Gold Skarns

BCGS GeoFile 1998-02

By G.E. Ray

This GeoFile consists of 3 parts: Characteristics of Gold Skarns; Gold Skarn Deposit Profile; and a Bibliography of Gold Skarns and Gold-rich Skarns

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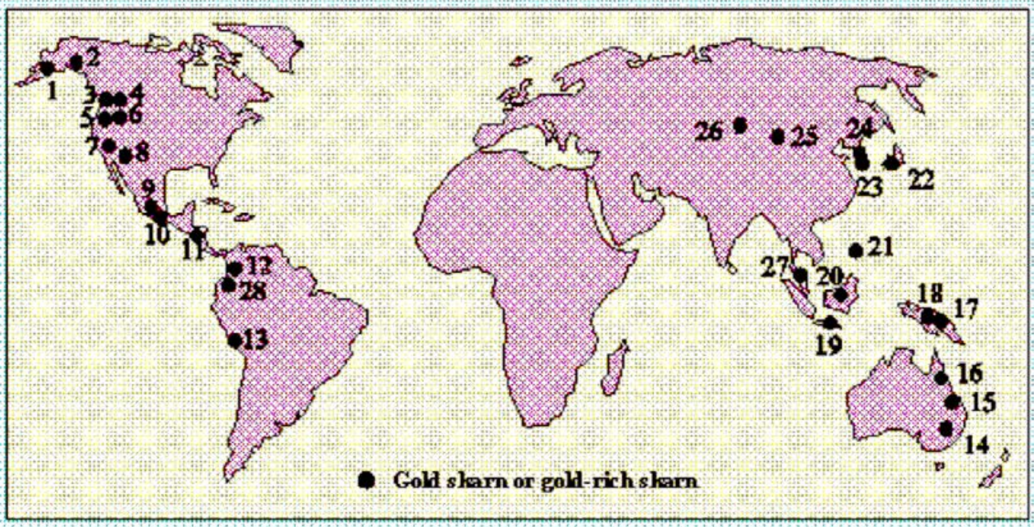
Characteristics of Gold Skarns

Gold skarns are defined as skarn deposits in which gold is the primary or dominant economic metal present. The following features should be noted about these deposits:

1. They occur worldwide along destructive plate margins (Figure 1) and tend to have a spatial and temporal association with Cu porphyry provinces.



1. Zackly, Alaska
2. Nabesna, Alaska
3. Nickel Plate, B.C.
4. Phoenix, B.C.
5. Buckhorn Mt, Washington
6. Butte Highlands, Cable & Elkhorn, Montana
7. Fortitude & McCoy, Nevada
8. Carr Fork, Utah
9. Golfo de Oro, Mexico
10. Naica, Mexico
11. La Luz, Nicaragua
12. Vieja, Columbia
13. Katanga, Peru
14. Browns Ck & Junction Reefs, Australia
15. Mt Biggendon, Australia
16. Red Dome, Australia
17. Ok Tedi, PNG
18. Wabu & Big Gossan, Indonesia
19. Pagaran Siayu, Indonesia
20. Bau, Malaysia
21. Siana & Thanksgiving, Philippines
22. Rokuromi, Japan
23. Suian, Korea
24. Tul Mi Chung, Korea
25. Lebedskoe, former USSR
26. Sinukhinskoe, former USSR
27. Ban La Lon, Thailand
28. Nambija, Ecuador

Figure 1. World distribution of some gold and gold-rich skarns. For grades and tonnages of some of these see Ray & Webster (1991 p. 219), Theodore et al. (1991, p. 40-57), and Meinert (1992, 152-153).

2. They are associated with subduction and arc-related plutonic rocks of largely gabbro-diorite-granodiorite composition (Figure 2). These intrusives tend to be calcalkaline, subalkaline and undifferentiated, being relatively depleted in LIL-elements such as Rb, Ce, Nb, and La, and enriched in Cr, Sc, Sr and V (Figure 2) and (Figure 3).

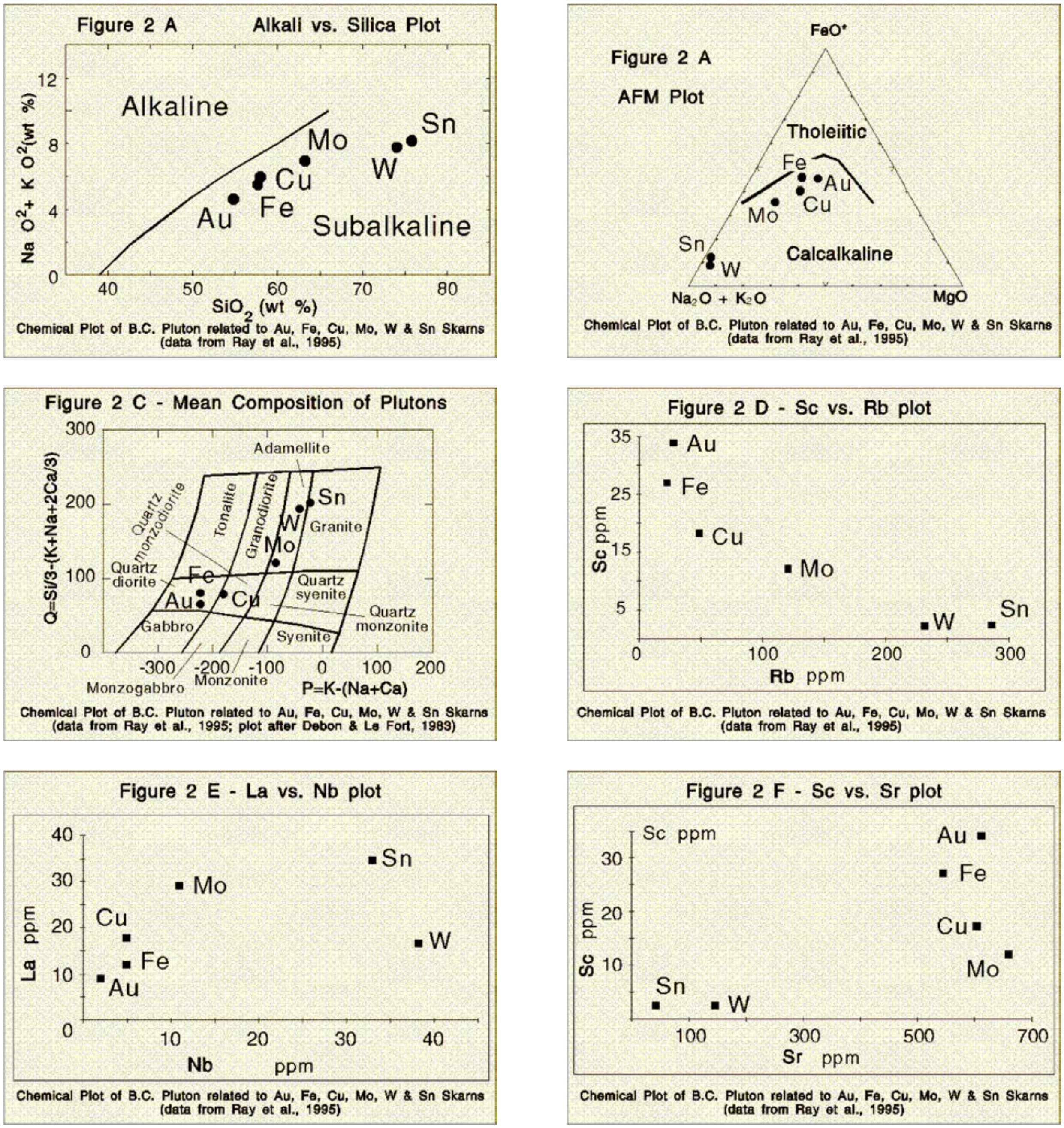
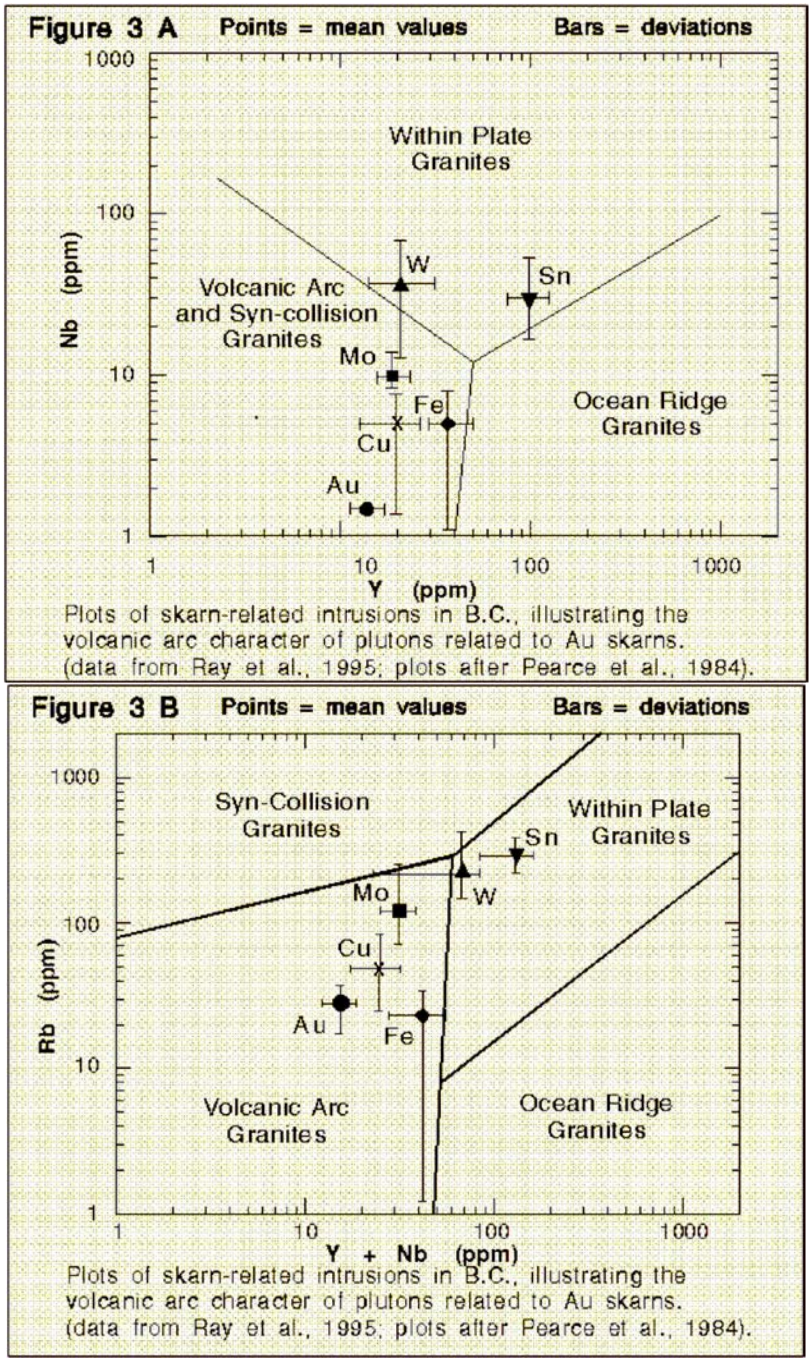


Figure 2. Chemical plots of BC plutons related to Au, Fe, Cu, Mo, W, and Sn skarns



Plots of skarn-related intrusions in B.C., illustrating the volcanic arc character of plutons related to Au skarns. (data from Ray et al., 1995; plots after Pearce et al., 1984).

Plots of skarn-related intrusions in B.C., illustrating the volcanic arc character of plutons related to Au skarns. (data from Ray et al., 1995; plots after Pearce et al., 1984).

Figure 3. Plots (after Pearce et al., 1984) of skarn-related intrusions in BC

3. They are mostly developed in calcic skarn with exoskarn envelopes dominated by Ca-silicate assemblages (clinopyroxene and garnet). Magnesian Au skarns (with Mg-silicates such as olivine and serpentine) are very rare; one example however, is the Butte Highlands deposit, Montana (Ettlinger et al., 1996).

4. The gold in Au skarns is commonly micron-sized; thus, the ore is visually indistinguishable from waste. It may be associated with Bi-tellurides and arsenopyrite, and in some deposits there is an enrichment in Co.

5. Depending on the mineralogy and garnet-pyroxene chemistry of the prograde exoskarn and ore, Au skarns can be separated into reduced and oxidized types (Figure 4).

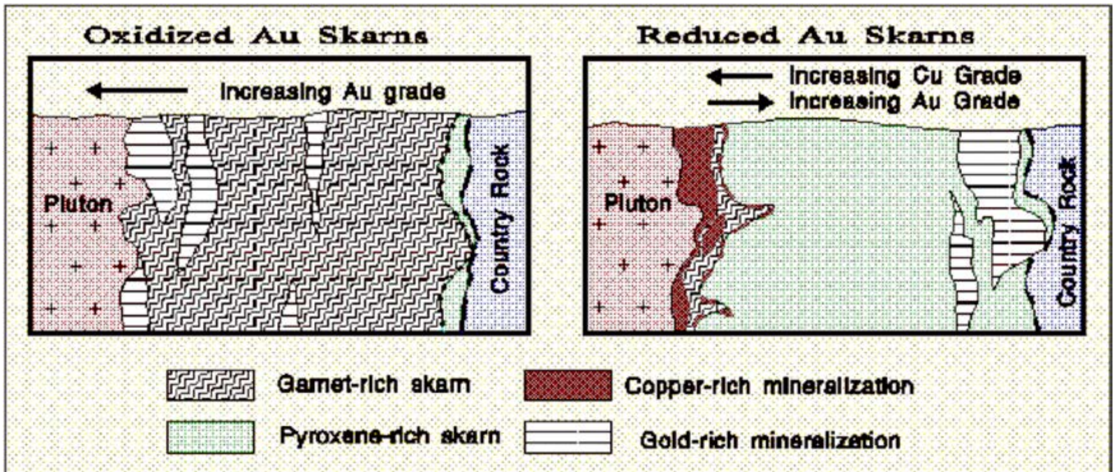
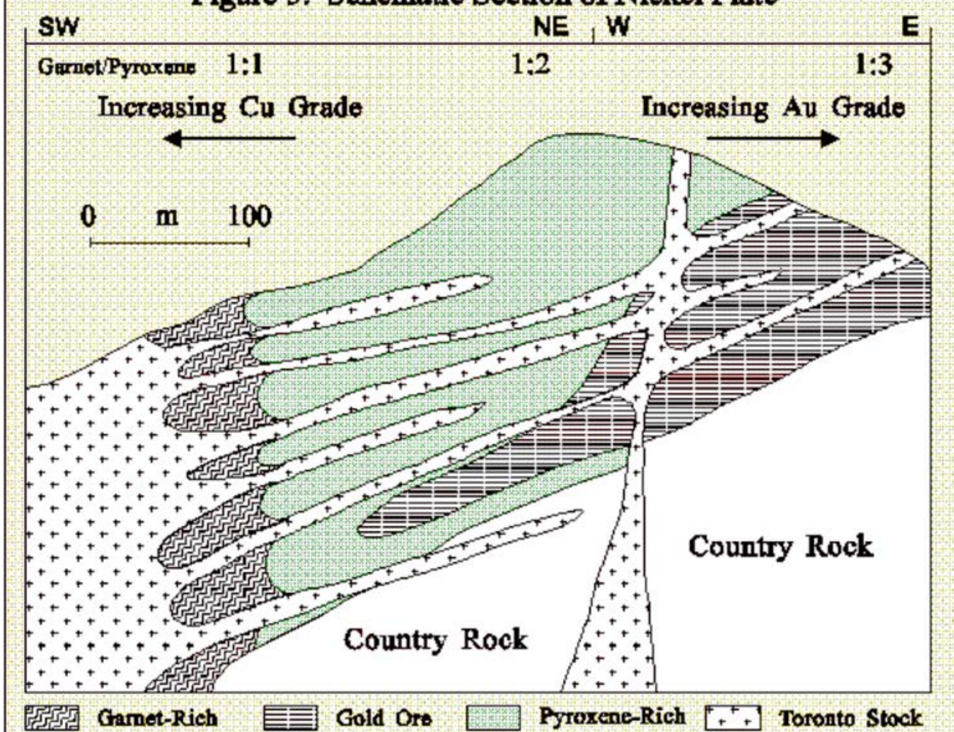


Figure 4. Schematic sections comparing the main features of "oxidized" & "reduced" Au skarns.

6. Reduced Au skarns are marked by low garnet/pyroxene and pyrite/pyrrhotite ratios and the presence of hedenbergitic pyroxene and Fe-rich biotite. The intrusives have low Fe2O3/FeO ratios and the ore bodies are developed distal to the pluton, in the outer parts of the pyroxene-rich exoskarn envelopes. Examples include Nickel Plate (B.C.; Figure 5), Fortitude (Nevada) and Buckhorn Mountain (Washington State).

Figure 5. Schematic Section of Nickel Plate



Generalized section across the Nickel Plate Au Skarn (reduced), B.C. (from Ettlinger et al. 1992).

7. Oxidized Au skarns are characterized by high garnet/pyroxene and pyrite/pyrrhotite ratios, and by the presence of diopsidic pyroxene, pyrite, magnetite and hematite. Ore bodies tend to form more proximal to the intrusions than those in the reduced Au skarns (Figure 4). Possible examples include Nambija (Ecuador), Wabu (Irian Jaya, Indonesia) and McCoy (Nevada; Fig. 6).

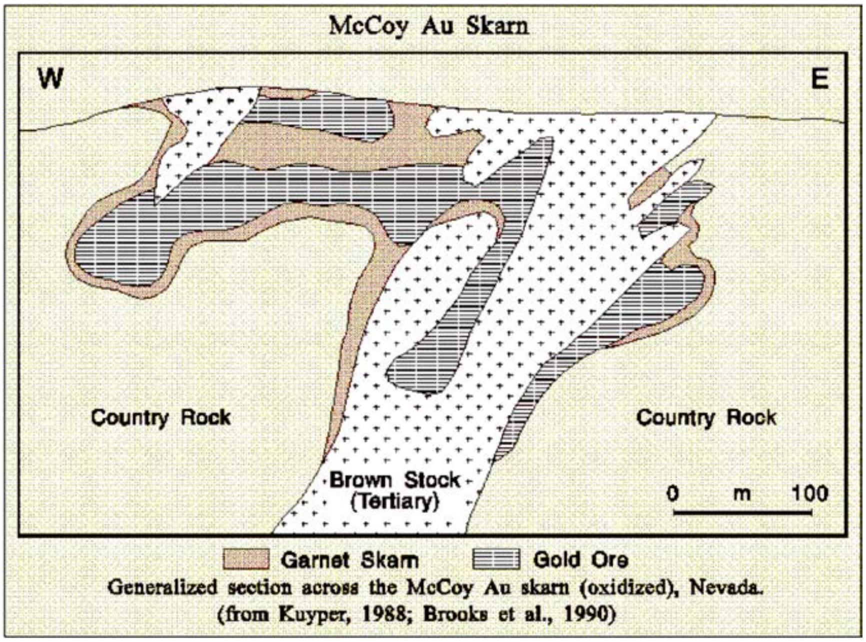
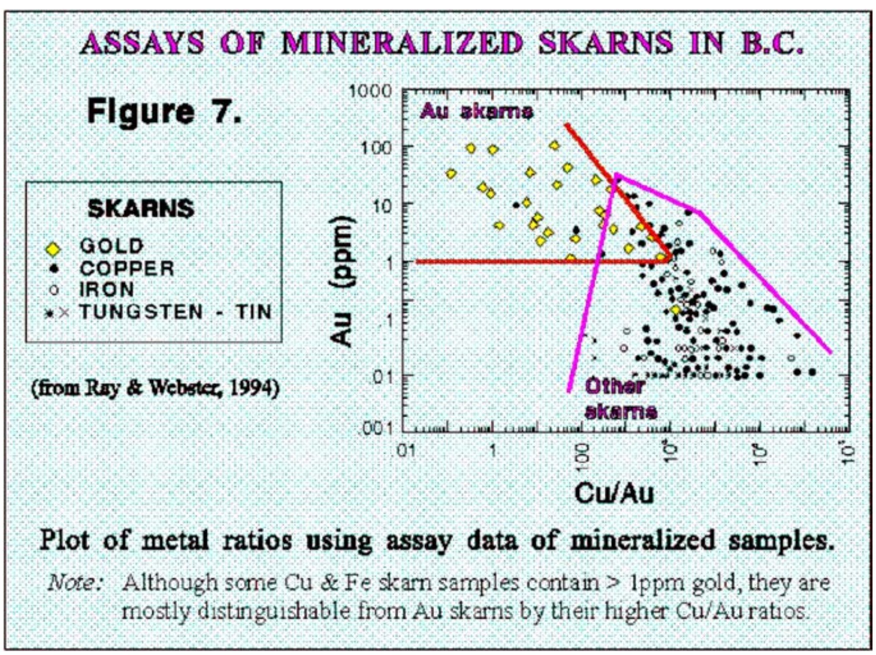
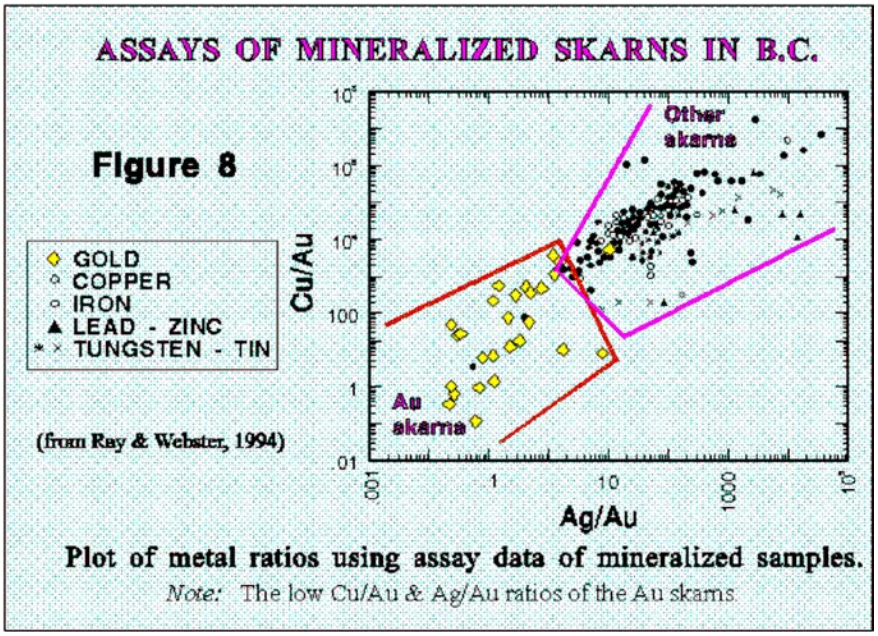
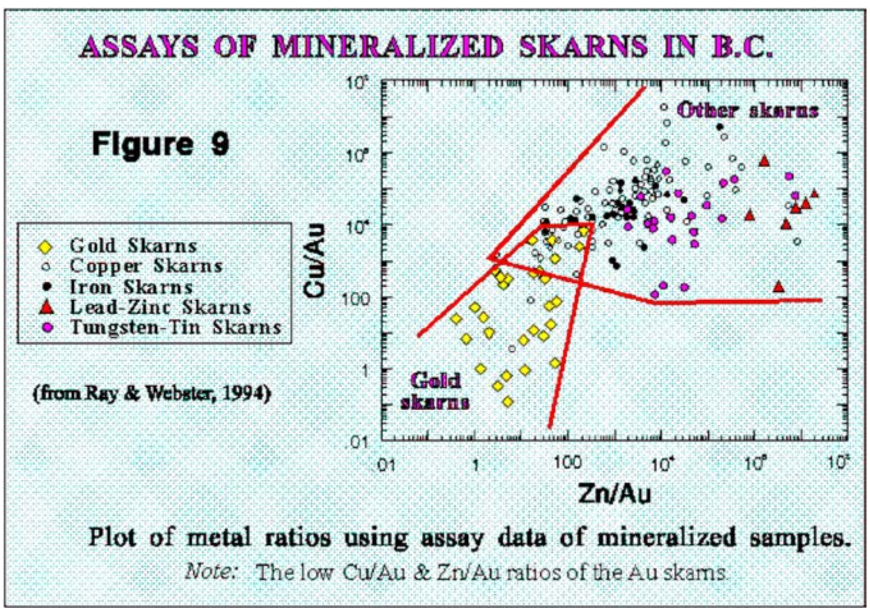


Figure 6.

8. Compared to the ore in Cu, Fe, Mo, W, Pb-Zn and Sn skarns, ore in most reduced and oxidized Au skarns has distinctly low metal ratios (Cu/Au <2000; Cu/Ag <1000; Zn/Au < 100, Ag/Au < 1) (Figure 7), (Figure 8), and (Figure 9).





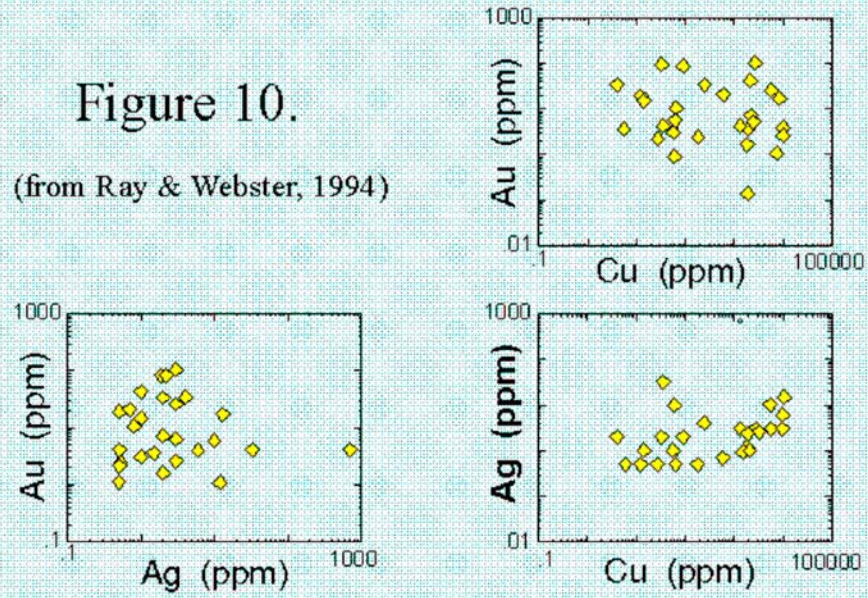


9. There is no correlation between Cu and Au in many Au skarns (unlike in Fe and some Cu skarns where a good correlation exists between these metals) (Figure 10), (Figure 11), and (Figure 12). Thus, the gold potential of a skarn can be easily overlooked if copper sulphide-rich outcrops are preferentially sampled and other sulphide-bearing or sulphide-lean assemblages ignored.

CORRELATION OF Au, Cu & Ag IN GOLD SKARNS

Figure 10.

(from Ray & Webster, 1994)



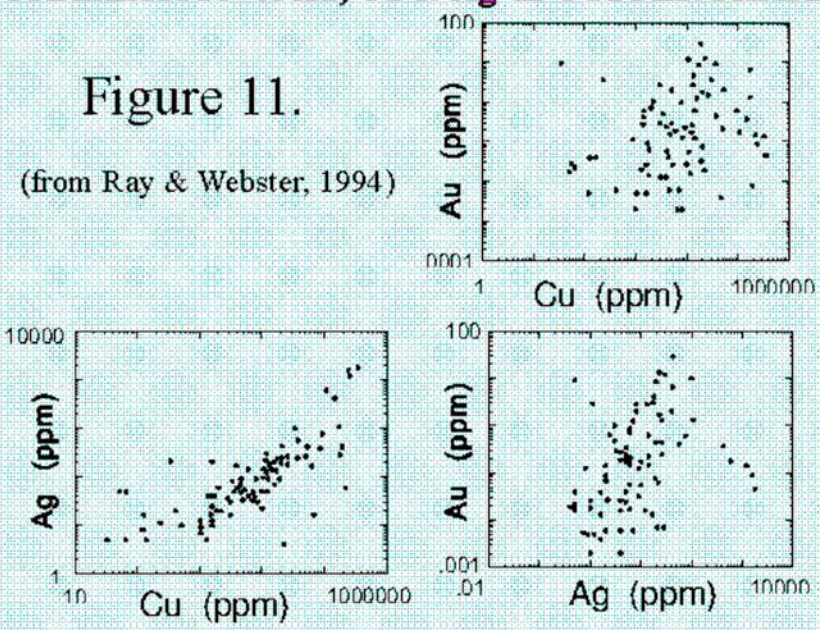
Plots using assay data of mineralized samples.

Note: Poor correlation between Au:Cu and Au:Ag

CORRELATION of Au, Cu & Ag in COPPER SKARNS

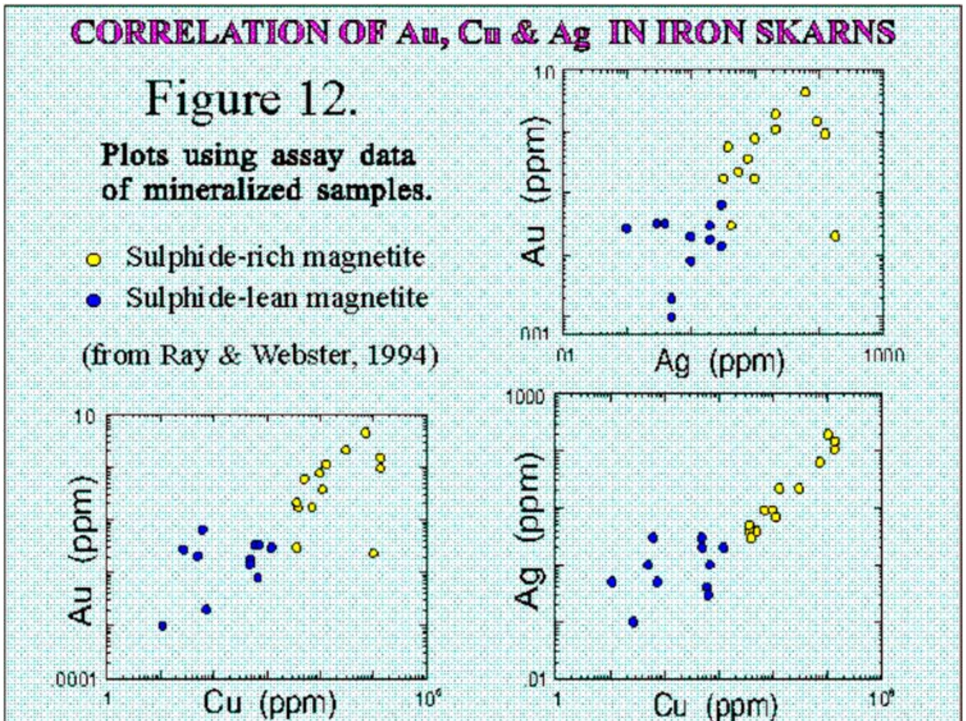
Figure 11.

(from Ray & Webster, 1994)



Plots using assay data of mineralized samples.

Note: Poor correlation between Ag:Cu and Au:Cu



Note: Excellent correlation between Au, Au & Cu. The sulphide rich samples are relatively enriched in these metals.

10. In some Au skarns (e.g. the Nickel Plate and Fortitude deposits) there is a metal and mineralogical zoning throughout the exoskarn envelope. This zoning consists of proximal garnet-dominant skarn with high Cu/Au ratios and distal pyroxene-dominant skarn with low Cu/Au ratios and the gold ore bodies.

Although most Au skarns have some or most of the above characteristics, individual deposits can have unique features, and it is likely that new types or varieties of Au skarns will be discovered. In exploration, any skarn of any class should be routinely and systematically assayed for gold. Essentially, any calcareous or carbonate rock package intruded by an arc pluton has a potential for hosting Au skarn deposits, although such favorable packages are generally small and relatively rare in typical island arc or back-arc environments. However, primary target areas would include (a) reefs aprons which flanked the original island volcanoes (b) carbonate facies formed either on intrabasinal platforms or along the margins of the back-arc basins, and (c) thrust slices of allochthonous platformal carbonates which were subsequently intruded by arc magmatism.

Gold Skarn Deposit Profile

SYNONYMS: Pyrometasomatic, tactite, or contact metasomatic Au deposits.

COMMODITIES (*BYPRODUCTS*): Au (Cu, Ag).

EXAMPLES (British Columbia - Canada/International): Nickel Plate (092HSE038), French (092HSE059), Canty (092HSE064), Good Hope (092HSE060); *Fortitude, McCoy and Tomboy-Minnie (Nevada, USA), Buckhorn Mountain (Washington, USA), New World district & Butte Highlands (Montana, USA), Thanksgiving (Philippines), Browns Creek & Junction Reefs-Sheahan-Grants (New South Wales, Australia), Mount Biggenden (Queensland, Australia), Nambija (Ecuador), Wabu (Irian Jaya, Indonesia), Savage Lode (Western Australia, Australia).*

Geological Characteristics

CAPSULE DESCRIPTION: Gold-dominant mineralization genetically associated with a skarn gangue consisting of Ca - Fe - Mg silicates. It includes calcic and magnesian Au skarns. On the basis of ore mineralogy and the garnet-pyroxene chemistry, Au skarns can be separated into reduced and oxidized types. Reduced types (e.g. *Nickel Plate* and *Fortitude*) have low garnet/pyroxene and pyrite/pyrrhotite ratios, hedenbergitic pyroxenes and Fe-rich biotite. Oxidized types (e.g. *McCoy, Wabu* and *Nambija*) have high garnet/pyroxene and pyrite/pyrrhotite ratios, and commonly contain diopsidic pyroxene, pyrite, magnetite and hematite.

TECTONIC SETTINGS: Most Au skarns form in orogenic belts at convergent plate margins. They tend to be associated with syn to late intraoceanic island arc intrusions emplaced into calcareous sequences in arc or back-arc environments. Both the *Wabu* (Irian Jaya) and *Butte Highlands* Montana, U.S.) Au skarns are hosted by platformal carbonates (Allen, 1995; Ettlinger *et al.*, 1995). The latter deposit is associated with melts that possibly include arc and continent components. The *Savage Lode* magnesian Au skarns of Western Australia are hosted by Archean greenstones.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Most deposits are related to plutonism associated with the development of oceanic island arcs or back arcs, such as the Late Triassic to Early Jurassic Nicola Group in British Columbia.

AGE OF MINERALIZATION: Phanerozoic (mostly Cenozoic and Mesozoic); in British Columbia they are mainly of Early to Middle-Jurassic age. The unusual magnesian Au skarns of Western Australia are Archean (Mueller, 1988, 1991; Mueller et al., 1991).

HOST/ASSOCIATED ROCK TYPES: High to intermediate level stocks, sills and dikes of gabbro, quartz diorite or granodiorite intruding carbonate, calcareous clastic or volcaniclastic rocks. The island arc related, I-type intrusions are commonly porphyritic, undifferentiated, Fe-rich and calc-alkaline. However, the *Nambija* (Ecuador) and *Wabu* (Irian Jaya) Au skarns are associated with alkalic plutons (Allen et al., 1995; O'Connor et al., 1994). Intrusions related to reduced-type Au skarns commonly have low $Fe2O3/FeO$ ratios.

DEPOSIT FORM: Variable from irregular lenses and veins to tabular or stratiform orebodies with lengths and widths ranging up to many hundreds of metres.

TEXTURE/STRUCTURE: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to layered textures in exoskarn. Some hornfelsic textures. Fractures and sill-dike margins can be an important loci for mineralization.

ORE MINERALOGY(Principal and subordinate):
Calcic Au skarns (reduced-type): Native gold ± chalcopyrite ± pyrrhotite ± arsenopyrite ± *tellurides* (e.g. *hedleyite, tetradymite, altaite* and *hessite*) ± *bismuthinite* ± *cobaltite* ± *native bismuth* ± *pyrit*e ± *sphalerite* ± *maldonite*. Generally high sulphide content and high pyrrhotite:pyrite ratios.

Calcic Au skarns (oxidized-type): Native gold ± chalcopyrite ± pyrite ± arsenopyrite ± sphalerite ± magnetite ± hematite ± *galena* ± *tellurides* ± *bismuthinite*. Generally low to moderate sulphide content and low pyrrhotite:pyrite ratios.

The ore in both reduced and oxidized types tends to have low Cu:Au (<2000), Cu:Ag (<1000), Zn:Au (<100) and Ag/Au (<1) ratios. Gold is commonly present as micron-sized inclusions in sulphides, or at sulphide grain boundaries. It is often associated with tellurides. To the naked eye, Au skarn ore is generally indistinguishable from waste rock.

Magnesian Au skarns: Native gold ± pyrrhotite ± chalcopyrite ± pyrite ± *magnetite* ± *galena* ± *tetrahedrite*.

EXOSKARN MINERALOGY (GANGUE):
Calcic Au skarns (reduced-type): extensive exoskarn, generally with high pyroxene:garnet ratios, although at the *Fortitude* deposit in Nevada, some higher gold values are concentrated in thin, structurally controlled garnet-rich zones. Prograde minerals include K-feldspar, Fe-rich biotite, low Mn grandite garnet (Ad 10-100), wollastonite, hedenbergitic clinopyroxene (Hd 20-100) and vesuvianite. Other less common minerals include rutile, axinite and sphene. Mineral and metal zoning common in skarn envelope (*e.g.* Nickel Plate and Fortitude; *see* Ettlinger et al., 1992; Myers and Meinert, 1989) with proximal coarse-grained, garnet-rich skarn containing high Cu:Au ratios, and distal, finer grained pyroxene-rich skarn containing low Cu:Au ratios and Au-sulphide orebodies. Late or retrograde minerals include epidote, chlorite, clinozoisite, vesuvianite, scapolite, tremolite-actinolite, sericite and prehnite.

Calcic Au skarns (oxidized-type): extensive exoskarn, generally with low pyroxene:garnet ratios. Prograde minerals include K-feldspar, low Mn grandite garnet (Ad 10-100), wollastonite, diopsidic clinopyroxene (Hd 0-60), epidote, vesuvianite, sphene and apatite. Late or retrograde minerals include epidote, chlorite, clinozoisite, vesuvianite tremolite-actinolite, sericite, dolomite, siderite and prehnite.

Magnesian Au skarns: olivine, clinopyroxene (Hd2-50), garnet (Ad7-30), chondrodite and monticellite. Retrograde minerals include serpentine, epidote, vesuvianite, tremolite-actinolite, phlogopite, talc, K-feldspar and chlorite.

ENDOSKARN MINERALOGY (GANGUE):
Calcic Au skarns: moderate endoskarn with K-feldspar, biotite, Mg-pyroxene (Hd 5-30) and garnet.

Magnesian Au skarns: details on endoskarn are poorly documented. Argillic and propyllitic alteration with some garnet, clinopyroxene and epidote occurs in the endoskarn at the *Butte Highlands* Au skarn.

WEATHERING: In temperate and wet tropical climates, skarns often form topographic features with positive relief.

ORE CONTROLS: The ore in both reduced and oxidized types of Au skarns exhibits stratigraphic and structural controls; some orebodies form along sill-dike intersections, sill-fault contacts or bedding-fault intersections as well as along fold axes. In reduced-type Au skarns, sulphide-rich ore commonly develops in the distal, pyroxene-dominant portion of the alteration envelope. In some districts, specific suites of reduced, Fe-rich intrusions are spatially related to this type of mineralization.

Ore bodies in the oxidized Au skarns tend to lie more proximal to the intrusions.

GENETIC MODEL: Many Au skarns are related to plutons formed during oceanic plate subduction. There is a worldwide spatial, temporal and genetic association between porphyry Cu provinces and Au skarns.

ASSOCIATED DEPOSIT TYPES:
Calcic Au skarns: Au placers, calcic Cu skarns, porphyry Cu deposits and Au-bearing quartz and/or sulphide veins).
Magnesian Au skarns: Au placers, Cu skarns, porphyry Cu and Mo deposits, Au-bearing quartz and/or sulphide veins; possibly W skarns.

COMMENTS: Most Au skarns throughout the world are calcic and are associated with island arc plutonism. However, the *Savage Lode* magnesian Au skarn occurs in the Archean greenstones of Western Australia (Mueller, 1991) and the *Butte Highlands* magnesian Au skarn in Montana, U.S.A., is hosted by Cambrian platformal dolomites (Ettlinger *et al*., 1996). Regionally, in British Columbia, there is a negative spatial association between Au and Fe skarns even though both classes are related to arc plutonism; Fe skarns are concentrated in the Wrangellia terrane whereas most Au skarn occurrences and all the economic deposits lie in Quesnellia.

Exploration Guides

GEOCHEMICAL SIGNATURE: Au, As, Bi, Te, Co, Cu, Zn or Ni anomalies, as well as some geochemical zoning patterns throughout the skarn envelope (notably in Cu/Au ratios). Calcic Au skarns (whether reduced or oxidized type) tend to have lower Zn/Au, Cu/Au and Ag/Au ratios than any other skarn class. There is little or no correlation between Au and Cu in many Au skarns (unlike in Fe and in some Cu skarns where a good correlation exists between these metals). Thus, the economic potential of a Au skarn can be easily overlooked if Cu-sulphide-rich outcrops are preferentially sampled and other sulphide-bearing or sulphide-lean assemblages are ignored.

The intrusions related to Au skarns may be relatively enriched in the compatible elements Cr, Sc and V, and depleted in lithophile incompatible elements (Rb, Zr, Ce, Nb and La), compared to intrusions associated with most other skarn classes.

GEOPHYSICAL SIGNATURE: Airborne magnetic or gravity surveys to locate plutons. Induced polarization and ground magnetic follow-up surveys can outline some deposits (magnesian Au skarns and oxidized-type calcic Au skarns can be magnetite-bearing).

OTHER EXPLORATION GUIDES: Placer gold. Any calcareous package intruded by arc-related plutons. Although carbonates are relatively rare in typical island arc environments, primary targets would include:
(a) reef aprons that flanked original island volcanoes.
(b) shallow-water carbonate facies deposited on intrabasinal platforms or along the margins of back arc-basins.
(c) thrust slices of allochthonous platformal carbonates which were subsequently intruded by arc magmatism.

Calcic Au skarns (reduced-type): Any exoskarn in an arc environment that has one or more of the following features:
(a) is associated with any undifferentiated, Fe-rich intrusions with low Fe_2O_3/FeO ratios.
(b) is pyroxene (particularly hedenbergitic pyroxene) and/or pyrrhotite-dominant.
(c) has proximal copper-rich skarn and distal, apparently barren skarn which could contain micron gold ore zones.
(d) has Bi-Te geochemical anomalies.

Calcic Au skarns (oxidized-type): Any exoskarn in an arc or platformal environment that has one or more of the following features:
(a) is associated with Fe-rich intrusions with moderate to high Fe_2O_3/FeO ratios.
(b) is garnet and/or pyrite-dominant.
(c) may contain magnetite, hematite and Bi-Te geochemical anomalies but is not neccessarily rich in copper mineralization.

Magnesian Au skarns: granodiorite intrusions in dolomitic sedimentary rocks.

Economic Importance

TYPICAL GRADE AND TONNAGE: These deposits range from 0.4 to 10 Mt and from 2 to 15 g/t Au. Theodore et al. (1991) report median Au and Ag grades and tonnage of 8.6 g/t Au, 5.0 g/t Ag and 213,000 t. Between 1904 and 1995, *Nickel Plate* produced over 71 Mt of Au from 13.4 Mt of ore (grading 5.3 g/t Au). Average grade for Au skarns worldwide is estimated to be between 10.6 and 4.5 g/t Au (Meinert, 1988, 1989).

IMPORTANCE: Recently, there have been some significant Au skarn deposits discovered around the world. Nevertheless, total historic production of gold from skarn (approximately 1000 t of metal; Meinert, 1989) is minute compared to production from other deposit types. The *Nickel Plate* deposit (Hedley, British Columbia) was probably one of the earliest major gold skarns in the world to be mined. Skarns have accounted for about 16 % of British Columbia's gold production, although nearly half of this was derived as a byproduct from Cu and Fe skarns

Au SKARNS WITH UNUSUAL FEATURES: Although most Au skarns have some or many of the above characteristics, individual deposits can have unique or unusual features. Examples include:

Butte Highlands (Montana): is hosted in platformal carbonates and has no As or Te enrichment.

Nambija (Ecuador): is associated with an alkalic intrusion; no Bi, As or Te enrichment in ore; abundant quartz veining in skarn (it is uncertain whether *Nambija* is a true skarn or whether the mineralization and the skarn alteration are the result of two different and unrelated events).

McCoy (Nevada): the main gold phase is associated with minor Zn enrichment.

Wabu (Irian Jaya, Indonesia): is associated with an alkalic intrusion. Mineralization generally has low Cu values but it can be enriched in Zn.

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