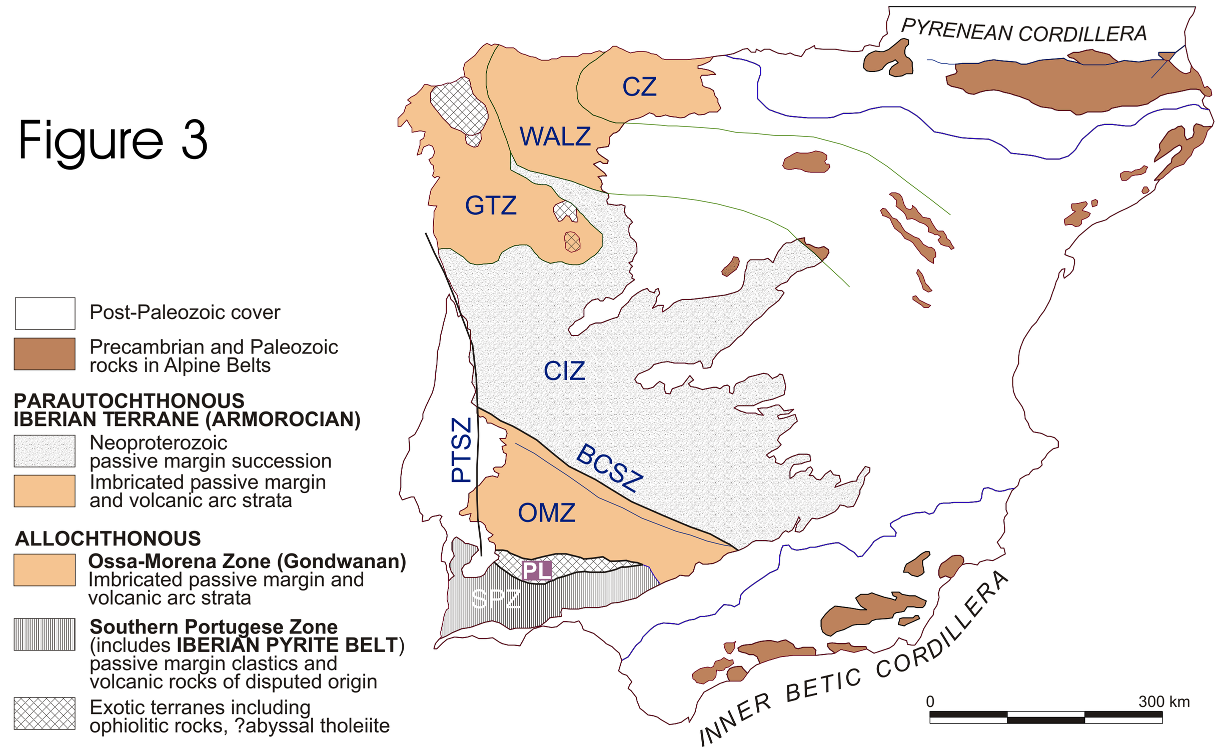
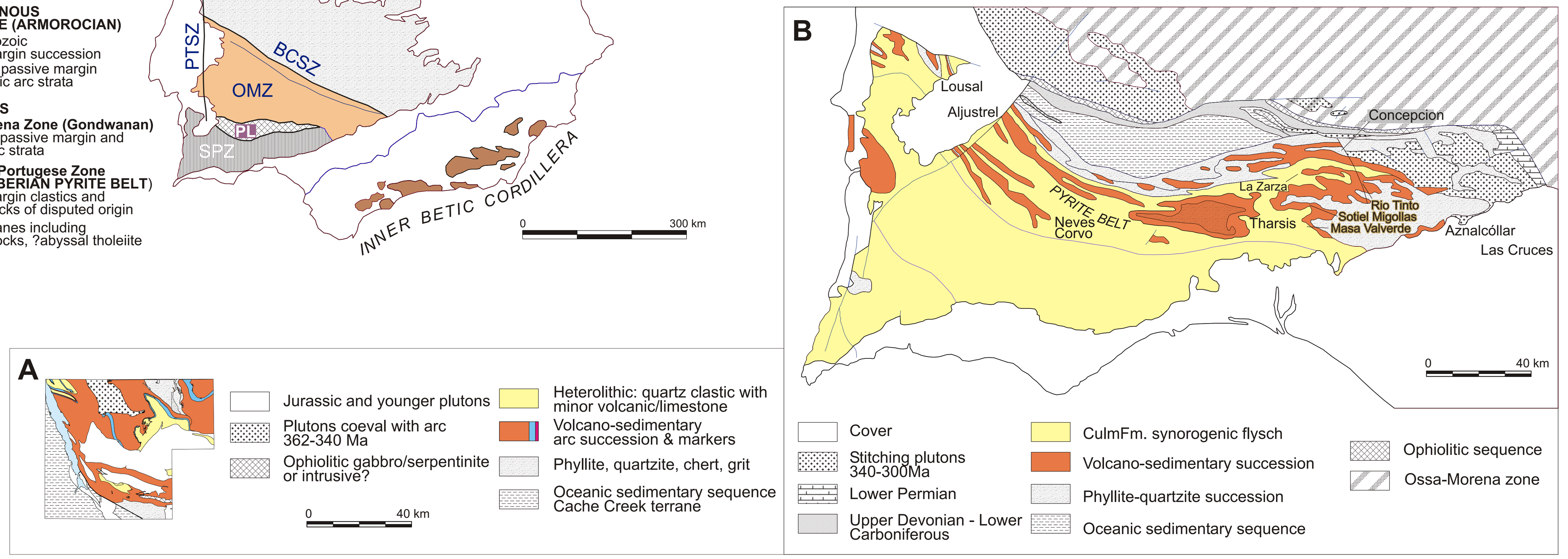


Figure 4

Regional geological setting of (a) the Big Salmon Complex (simplified from Mihalynuk et al., 2000). (b) the Iberian Pyrite Belt (modified from Quesada, 1991) Both are plotted at the same scale. They show gross similarities in the distribution of rock types. For more geologic detail in the Big Salmon Complex see the adjacent poster session..



Geochemistry

Figure 5

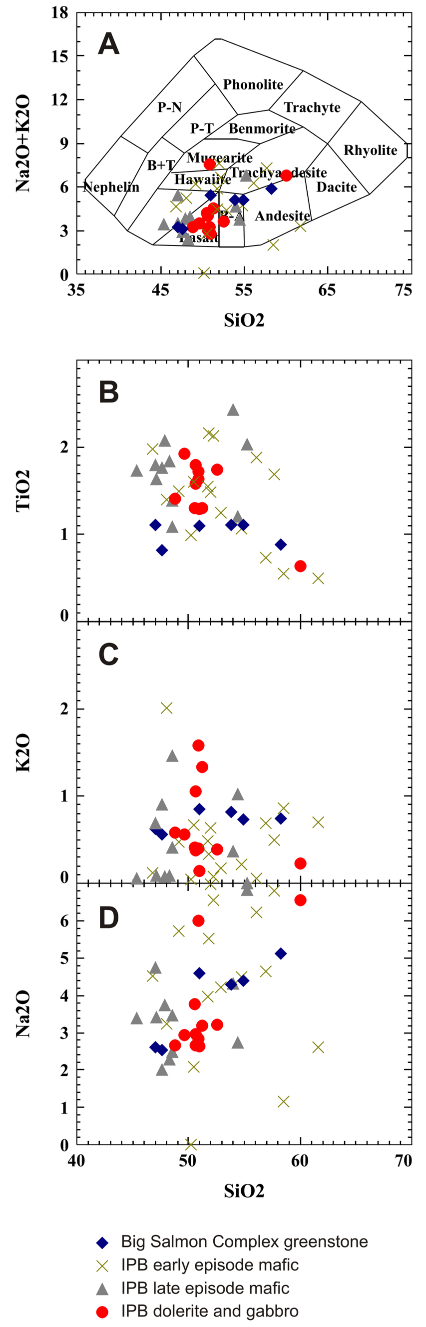


Figure 6

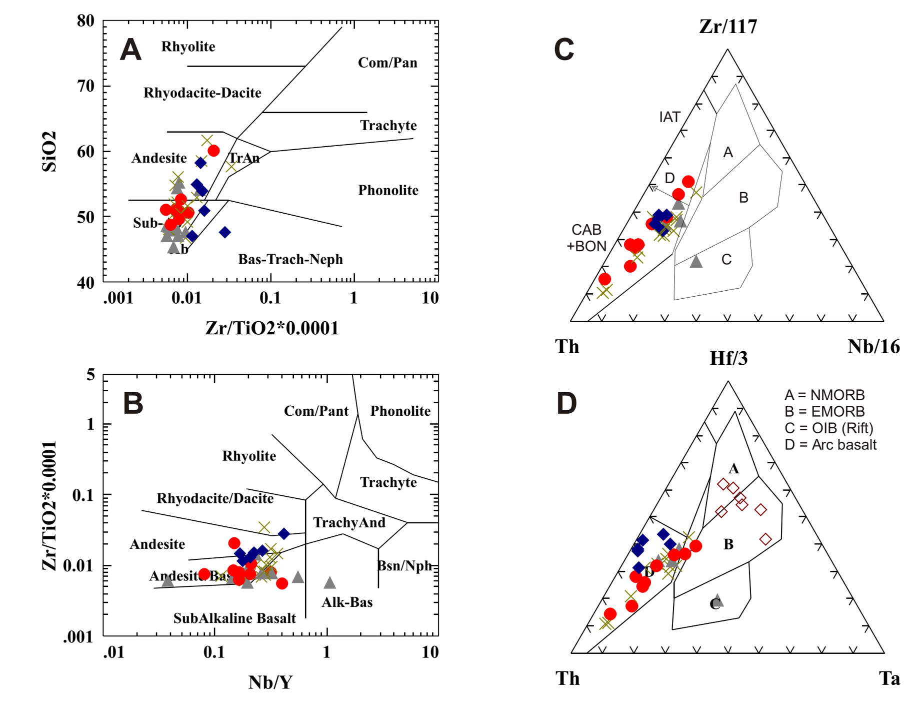


Figure 5.

A. Silica versus total alkalis diagram of Cox (1979) shows overlap of compositions of mafic rocks from the Big Salmon Complex (this study) and the Iberian Pyrite Belt (from Thiéblemont et al., 1998).

B,C,D.. Harker variation diagrams showing SiO_2 versus TiO_2, K_2O and Na_2O respectively, for mafic rocks from the Big Salmon Complex and the Iberian Pyrite Belt (from Thiéblemont et al., 1998).

Figure 6.

A,B. Rock classification diagrams of Winchester and Floyd (1977), based on largely immobile elements shows that both IPB and BSC rocks range from basalt to andesite.

C,D. Tectonic discrimination diagrams of Wood (1980) are effective at separating arc from non-arc rocks. Abbreviations are: Plotted on the Hf-Th-Ta diagram as diamonds are compositions of Slide Mountain basalt (data from Ferri, 1997). The diagrams show that BSC basalts are clearly unlike Slide Mountain MORB with which they were originally correlated, but overlap IPB rock compositions in the arc field.

Figure 7

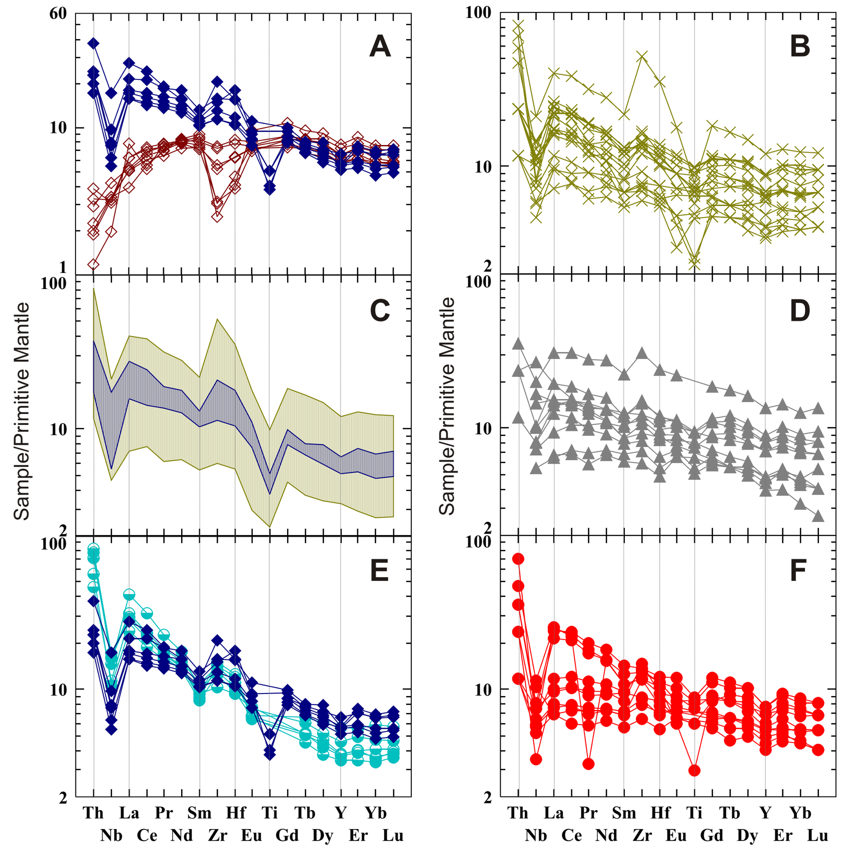


Figure 7.

Multi-element plots of mafic volcanic rocks from A. the Big Salmon Complex samples (closed diamonds) compared with Slide Mountain basalt (open diamonds, data from Ferri, 1997);

B. Iberian Pyrite Belt early mafic episode samples;

C. Big Salmon Complex (dark shade) and Iberian Pyrite belt early episode (light shade) samples compared;

D. late mafic episode samples of the Iberian Pyrite Belt;

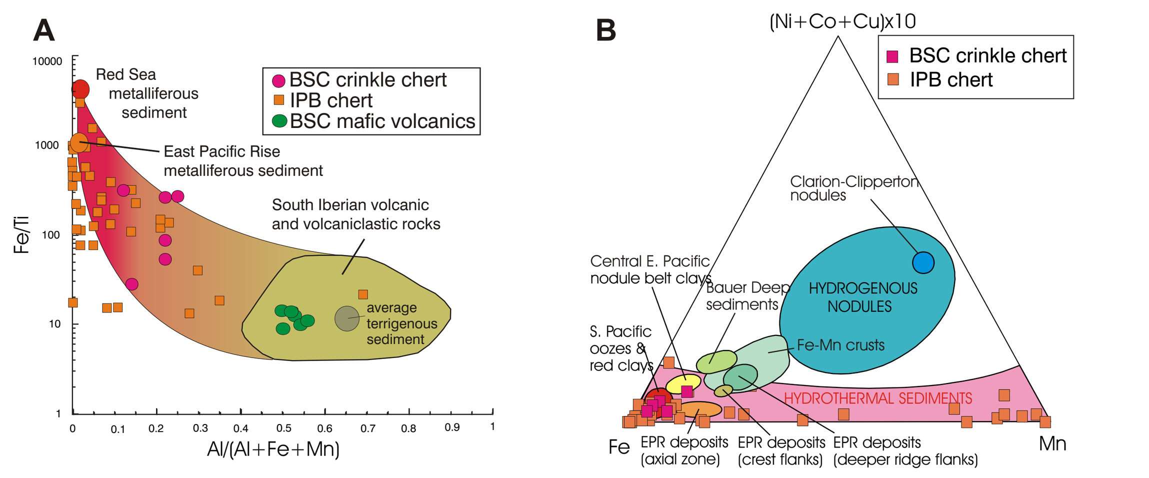
E. Big Salmon Complex samples compared with fresh basalt from the Eocene Sloko Group formed in a continental arc setting (Mihalynuk, unpublished); and

F. dolerite and gabbro data from the Iberian Pyrite Belt. All Iberian Pyrite Belt data are from Thiéblemont et al. (1998).

Figure 8

A. Bivariate plot of Al/(Al+Fe+Mn) versus Fe/Ti is used to estimate the hydrothermal contribution to the cherts. Shown is field for South Iberian “volcanites” (volcanic and volcaniclastic rocks; Leistel et al., 1998), average terrigenous sediment and Red Sea metalliferous sediment (Boström, 1973a) and Big Salmon Complex mafic volcanic rocks (data of Cook and Pass, 2000), and hypothetical mixing curves between endmembers.

B. (Ni+Co+Cu)*10-Fe-Mn ternary plot shows the general fields for hydrothermal sediments and hydrogenous nodules (Bonatti et al., 1972), Fe-Mn crusts (Toth, 1980), for Bauer Deep sediments (Sayles and Bischoff, 1973), East Pacific Rise deposits (axial zone, crest flanks, and deeper ridge flanks; Germain-Fournier, 1986), South Pacific biogenous oozes and red clays, siliceous clays from the Central East Pacific nodule belt, and Clarion-Clipperton zone associated Mn nodules (Karpoff et al., 1988). In both plots BSC crinkle chert displays a hydrothermal character.



Summary

It can be concluded that the Big Salmon Complex shows many of the characteristics that seem to be key to the production and preservation of VMS mineralization in the IPB. Perhaps the most important are:

- the regional baritic, manganiferous and iron-rich crinkle chert unit indicates a widespread and vigorous exhalative event

- hydrothermal activity near or at the Devono-Mississippian boundary which is a metallogenic time-line of global significance

- tectonic setting and volcanic geochemistry of the BSC and IPB are similar continental arc volcanics. This is despite published claims that IPB volcanics are alkaline and intraplate, and that BSC volcanics are correlative with Slide Mountain volcanic rocks, which are MORBs.

The BSC does contain a greater ratio of mafic:felsic volcanic rocks than does the IPB, but felsic volcanic rocks are locally dominant. Based upon its similarity to the prolifically mineralized IPB, the BSC should provide fertile ground for the future discovery of VMS deposits.

Stratigraphy

Figure 9

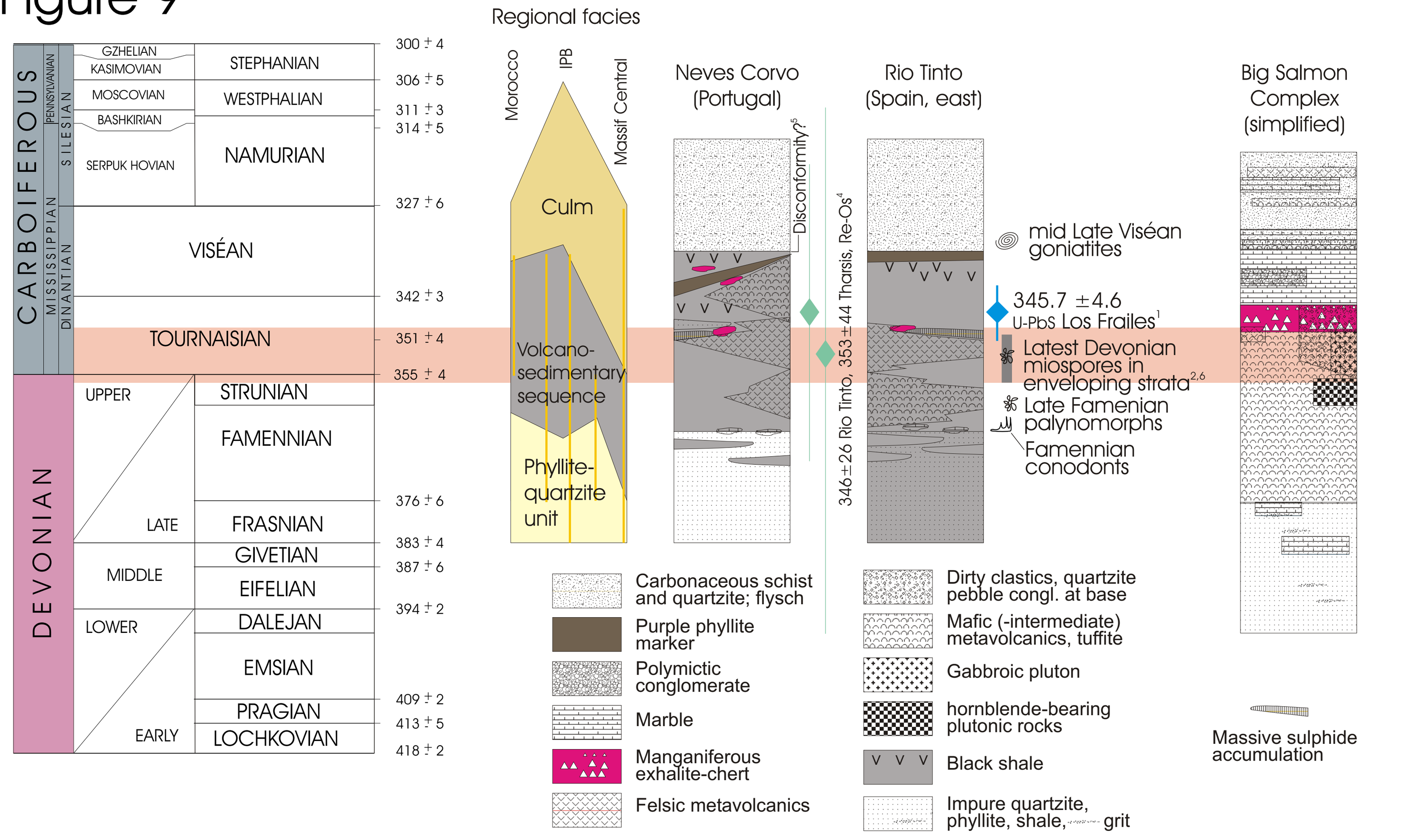


Figure 9.

Generalized stratigraphy of the Iberian Pyrite Belt and Big Salmon Complex compared. Time scale is modified from Okulitch (1999); the shaded horizontal bar indicates the disparity between the isotopically and biogeochronologically indicated age of ore formation. Note that if the bar was extended to the youngest error limit of the “best” isotopic age date on mineralization (from Los Frailes) the shaded region would nearly double. Stratigraphic columns of Neves Corvo and Rio Tinto after Liestel et al. (1998a); IPB regional facies distribution and mineralizing episodes, shown by bars, is adapted from Lescuyer et al. (1998).

Data sources:

[1] Nesbitt et al. (1999), U-Pb Shrimp;

[2] Pereira et al. (1996), Oliveira et al. (1997), microfossils;

[3] according to Claoué-Long et al. (1995), the D-C boundary is 353.2 ±4Ma;

[4] Mathur et al. (1999) Re-Os dates;

[5] Barriga et al. (1997) propose a 20 m.y. break in sedimentation following Neves Corvo ore formation (including Tournaisian and Lower Viséan);

[6] Oliveira et al. (1997) show that Strunian strata enveloping ore are overlain by middle Late Viséan strata with abundant reworked Strunian+Tournaisian miospores and goniatites.

[7] approximate duration of Hangenberg anoxic event spanning lower to middle S. Praesulcata conodont zone in Late Famennian time according to Hallam and Wignall (1997).

[8] Re-Os age of Niero et al. (1999) from Aznalcóllar of 351±9.

Introduction

Recent discoveries of volcanogenic massive sulphide (VMS) deposits in Yukon-Tanana Terrane (YTT) rocks of the southern Yukon (*e.g.* Kudz Ze Kayah, Wolverine, Fyre Lake) has focused attention on the VMS potential of the proposed southern extensions of they Yukon-Tanana Terrane within British Columbia. The Big Salmon project was initiated in 1997 with the aim of determining the tectonic affiliation of the Big Salmon Complex (BSC), a poly-metamorphosed rock package just south of the Yukon border and east of Teslin Lake (see Figure 2). These rocks had historically been considered part of the oceanic Slide Mountain Terrane (Wheeler et al., 1992), but preliminary investigations by J. Nelson in 1996 revealed their quartz-rich nature and probable pericratonic terrane affiliation.

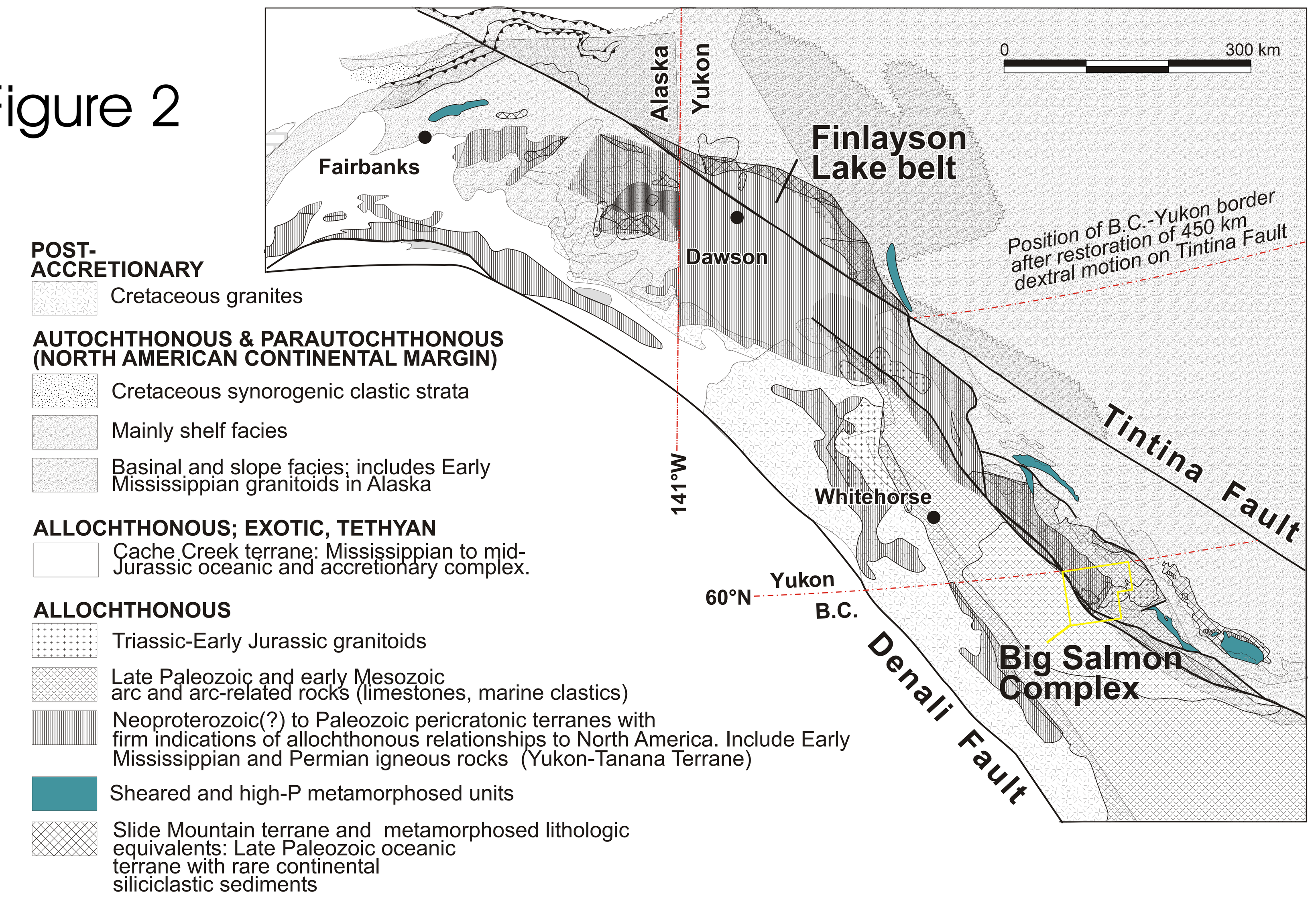
Reconnaissance mapping was begun in 1997 to test the Yukon-Tanana Terrane correlation. Advances in our understanding of the lithostratigraphy, isotopic age, geochemical signature and structural architecture of the BSC that arose from the 1997 field mapping program enabled conclusive correlation with the YTT. The BSC includes orthogneisses dated as Early Mississippian and volcanic rocks broadly correlative with VMS-bearing units in the Yukon.

Work on the BSC project was postponed in 1998 with the aim of continuing the project under the auspices of the Ancient Pacific Margin NATMAP program planned to commence in 1999. In this way the BSC project was able to benefit from infrastructure and expertise through affiliation with NATMAP. Map coverage planned for 1999 was completion of the two 1:50K sheets: 104O/13, 104N/16 (east of Teslin Lake) and small portions of adjacent areas including 104N/9 and 104O/11. However, the availability of a contract helicopter permitted extension of the coverage to include 104N/9 (east of Teslin Lake), all of 104O/12 and most of 104O/14W, a total of 3.5 mapsheets. The mapped area extends for 70km from the western shore of Teslin Lake as far east as the community of Swift River. It extends from the British Columbia-YT border to the south, about 56 kilometres.

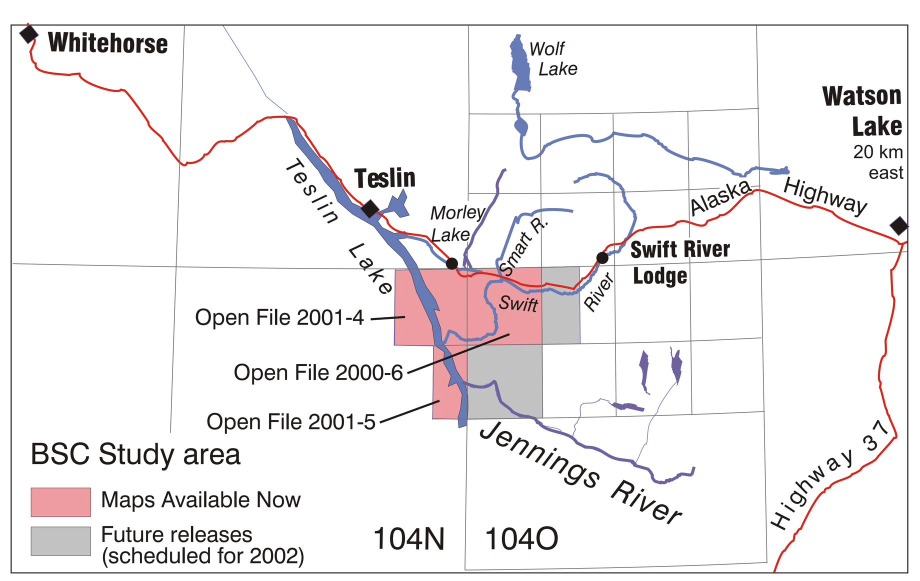
Mapping in 2000 was aimed at providing fill-in traverses, principally in 104O/14W, and to address systematic problems illuminated during compilation of 104O/13, especially around the Arsenault property.

Regional Geology

Figure 2



Location



Mineral Potential

Within the entire Big Salmon Complex in British Columbia, the only base metal mineral occurrences recorded in MINFILE are those on the Arsenault copper (+/-Au) prospect and adjacent claims about 14 km south of the Smart and Swift River confluence. Mineral textures preserved suggest static crystallization, but mineral development at a persistent stratigraphic horizon has prompted comparison with Besshi or Kuroko styles of deposits.

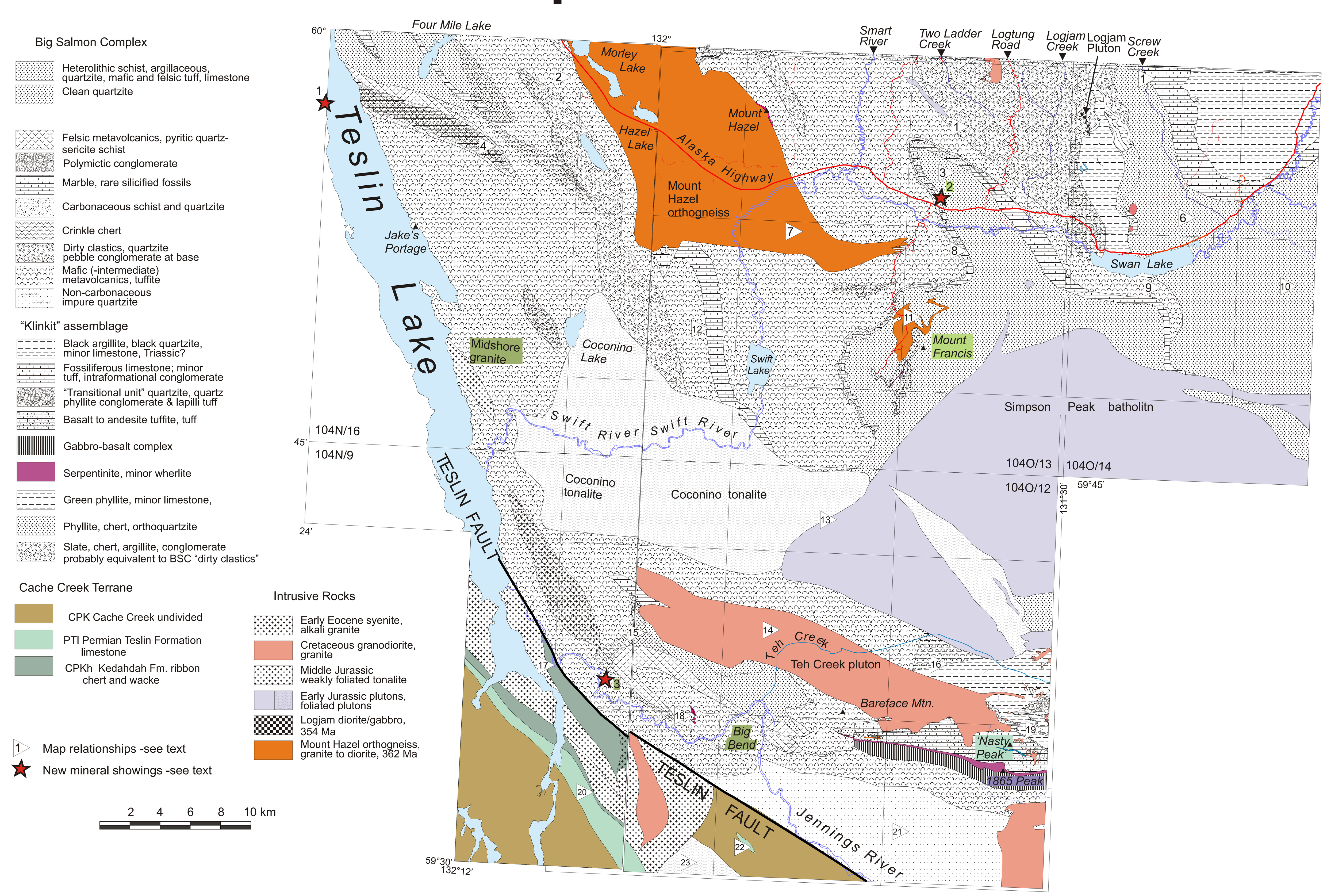
A large hydrothermal system
The Big Salmon Complex does display characteristics typical of world class VMS camps (see adjacent poster). One regional marker unit, known as the Crinkle Chert, indicates a major exhalative event immediately following deposition of a voluminous, dominantly mafic continental arc succession. Stratiform magnetite layers up to a decimetre thick within, and near the top of the crinkle chert when combined with elevated barium, copper and manganese, are difficult to explain other than by a hydrothermal origin. Numerous occurrences of minor sulphide mineralization and copper staining were encountered in the crinkle chert unit, further indication of the high mineral content of this unit.. Most significantly, a chlorite porphyroblasic 6 metre by 0.5 metre lens with disseminated chalcopyrite returned 0.9% Cu; 0.3g Au, 2.9g Ag, 6.8% Fe, and 0.17% Ba from a chip sample across its width (location 2, Fig. 3).

Our evaluation of five existing geochemical analyses of the crinkle chert supports a hydrothermal, not hydrogenous origin (e.g., see Fig. 8 adjacent). The recognition of seafloor hydrothermal origin for the crinkle chert unit points to the possible presence of undiscovered volcanogenic massive sulphide (VMS) mineralization in the area. Explorationists can consider the crinkle chert as a time-stratigraphic marker for hydrothermal activity.

Other indications of mineralization are:
1. West Teslin Lake border area. Along west shore of northern Teslin Lake, a set of moderately to steeply west to northwest dipping brittle shears are spaced about 5-10 metres apart within an Eocene granitoid body are invaded by quartz veins that show rusty, pyritic mineralization with rare malachite staining and variably developed alteration envelopes. One 2-3 cm thick vein, with a somewhat wider than average 20 centimetre alteration envelope, was chip sampled for 2.5 metres along the vein. It returned values of 1320 ppb Au, 0.4% As, and 194 ppm Sb (location 1 on Fig. 3).
2. Jennings River "knee". Pyrite-rich sericite schist crops out at many localities within the map area. Here it is well developed within a regional quartz-phyric horizon of probable dacite composition. Despite scant exposures, the felsic host unit is intermittently exposed for at least 16 km (Location 3 on Figure 3), if it truly is so continuous, it could represent a significant mineralizing system that warrants further work.

Figure 3

Big Salmon Complex map area



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Mapping results from the Big Salmon Project(Yukon-Tanana Terrane)

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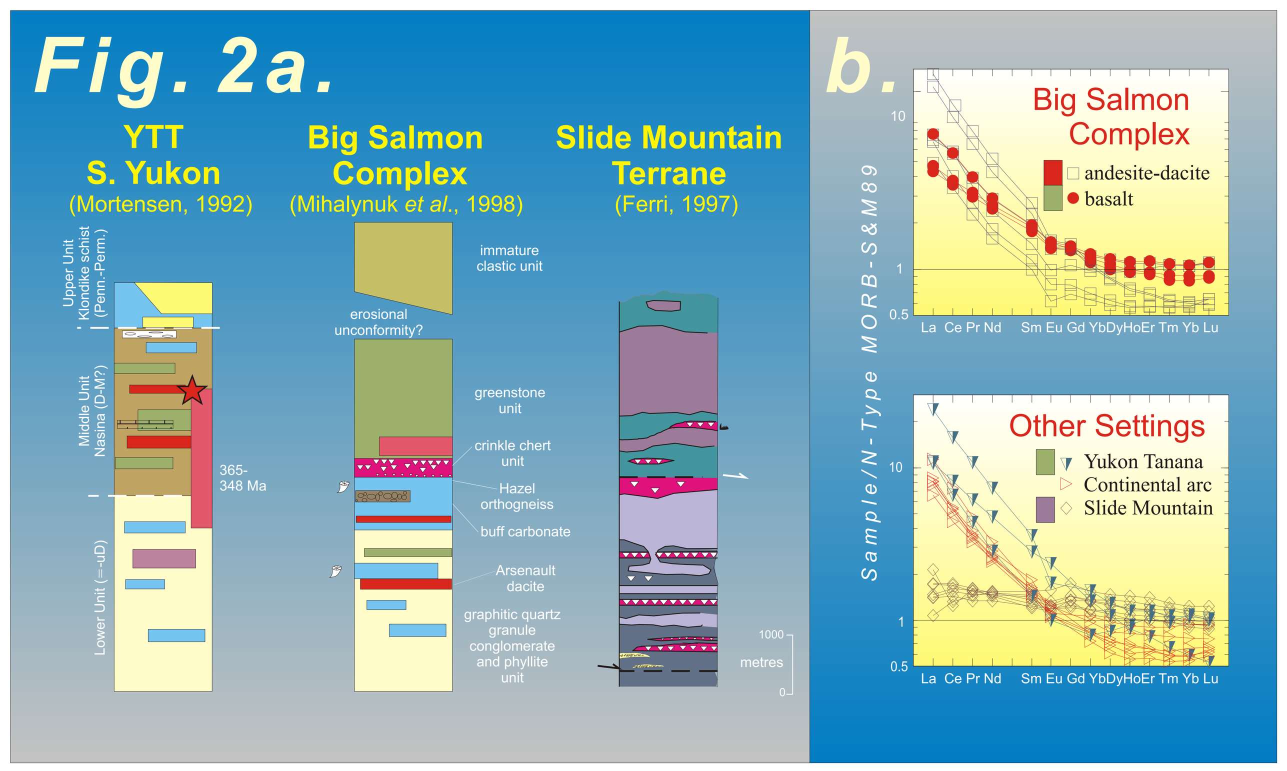
INTRODUCTION

Regional geological mapping of the Big Salmon Complex in northwestern British Columbia (104N/09 & 16 and 104O/12, 13 & 14W) was conducted in 1999 under the aegis of the Ancient Pacific Margin National Mapping Program (NATMAP, Fig. 1). This mapping builds on 1997 reconnaissance work that confirmed long-standing correlations between the Big Salmon Complex in British Columbia and the Yukon (Fig. 2a).

In southern Yukon, Big Salmon Complex (BSC) rocks have been included with the Kootenay Terrane (Gordey, 1995) which include the Lower and Middle Units of the Yukon-Tanana Terrane (YTT) as used by Mortensen (1992). However, the extension of this belt of rocks within B.C. was included with the oceanic Slide Mountain terrane (SM). REE data do not permit the SM assignment, but confirm the YTT association. This correlation is important because YTT rocks, historically ignored by mineral exploration geologists, have been the focus of mineral exploration programs since 1993 with the discovery of mineralized float at what came to be the Kudz Ze Kayah deposit. Other exploration successes include the Wolverine and Fyre Lake volcanogenic massive sulphide deposits.



STRATIGRAPHY

A persistent stratigraphy provides the foundation for correlating from one area to another in the Big Salmon Complex. In B.C., three distinctive and contrasting units are recognized as forming a marker succession. Based on new isotopic and geologic constraints, their stratigraphic order, inverted from that of Mihalynuk *et al.* (1998), is now known to be (oldest to youngest):

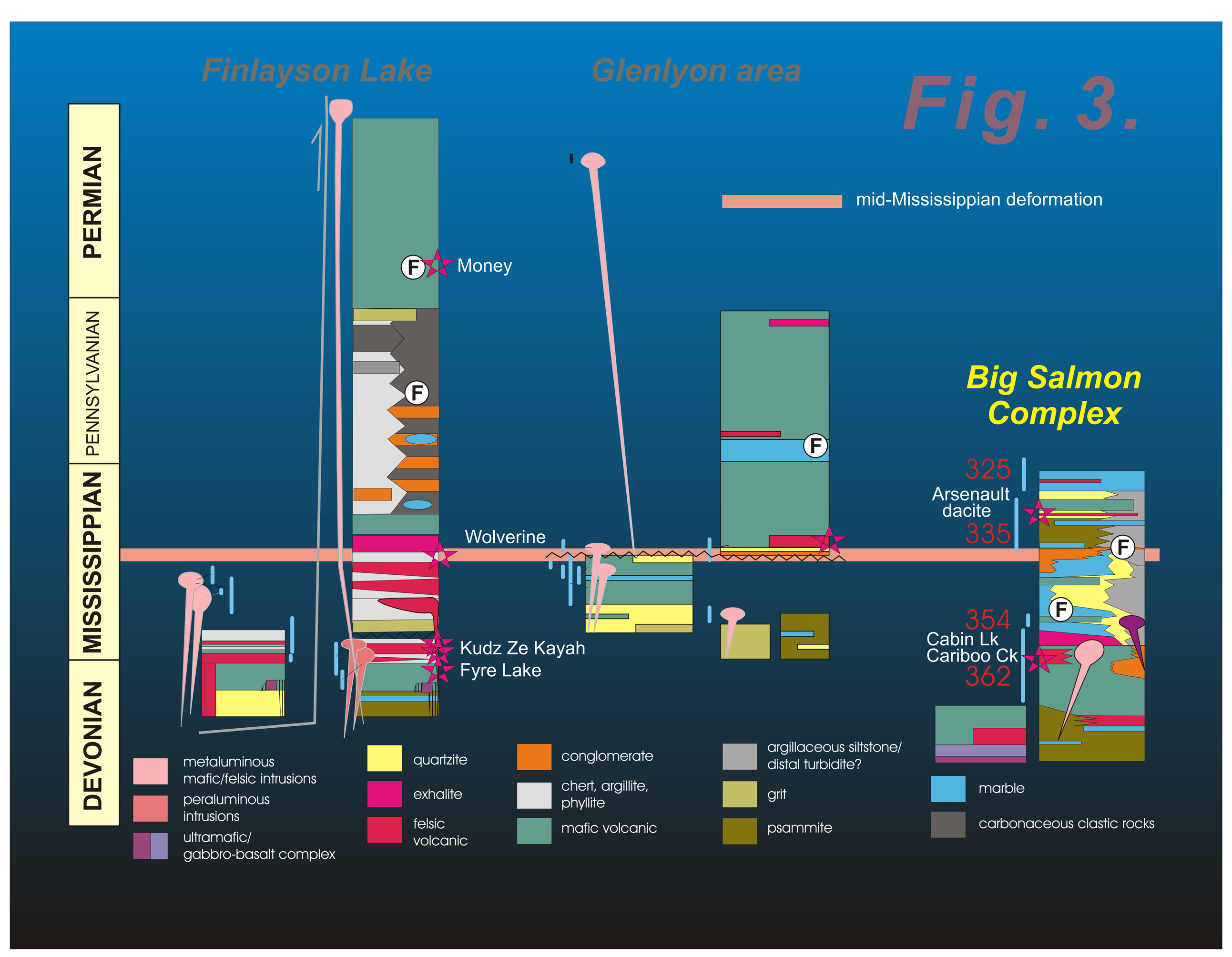
- 1200 m of tuffite-dominated greenstone;
- 30-150 m of buff to grey weathering limestone with metre-thick tuffaceous and thin centimetre to decimetre quartzite layers;
- 20-50 m of thinly bedded, finely laminated manganiferous crinkle chert / quartzite with muscovite partings;

This marker succession persists in southeast and northwest 104O/13 and south-central 104O/12. In northern 104N/16 a hybrid unit having some characteristics of felsic tuff mixed with crinkle chert occurs in place of the crinkle chert unit.

Two other more broadly defined rock packages are recognized:

- >150 m of dirty clastics: brown to tan wacke, stretched quartzite-pebble and granule conglomerate and slate;
- >1000 m of heterolithic, quartz-rich clastics interbedded with thin limestone and mafic and felsic tuffs.

In very general terms, the BSC stratigraphy might be correlative with stratigraphy farther north in the Glenlyon and Finlayson Lake areas. Such correlations are important because the prolifically mineralized horizons in the Finlayson Lake area appear to have temporal equivalents in the BSC, and these could be similarly mineralized.



GEOCHRONOLOGY

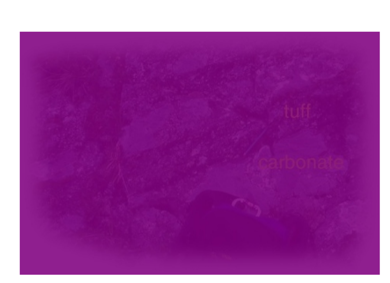
Critical age data from two units provide a younging direction within the stratigraphy. Hazel orthogneiss occurs within the greenstone unit, which it apparently cuts, thereby providing a minimum age on the greenstone which underlies more than half of the map area. Intermediate to dacitic tuff that is interbedded with limestone on the north flank of Mount Francis is believed to occupy one of the highest stratigraphic positions within the Big Salmon Complex (Fig. 3).

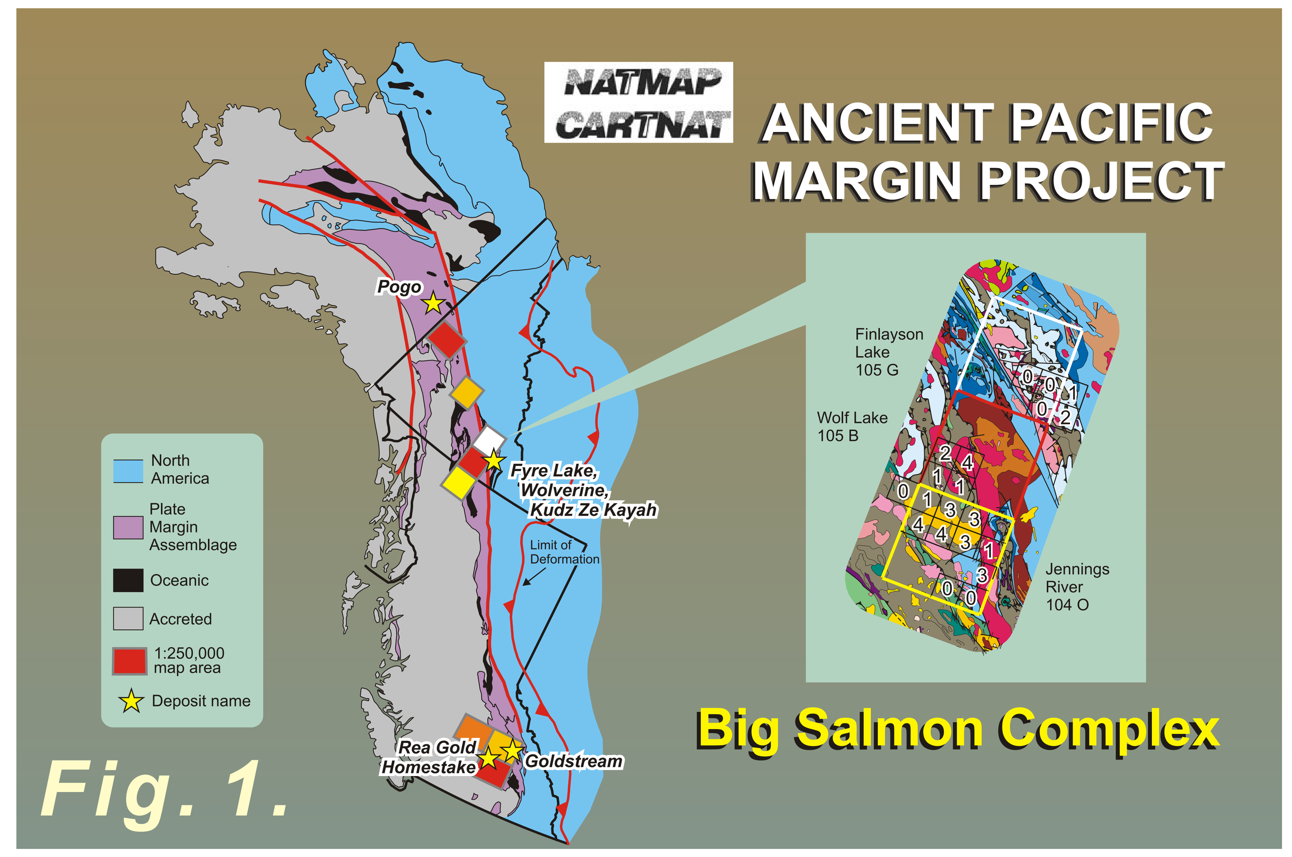
Mount Hazel orthogneiss

Eight fractions of the clearest and coarsest grains available all gave discordant results (2-10% discordant), with ellipses aligned in a linear fashion. An upper intercept of 362.3+7.9/-6.8 Ma is interpreted as the best estimate for the igneous age of the Mt. Hazel pluton. A well-defined lower intercept of 189+16/-17 Ma may correspond with the time of Pb loss, possibly due to a late deformational event which produces a strong fabric in the *circa* 196 Ma Coconino tonalite, whereas the *circa* 185 Ma Simpson Peak batholith is mostly undeformed.

Mount Francis dacitic tuff

Seven strongly abraded fractions of the clearest grains available all likely show the effects of Pb loss, despite abrasion. Four fractions (A, F, G and H) are discordant, and are inferred to contain significant inheritance; they give 207Pb/206Pb ages of ca. 546-1235 Ma. Fractions B and C give 207Pb/206Pb ages of about 325 Ma. The weighted average 207Pb/206Pb age for these two fractions, 325.1 ±3.0 Ma, provides the best estimate for the age of the rock.





Mapping by:
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C. Roots (GSC), T. Gleeson (UVic),
M. deKeijzer (UNB), R. Friedman (UBC)
Geochronology by:
R. Friedman (UBC)

MINERALIZATION

Big Salmon

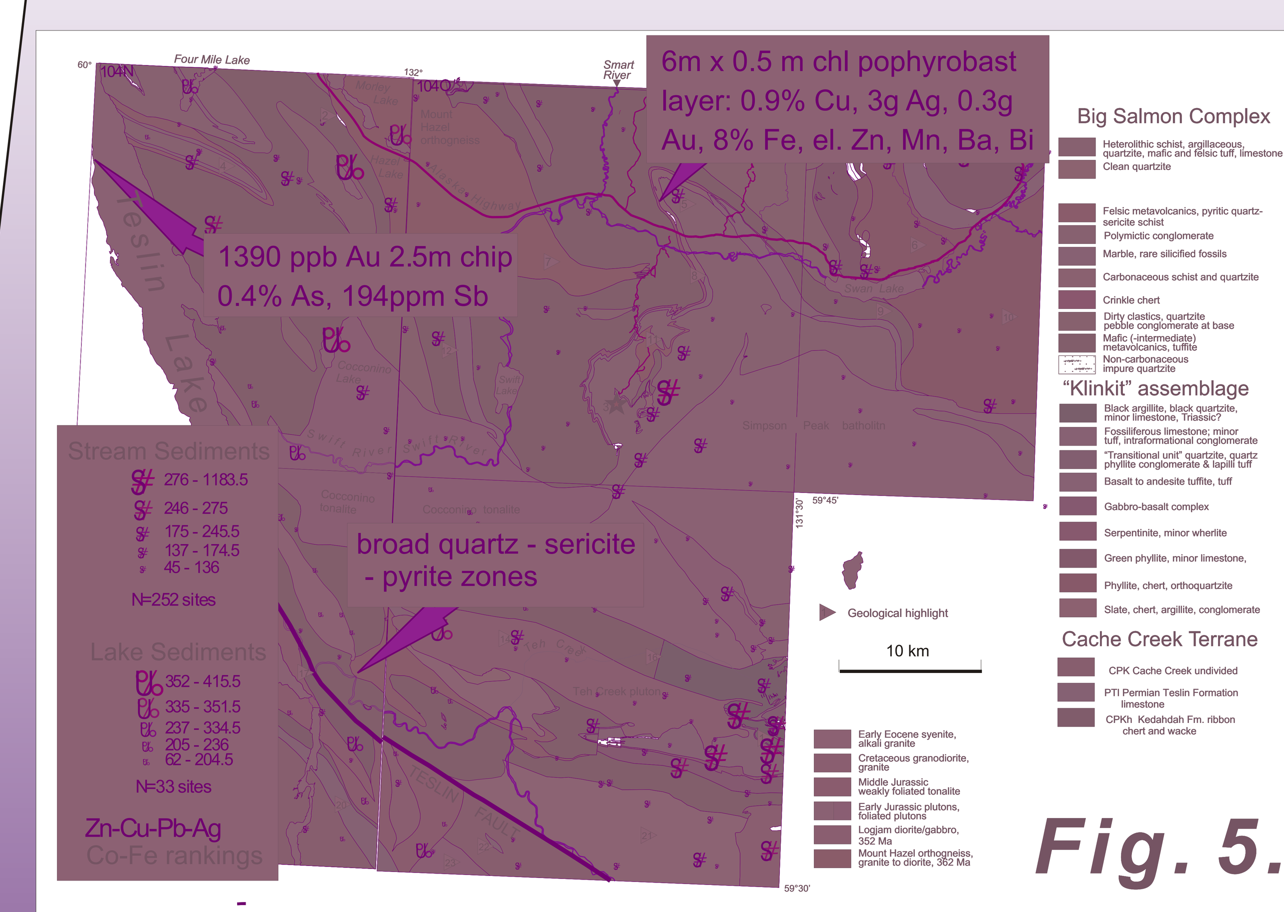
Several new mineralized zones were discovered in 1999. They are either intrusion-related gold veins or stratabound copper-rich lenses in crinkle chert. One pyritic sericite schist is geochemically unremarkable, but extensive. Along west shore of northern Teslin Lake, 6km south of the Yukon border, a set of moderately to steeply west to northwest dipping, west-side-up brittle shears are spaced about 5-10 metres apart within an Eocene granitoid body. They are invaded by rusty, pyritic quartz veins with rare malachite staining. One 2-3 cm thick vein with a 20 centimetre alteration envelope was chip sampled for 2.5 metres along its length. The sample returned 1320 ppb Au, 0.4% As, and 194 ppm Sb.

Numerous occurrences of minor sulphide mineralization and copper staining were encountered in the crinkle chert unit, further indication of its high mineral content. Most significantly, a chlorite porphyroblastic 6 metre by 0.5 metre lens with disseminated chalcopyrite returned 0.9% Cu, 0.3g Au, 2.9g Ag, 6.8% Fe, and 0.17% Ba from a chip sample across its width.

Pyrite-rich sericite schist crops out at many localities within the map area. Most extensive are those near the Jennings River "knee" occurring within a regional quartz-phyric horizon of probable dacite composition. Despite scant exposures, the felsic host unit is intermittently exposed for at least 16 km, representing a significant mineralizing system.

Most ground is open for staking as of Jan 19, 2000 (Fig 4).

Opportunities



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