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PREFACE

In the history of mankind there has never been such a concerted effort to explore for and mine gold throughout the world. At the same time there has never been such a concerted or sophisticated research effort to understand gold deposits and the processes active in producing them.

Bicentennial Gold 88 represents in many ways a celebration of the coming of age of gold research and exploration, as well as being part of the celebration of a nation which owes much of its early and recent economic wellbeing to gold mining. Gold 88 continues the informal tradition of international gold conferences established by Gold 82 in Zimbabwe and Gold 86 in Canada.

The aim of Bicentennial Gold 88 is to act as a forum for the presentation and discussion of new data and ideas on gold deposits. The conference offers one of the most comprehensive and international technical programmes ever presented on gold. Almost 300 oral and poster papers from about 30 countries from every inhabited continent will be presented at the conference. Many papers deal with case studies and regional settings of gold deposits, with others on laboratory studies and exploration techniques. The final group of papers deals with conceptual models on the genesis of gold deposits.

The Technical Programme Committee would like to thank all the many contributors to the technical programme of the conference for their effort, as well as the principal sponsors and many corporate sponsors for their invaluable financial contributions. The Committee would also like to express their appreciation to several groups who have specifically donated travel funding assistance to students presenting papers at the conference viz Geological Society of Australia Specialist Group for Economic Geology, the Australian Institute of Mining and Metallurgy (North Queensland Branch), the Eastern Goldfields Discussion Group (Kalgoorlie) and BHP Gold Mines.

I personally wish to thank my fellow members of the Technical Programme Committee (Andrew Button, Bill Birch, Reid Keays and Geoff Loftus-Hills) for their help, as well as many individuals for their assistance and support. These include Ross Ramsay (Ballarat CAE), Liedeke Bosma, Cathy Hough and Erica Smyth (BHP), Wally Churchill (WMC), Pat Tart and Beth Steward (ACTS). I would also like to gratefully acknowledge the seemingly never ending support of my former employer, BHP and in particular Dick Carter and Colin Palethorpe. I would especially like to acknowledge the dedicated and invaluable assistance of Belinda Stevens of BHP for her tireless and cheerful help in putting the technical programme together, and my family for their patience.

A.D.T. Goode,
Chairman, Technical Programme Committee

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REGIONAL & CASE STUDIES

Topic 1A

ARCHAEAN REGIONAL STUDIES

ARCHAEAN EPIGENETIC GOLD MINERALISATION IN HUTTI-MASKI SUPRACRUSTAL BELT, KARNATAKA, INDIA.

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The narrow curvilinear Hutti-Maski supracrustal belt in Karnataka, India, of Archaean age is predominantly made up of volcanics with minor amount of sedimentaries. The volcanics constitute about 95% of the assemblage in which the basic members are predominant, followed by acidic suite of rocks. Three phases of deformation (D_1, D_2 & D_3) are imprinted on the rocks. Grade of metamorphism ranges from green-schist to amphibolite facies. Gold mineralisation is hosted by both metabasic and meta-acid volcanic rocks but the gold lodes occurring within the basic rocks are economically important. Sedimentaries are devoid of any gold mineralisation. Sheet like bodies of basic rock represented by metagabbro, forming part of the volcano-sedimentary sequence, is also mineralised. Chemically the basic volcanics are of tholeiitic composition generated at marginal basin tectonic evnironment.(1)

Discontinuous auriferous zones are restricted to late D_1 ductile to ductile brittle shear zones occurring along the axial zone of F_1 folds, formed during D_1 deformation. D_2 deformation has refolded F_1 folds and the mineralised zones also show similar structure controlled disposition. Local remobilisation is noticed along F_2 fold closure. Localenrichment is noticed along post mineralisation minor faults. D_3 deformation did not cause any significant remobilisation.

Auriferous zones, occurring along structural dilatant zones, are characterised by retrogressive metamorphism with lower greenschist facies assemblage. Both the mafic and felsic volcanic rocks of amphibolite facies in the mineralised zone are characterised by chloritisation, biotitisation and carbonatisation (calcite) with veinlets of quartz and disseminations of arsenopyrite, pyrite, pyrrhotite, chalcopyrite and scheelite in order of abundance. Mineralisation in green-schist facies host rock is represented by sericitisation, carbonatisation (ankerite) and silicification with disseminations of pyrite, chalcopyrite and arsenopyrite in order of abundance. Gold mainly occurs in association with arsenopyrite and rarely with pyrite. It is interesting to note that gold concentration is appreciable where in association with anhedral and smaller sulphide grains, where the sulphides are euhedral and coarse grained, the gold values are always low or nil. The relationship of gold with pyrite, and arsenopyrite is of two types: one is mutual boundary type indicating a possibility of simultaneous formation and the second is fracture filling type in pyrite and arsenopyrite crystals.

Seventy percent of the gold is free milling type and the rest 30% occurs in association with sulphides. Free milling gold occurring as nodular form, lumpy masses and platy forms, has a general affinity to be associated with vein quartz. The first two forms of gold are mainly localised in the zone of faulting whereas the third type follows shear planes. Lodes are of gold-silver type (2), where silver occurs as isomorphous mixture covering about 8-9% of the total metal content. In general gold-silver ratio is more than 1 and the ratio increases in the ore-shoot portion.

Major element chemistry of the immediate wall rock when compared with the host rock shows appreciable gain in K_2O and volatiles and fall in Na_2O and SiO_2. The ratio of K_2O/Na_2O commonly shows an increase and SiO_2/volatile ratio shows a fall in the mineralised zone. Enrichment of As,Cu, W & Ag. is noticed in the mineralised zone.

The occurrence of mineralisation in structurally dilatant zones, change in the chemistry of both major and trace elements in the wall rock and retrogressive metamorphism from adjoining host rocks, suggest that the mineralisation is epigenetic and structurally controlled. There is a productive mine in this belt and several promising prospects are under exploration.

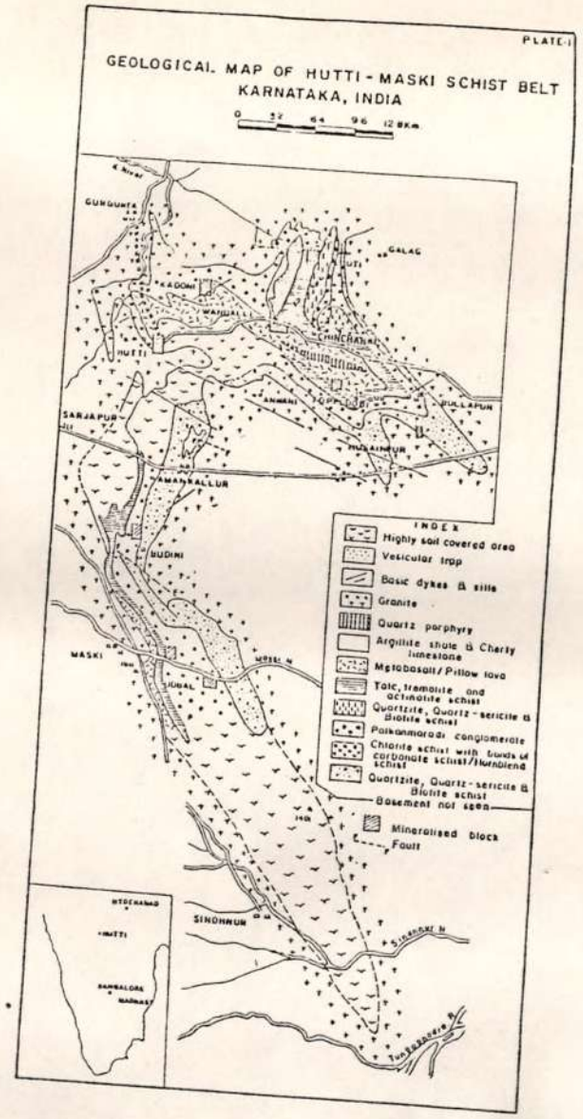
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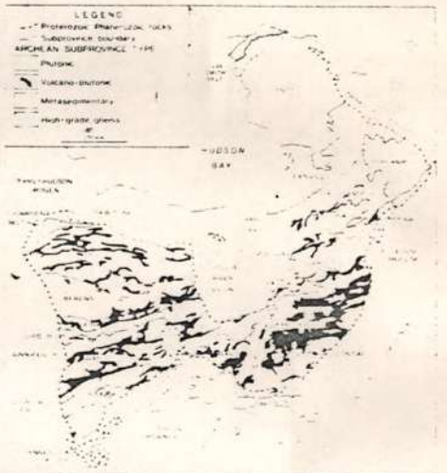


GREENSTONES, GRANULITES AND LODE GOLD DEPOSITS OF THE ARCHEAN SUPERIOR PROVINCE, CANADA

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Superior Province Archean craton consists mainly of rocks derived from mantle or juvenile crustal sources, and was formed during several Late Archean (3.1-2.6 Ga) tectono-magmatic events. This new crustal addition is particularly rich in mineral deposits and has yielded over 170 million ozs. of gold, second only to the Witwatersraand.

Alternating volcano-plutonic and metasedimentary subprovinces form much of the central, striped region of Superior Province with northern, southern, and central high grade gneiss domains[1]. Boundaries between subprovinces are commonly zones of lithologic and metamorphic transistion and structural complexity; many are telescoped by major east-west faults with lengthy histories involving late transcurrent movements[2]. Geophysical data show changes in depth to the Conrad and Moho discontinuities across some subprovince boundaries indicating significant structural relief across the crustal-scale boundary faults[3]. In contrast, modelling of gravity and magnetic data indicates that greenstone and metasedimentary belts extend to depths of only 5-10 km[4].

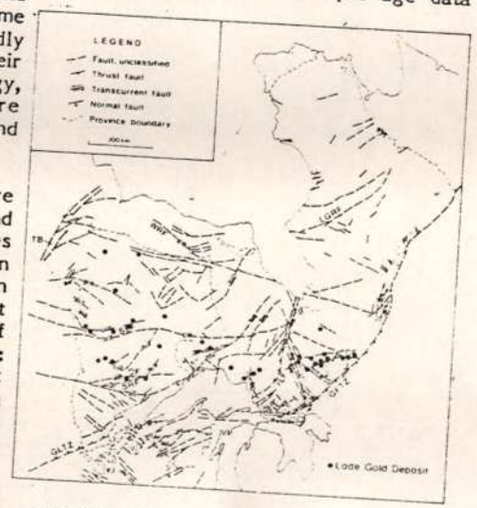


Volcano-plutonic subprovinces consist of sinuous greenstone belts bordered and intruded by voluminous plutonic rocks, including early, in part synvolcanic, commonly tonalitic suites, and syn- to post-kinematic, granodioritic, granitic, and syenitic suites. Supracrustal rocks include komatiitic, tholeiitic, calc-alkalic, and rare alkalic volcanics with turbiditic (wacke, conglomerate), chemical (iron formation, chert), rift-type alluvial/fluvial (arkose, conglomerate), and rare shelf-type (quartz arenite, limestone) sediments. Many belts consist of lower, extensive, submarine platform tholeiitic-komatiitic sequences, and upper, partly subariel, central volcanic complexes of calc-alkalic and tholeiitic volcanics with aprons of epiclastic sediments. Most belts comprise several volcanic piles each containing several polymodal or bimodal volcanic cycles[5]. In terms of their stratigraphy and geochemistry, the greenstone belts are comparable to modern island arc sequences[6]. Contacts between supracrustal sequences and

enclosing plutonic rocks are mainly intrusive or tectonic with rare unconformities. This, combined with the general lack of evidence for isotopic inheritance in magmatic rocks suggests that Superior Province rocks were not derived from reworking of appreciably older (+ 3.1 Ga) rocks nor were most of the supracrustal sequences deposited on sialic crust.

Most volcano-plutonic subprovinces have curvilinear structural patterns with upright isoclinal folds with curved axes, steep foliations and lineations, and domal culminations and depressions, the products of polyphase deformation under conditions of regional north-south compression. Metamorphic grade generally ranges from greenschist, or subgreenschist in greenstone belt interiors to low-pressure amphibolite facies in belt margins and surrounding gneisses.

Metasedimentary subprovinces consist mainly of turbiditic wacke metamorphosed at grades ranging from low greenschist at belt margins to upper amphibolite, and locally low-pressure granulite facies in belt interiors. Anatectic granitic rocks are prevalent in the high grade migmatitic interiors of these belts. Most metasedimentary belts have linear structural patterns attributable to upright isoclinal folds with subhorizontal axes, again formed by north-south compression. Geological relationships and isotopic age data indicate that the sedimentary and volcanic sequences of some adjacent subprovinces are broadly coeval. In terms of their stratigraphy and sedimentology, the sedimentary sequences are comparable to distal, fan and inter-arc turbidites.



Granulite terranes are characterized by granulite and upper amphibolite facies gneisses of plutonic and supracrustal origin with ductile deformation structures and domal to straight structural patterns. Two types of granulite terrane are present: 1) regions that underwent tectonic thickening resulting in metamorphism, uplift, and erosion of up to ca. 20 km of overburden; and 2) basal parts of magmatic arcs exposed by faulting. The first type has modest metamorphic pressures (4.5-6.5 kb) and structural-lithologic continuity with lower grade terranes whereas the second displays features of crustal cross-sections adjacent to major faults[7] and metamorphic pressures of 7-9 kb[8].

U-Pb zircon dates demonstrate that several magmatic and tectonic events, each of relatively brief duration, affected Superior Province at different times in different areas[9]. In the north major volcanism and plutonism occurred at ca. 3.1-2.8 Ga and again at ca. 2.75-2.70 Ga. In the south there is scattered evidence for 3.1-2.8 Ga magmatism but most of the volcanism occurred at 2.75-2.7 Ga. Similarly, in the north major deformation, metamorphism, and plutonism occurred at ca. 2.73-2.7 Ga and in the south at ca. 2.7-2.68 Ga. Age data from the granulite terranes show that high grade metamorphic conditions persisted at depth while transcurrent faulting and shearing, deposition of late rift-type alluvial/fluvial/alkalic volcanic sequences, rock alteration, and formation of lode gold deposists occurred at higher crustal levels.

Most Superior Province lode gold deposits are structurally controlled, many being associated with major transcurrent faults and subsidiary deformation zones, and with alteration, including zones of carbonatization, silicification, and sericitization. Granulite metamorphism at depth resulted in dehydration and formation of fluids rich in CO_2, Si, K, Li, Au, etc. The fluids moved upward, channeled by crustal-scale faults that behaved in a brittle fashion at high levels, resulting in fracturing, rock alteration, and formation of lode gold deposits[10].

Contemporaneity of magmatic and tectonic events along the lengths of the subprovinces and the apparent southward younging of tectonism is consistent with assembly of Superior Province craton by accretionary processes in subduction-dominated convergent plate tectonic settings similar to those now existing in the Pacific Basin.

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CHARACTERISTICS OF EARLY ARCHAEAN (>3.0 GA) AU-QUARTZ LODE DEPOSITS FROM THRUST ZONES IN THE MAFIC/ULTRAMAFIC ROCKS OF THE BARBERTON GREENSTONE BELT, SOUTH AFRICA

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The circa 3.5 Ga Barberton Greenstone Belt, which consists of a complex sequence of mafic-ultramafic rocks overlain by fine to coarse grained sediments, is intruded along all its margins by tonalitic to trondjemitic plutons (Fig. 1, modified from Anhaeusser et al., 1983). Recent work has shown that the greenstone belt is a high-level fold and thrust belt (de Wit, 1982; 1983; this study).

Seven small to moderately-sized gold deposits (with total productions of between 100 kg and 5,000 kg Au) within the greenstone belt (Fig. 1) are hosted in shear zones almost entirely confined to

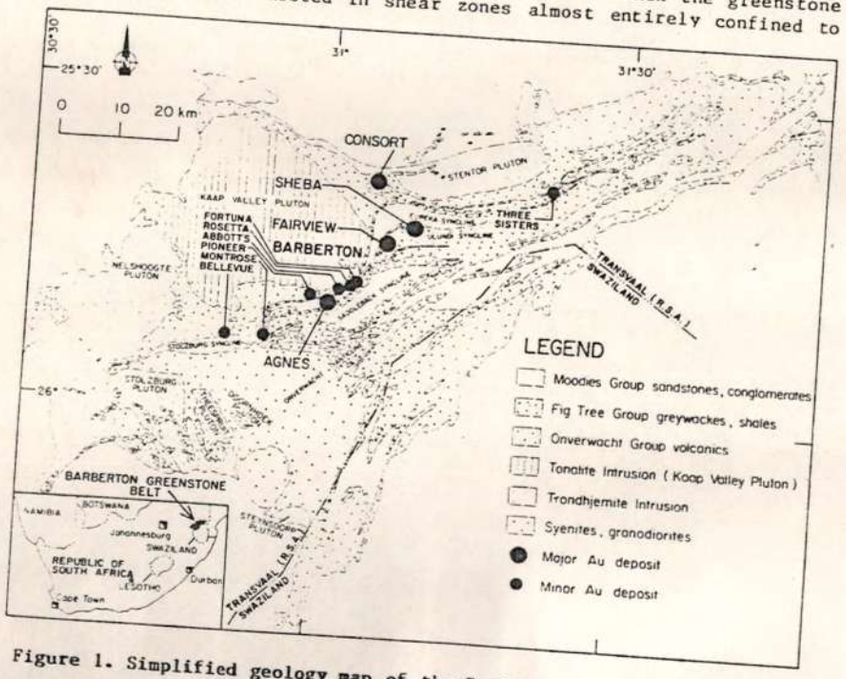


Figure 1. Simplified geology map of the Barberton Mountain Land.

mafic-ultramafic rocks (some with remnant spinifex textures). These deposits account for >15,500 kg Au and >1,400 kg Ag (6.2% and 15.9% respectively, of the total pre-1984 Au and Ag production from this

greenstone belt). Currently, the Pioneer and Three Sisters Mines are producing gold while Bellevue Mine is being intensively explored.

Because the deposits are all structurally controlled, the area provides an excellent example of "chemo-tectonic" analysis of high-level fold and thrust structures in practical Au-exploration.

The studied deposits (from SW to NE)- Bellevue, Montrose, Pioneer, Rosetta, Abbotts, Fortuna and Three Sisters, which occur over a distance of ~60 km, have a number of important aspects in common:

1) Close proximity to the Greenstone Belt/Kaap Valley tonalite contact (except Three Sisters Mine; see Fig. 1).

2) Shear zones within major structural breaks controlling the localization of Au mineralization; the structural breaks are high-level, north directed thrust faults. The shear zones are usually sub-vertically dipping structures sub-parallel to regional foliation. Bellevue, Montrose and possibly Rosetta and Fortuna have narrow (<10 m) ferruginous silicified shales in the vicinity of the mineralized shears. Competency contrasts may have caused preferential development of the shear zones, and a concentration of mineralization, in the footwall of the silicified shale units.

3) Quartz-porphyry intrusions with tonalitic to trondhjemitic affinities locally intruding along the structural breaks (e.g. de Wit et al., 1987). For example, a fine grained dike intrudes the mineralized shear of Pioneer Mine. Quartz-porphyry dikes are also found 1,400 m below ground surface in Fairview Mine (37,492 kg Au, to 1983; Anhaeusser, 1986) and deformed "granitoid-pegmatites" in Consort Mine (54,760 kg Au, to 1983; Anhaeusser, 1986). These are two of the largest Au mines in the greenstone belt, both of which occur within <3 km from the contact with the surrounding granitoids.

4) A correlation between wall-rock alteration type and intensity of deformation. The following alteration zones (and their field colours) can be observed from the least to the most intensely deformed rocks: talc ± carbonate (chlorite at Three Sisters; dark blue), quartz-carbonate (grey-brown), fuchsite-quartz-carbonate (bright green), sericite-quartz ± fuchsite ± carbonate (khaki). Similar alteration patterns are noted in the ultramafic rocks from Au-bearing shear zones in Fairview Mine.

5) Au mineralization occurring within quartz-carbonate veins and locally in adjacent wallrock (Au is only found in the sericite and fuchsite-bearing alteration zones closest to the quartz-carbonate veins). Bellevue Mine has most of the Au in wallrock only. The mineralization is often concentrated within the quartz-carbonate veins as crack-seal selvages of chlorite ± fuchsite wallrock. The Au-bearing quartz veins, which pinch and swell in 3 dimensions, are late syntectonic.

6) Typically refractory Au ore, seen as inclusions in sulphides (pyrite, arsenopyrite, and more rarely, tetrahedrite, chalcopyrite (Rosetta), and stibnite (Bellevue)) and less commonly as free Au (Pioneer, Three Sisters). Au grains are usually equant and typically <10 μm and rarely >50 μm in size. Gangue minerals are dominated by quartz, Fe-carbonate, fuchsite, sericite, rutile and tourmaline, the latter two seen occasionally intergrown with Au. Gold appears to be early in the paragenetic sequence, having formed during a period of intense deformation as shown by rotated and brittly deformed pyrite and arsenopyrite grains. Later, non Au-bearing phases including

later generations of pyrite and arsenopyrite) are not affected by the deformation. Base metals (Cu, Zn, Pb?) occur as minor phases in most of the deposits, while Sb mineralization (native Sb, stibnite, berthierite) is abundant at Bellevue Mine.

8) Late, non Au-bearing quartz-carbonate veins (± sulphides) cross-cutting earlier Au mineralized quartz-carbonate veins and wall-rock foliation.

9) Consistent $\delta^{13}C_{PDB}$ and $\delta^{18}O_{SMOW}$ results for carbonate from Au-bearing quartz-carbonate veins and adjacent wallrock from the various mines. Results are as follows; Bellevue, n = 25, $\delta^{13}C$ $\bar{x}$ = -2.5 °/oo ± 0.6 °/oo (1σ), $\delta^{18}O$ $\bar{x}$ = 12.1 °/oo ± 1.4 °/oo (1σ); Pioneer, n = 17, $\delta^{13}C$ $\bar{x}$ = -2.2 °/oo ± 0.7 °/oo, $\delta^{18}O$ $\bar{x}$ = 11.7 °/oo ± 0.6 °/oo; Rosetta, n = 7, $\delta^{13}C$ $\bar{x}$ = -4.4 °/oo ± 1.2 °/oo, $\delta^{18}O$ $\bar{x}$ = 11.9 °/oo ± 1.8 °/oo; Abbotts, n = 2, $\delta^{13}C$ $\bar{x}$ = -4.3 °/oo ± 0.2 °/oo, $\delta^{18}O$ $\bar{x}$ = 17.7 °/oo ± 4.0 °/oo; Fortuna, n = 6, $\delta^{13}C$ $\bar{x}$ = -3.2 °/oo ± 0.6 °/oo, $\delta^{18}O$ $\bar{x}$ = 12.0 °/oo ± 1.2 °/oo; Three Sisters, n = 20, $\delta^{13}C$ $\bar{x}$ = -0.9 °/oo ± 0.8 °/oo, $\delta^{18}O$ $\bar{x}$ = 12.0 °/oo + 0.9 °/oo. For comparison, carbonate samples from a ultramafic-hosted Au-bearing shear zone in Fairview Mine give results of; n = 5, $\delta^{13}C$ $\bar{x}$ = -3.5 °/oo ± 0.5 °/oo, $\delta^{18}O$ $\bar{x}$ = 12.1 °/oo ± 0.7 °/oo. Wallrock carbonate adjacent to the Au-bearing quartz-carbonate veins was found to have similar $\delta^{13}C$ and $\delta^{18}O$ values to that of the veins themselves (see Figs. 2a and 2b). Averaged $\delta^{13}C$ values from the various mines are between -2.2 °/oo and -4.4 °/oo except Three Sisters which averages -0.9 °/oo. Those mines located closest to the Kaap Valley tonalite intrusion typically have the most negative $\delta^{13}C$ values (Abbotts, Rosetta, Fortuna) while Three Sisters, located ~32 km away has the most positive $\delta^{13}C$ values; mines at intermediate distances (Bellevue, Pioneer) have intermediate $\delta^{13}C$ values. These results suggest a similar CO_2 source and CO_2/CH_4 ratios for all the mines with Three Sisters possibly exhibiting mixing of two $\delta^{13}C$ sources (Barberton regional ultramafic/mafic-hosted carbonate $\delta^{13}C$ values are between 0 °/oo and 4 °/oo i.e. ambient to moderately heated seawater; Smith, 1986) or continued fractionation of the carbon. Similarly, averaged $\delta^{18}O$ carbonate values for quartz-carbonate veins and adjacent wallrock for the various mines are remarkably consistant, with averaged values between 11.6 °/oo to 12.1 °/oo (excluding Abbotts Mine) suggesting both similar depositional temperatures and fluid $\delta^{18}O$ values. The narrow range of the $\delta^{13}C$ data together with their negative values are consistent with a "magmatic" derivation of CO_2 (Burrows et al., 1986) and combined with the $\delta^{18}O$ data, suggest a simultaneous Au mineralizing process for the region, which exploited pre-existing thrust fault planes. A "magmatic" CO_2 origin is consistent with the observed progressive change in $\delta^{13}C$ away from the Kaap Valley intrusion.

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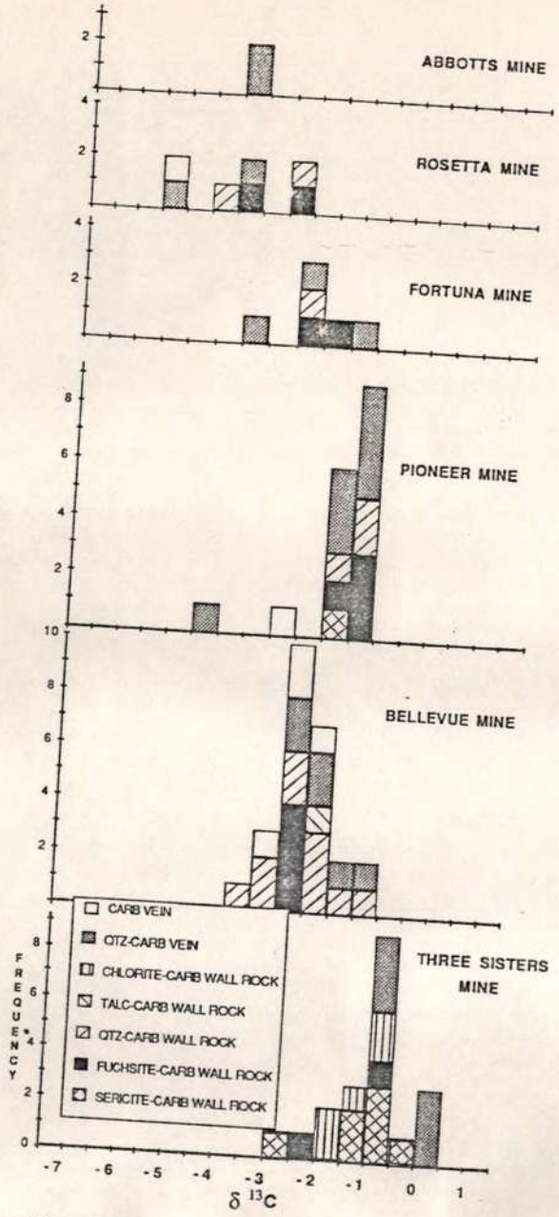


Figure 2a. $\delta^{13}C_{PDB}$ results.

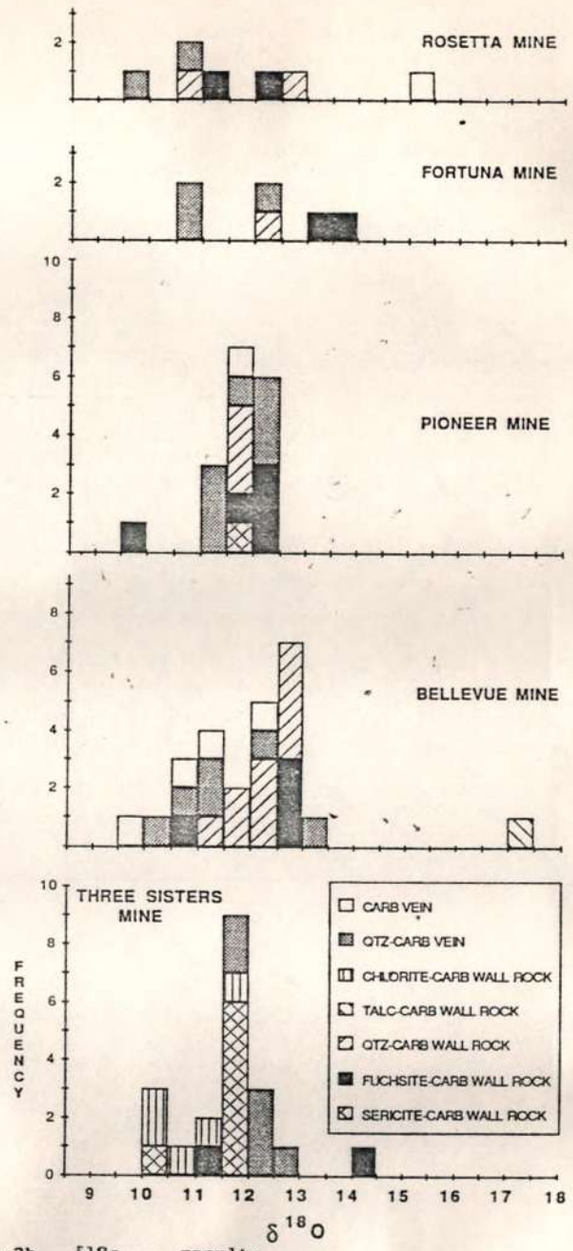


Figure 2b. $\delta^{18}O_{SMOW}$ results

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THE CADILLAC-LARDER LAKE FAULT ZONE, ABITIBI BELT, CANADA: AN EXAMPLE OF AN ARCHEAN ACCRETIONARY PRISM HOSTING GOLD DEPOSITS

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The Cadillac-Larder Lake fault zone in Québec and Ontario (Canada) hosts important gold deposits. This zone delineate two major archean terranes: 1) a block of volcanic rocks in the north and 2) a block of metasedimentary rocks in the south. The effusive rocks belong to a bimodal sequence of calc-alcaline and tholeiitic affinities, in which andesites and rhyolites clearly dominate (Gélinas et al., 1983). The tholeiitic units are found in the proximity of the Cadillac-Larker Lake fault zone. The sedimentary rocks in the south consists of graywacke and mica schists.

The tectonic zone between these two terranes is more than 200 km in length by 3 to 4 km wide. This zone, in the Rouyn-Beauchastel area (Québec), consists of lithotectonic blocks or lenses bounded by anastomosing E-W shear zones. These blocks are of three types: 1) thin lenses of ultramafic (komatiites) to mafic rock 2) lens-shaped bodies of mafic volcanics and volcaniclastic rocks 3) blocks of argillitic sediments with intercalated lavas and lenses of petromict conglomerate. The thin ultramafic lenses are composed of talc-chlorite-carbonate schist, massive carbonate rock and undeformed komatiites with spinifex and cumulate textures. Thin felsic dykes cut these ultramafic to mafic rocks all along the Cadillac fault zone in Rouyn-Beauchastel area. The mafic volcanic bodies of tholeiitic affinity (mainly variolitic, porphyritic or massive aphanitic magnesian lavas), if compared to modern tectonic environments are similar lavas to modern island arc (fore-arc) environments. The horizons of lithic wacke, mudrock and argillite intercalated with horizons of mafic lavas and mafic to felsic tuffs represent a "tectonic mélange".

The E-W anastomosing shears, measure 3 to 200 meters in width and dip 60° to 70° to the north; individual shear, extend to more than 300 meters in depth, curve at depth to reach a 30° dip-NE and NW shear zones or faults, often injected by proterozoic diabase dykes, offset the main E-W shears.

The main deformation in shear zones is represented by an E-W strongly penetrative foliation with associated closed to isoclinal folds. Macroscopic and microscopic structures associated with the main foliation indicate thrusting from north to south. In the E-W shear zones, later faults, with a high angle to E-W shear zones, have produced a puzzle-like array of blocks. Many vertical and minor horizontal movements are present along these later faults. All these faults offset the ore-zones.

The main gold-bearing zones occur within the E-W shear zones (carbonated schists), at the contact between ultramafic lenses and adjacent lenses, or within the ultramafic lens, in an hydrothermally brecciated carbonate rock. Some minor gold bearing zones in adjacent

sediments are found far removed from this sheared ultramafic setting. These ore zones consist of boudinated and fractured, arsenopyrite/pyrite quartz-tourmaline veins occuring in the fold hinge ("saddle reefs") or along fold limb ("legs") in intensely sheared rocks.

Two distinct types of alteration are associated with these ore zones: an earlier sulphurization often superposed by an intense later carbonatization and silicification. The carbonatization affected a greater volume of rocks around the shears than did the sulphurization. Between the shears, the rock is intensely, if not completely, transformed to carbonate-quartz aggregates which occur as delineated by later faults at a high angle to the E-W shears.

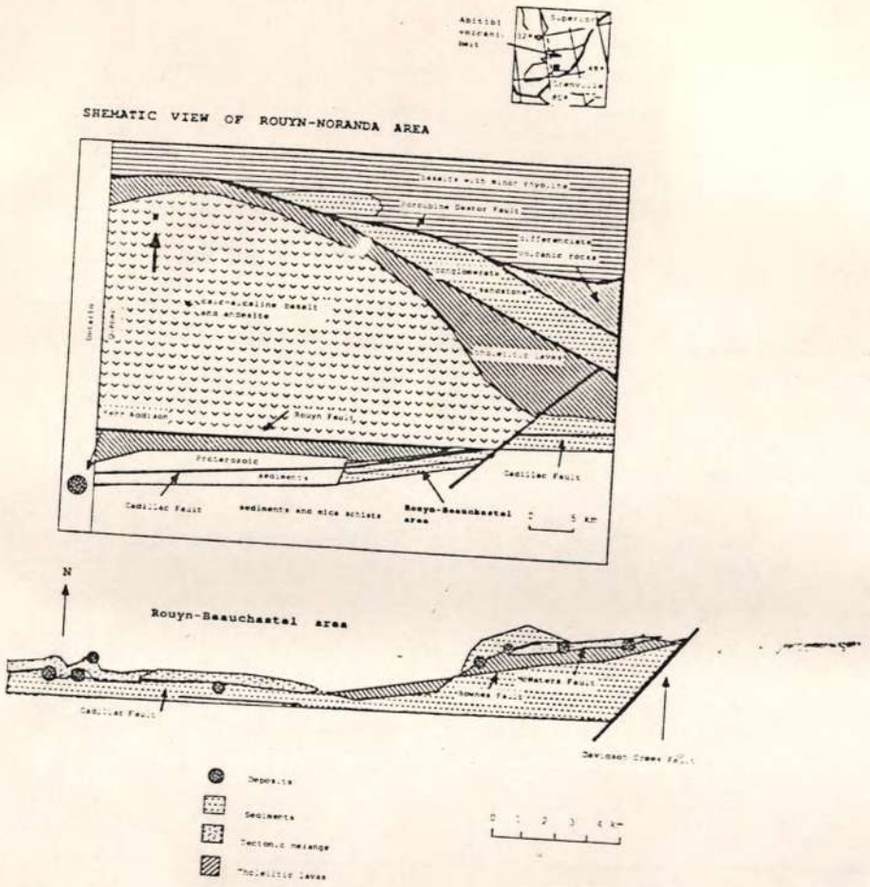
The gold-bearing shoots in the ore zones occur in three forms:
1) stockworks or disseminated gold enclosed in the hydrothermal carbonate-quartz-fuchsite alteration facies (arsenopyrite-pyrite) derived from an ultramafic protolith.
2) disseminated gold in volcanogenic sediments occuring at the shear contact between an ultramafic lens and adjacent sedimentary rocks. These are characterized by the presence of one another of the minerals, graphite, tourmaline, iron oxides, iron sulphides.
3) as arsenopyrite-rich quartz veins in late fractures (E-W and NNW) or in the fractures within felsic dykes.

The better grade ore is found in the brecciated carbonate-quartz-fuchsite rocks along the late fractures or along the hinge of open fold (with axial fault), in the shear zone.

The most important structures controlling the ultimate geometry and the distribution of the "ore zones" are the late fractures related to the shear zones: the veins, veinlets or stockworks occur within and along the main E-W schistosity by they are sliced and displaced by these late fractures. The presence of the late faults (sub-vertical and sub-horizontal), could account for the "en échelon" distribution of the ore-zones in both the horizontal and vertical plans.

Hydrothermal fluids escaped along the major fractures and shears during the main deformation and continued until the end of the late pulsations to allow for the formation of the gold deposits. The control on the distribution of the gold mineralization is structural, the types of mineralizations are controlled by the host lithochemical environment through which the fluids travelled and exchanged.

Although this present study concerns only a narrow zone along the main E-W shear zone, it can be inferred that the greater Rouyn-Beauchastel area could represent a part of an accretionary complex. The presence of a tectonic mélange, accompanied by distinct lithotectonic lenses, some of which consisting of modern island arc-type volcanics support this conclusion.



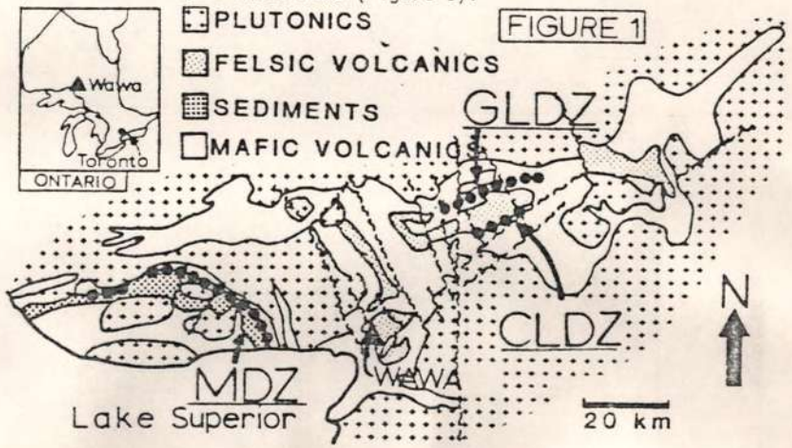
THE WAWA GOLD CAMP, ONTARIO, CANADA: GOLD MINERALIZATION ASSOCIATED WITH CONTRASTING STRUCTURAL STYLES

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The Wawa gold camp consists of four gold-bearing districts; the Renabie-Missinabie district, the Goudreau-Lochalsh district, the Michipicoten district, and the Mishibishu Lake district. The strong structural control on gold mineralization within each of these districts has been documented by Heather et al.(this volume). Distinct structural styles characterize each of the districts within the Wawa gold camp, with the Goudreau-Lochalsh and the Mishibishu Lake districts serving as contrasting examples of how structural style can control how and where gold mineralization occurs.

Gold mineralization in both the Goudreau-Lochalsh and Mishibishu Lake districts is found within regionally extensive deformation zones which are coincident with major lithological boundaries (Figures 1 and 3). The Goudreau Lake Deformation Zone (*GLDZ*) and the Cradle Lakes Deformation Zone (*CLDZ*) host all the known gold mineralization in the Goudreau-Lochalsh district (Figures 1, 2, and 3), while the Mishibishu Deformation Zone (*MDZ*) hosts the majority of the gold mineralization in the Mishibishu Lake district (Figure 1). The *GLDZ* is a 30 km long by up to 4 km wide, east-northeast-trending arcuate zone coincident with a major mafic metavolcanic-felsic metavolcanic contact. The subparallel *CLDZ*, exhibiting similar features to the *GLDZ* and therefore not discussed in detail here, is located 4 km south of the *GLDZ*, coincident with a felsic metavolcanic-mafic metavolcanic contact (Figures 2 and 3). The *MDZ* is a 40 km long, by up to 1 km wide, arcuate zone (Figure 1).



The *MDZ* is coincident with a major mafic metavolcanic-clastic metasediment contact. Both the *GLDZ* and *MDZ* are proximal to the northern margin of their respective greenstone belts (Figure 1).

The *GLDZ* is a zone of dominantly dextral transcurrent displacement comprising numerous, discrete, narrow brittle and brittle-ductile shear zones which can be classified into six groups based on their orientation. These groups, and the sense of shear displacement along them, are:

(a) 020° to 035°, sinistral
(b) 050° to 065°, variable
(c) 080° to 090°, dextral
(d) 110° to 115°, dextral
(e) 130° to 140°, dextral
(f) 350° to 010°, variable

These shear zones range from several centimetres up to tens of metres in width and from metres to several hundred metres in length. The *GLDZ* is subdivided into four structural domains (**southern**, **northern**, **eastern**, and **western**) based on the style of deformation, on the orientation and sense of shear displacement on sets of shear zones, and on lineation patterns (Figure 2). Within the *GLDZ*, the **western** domain and the **eastern** domain are seperate from a central area, encompassing both the **southern** and **northern** domains, by northwest-trending regional faults (Figure 2). The **southern** domain is composed of an 070°-trending ductile-brittle zone of subparallel dextral shears with horizontal to subhorizontal mineral lineations. The **northern** domain is composed of brittle to brittle-ductile shear zones oriented at high angles to the 070° trending schistosity. Northeast-trending (030°) shears display sinistral, oblique-slip displacement, while conjugate, northwest-trending (140°) shears display dextral, oblique-slip displacement. The **eastern** and **western** domains are composed of brittle to brittle-ductile shear zones, displaying dextral shear displacement, oriented at approximately 085° and 115°. Lineations plunge shallowly to moderately to the east within the **eastern** domain, and steeply to the west within the **western** domain.

Gold mineralization in the *GLDZ* occurs regionally within five of the six shear zone orientation-groups, however at any one individual gold occurrence only one, two or rarely three orientations host significant gold (Figure 3). Gold mineralization in the **southern** domain is hosted by 085°- and 055°-trending quartz vein structures within 070°-trending shear zones (eg., Magino Gold Mine). Insufficient data exists at present to define a plunge on any of the known gold mineralization within this domain, nevertheless, the intersection of the 085° and 055° vein structures may be important in localizing higher grade 'ore-shoots'. In the **northern** domain, gold only occurs in quartz veins within the 030°-trending (eg., No. 2 Zone) and 140°-trending (eg., Kremzar Gold Mine) shear zones. Higher grade 'ore-shoots' plunge moderately to steeply to the north, consistent with measured intersection lineations. In the **western** domain, gold is preferentially found in quartz veins within 085°- and 115°-trending shear zones, with the higher grade 'ore-shoots' plunging steeply to the west, parallel to measured intersection lineations (eg., Murphy Gold Mine). Similarly, in the **eastern** domain gold is found in quartz veins within 085°- and 115°-trending shear zones, except the plunge of the higher grade 'ore-shoots' is moderate

to the east, parallel to measured intersection lineations (eg., Cline Lake Gold Mine). Within the *GLDZ* the alteration associated with most of the gold occurrences (Heather et al., this volume) is of limited areal extent, being confined to the narrow shear zones.

In the Mishibishu Lake district, the moderately to steeply, north-dipping *MDZ* is a lithologically and structurally complex zone made up of anastomosing ductile and brittle-ductile shear zones. These shear zones are upwards of ten metres wide and of variable strike-length, measuring from tens of metres up to several hundreds of metres. The *MDZ* is characterized by dominantly oblique-slip (north side up) displacement with a sinistral component of shear. However, conflicting kinematics for parts of the *MDZ* provide evidence of a complex structural history. A long linear package of coarse clastic metasediments coincident with the *MDZ* may represent fault bounded 'Timiskaming-type' sediments which are commonly found associated with gold deposits in the Superior Province of the Canadian Shield. No metasediments are found in the immediate vicinity of the *GLDZ*, suggesting a possibly different tectonic setting.

The structural setting of gold mineralization within the *MDZ* is exemplified by the Magnacon deposit, at present the best understood deposit in the Mishibishu Lake Greenstone Belt. Auriferous quartz vein systems occupy late dilational, brittle structures that crosscut the ductile, penetrative shear fabric of the *MDZ* at a low angle of approximately 10°. These vein structures are arranged in a left-stepping, en echelon pattern in plan view. In cross section (looking east), the vein structures are arranged in a right-stepping, en echelon pattern within the north-dipping *MDZ*. Within these tabular vein structures are higher grade 'ore-shoots' which plunge moderately to the east, parallel to measured intersection lineations. Alteration associated with the gold mineralization is widespread throughout the *MDZ* (Heather et al., this volume) which contrasts with the relatively 'tight' control of alteration observed within the *GLDZ*.

There is a spatial association of cross structures with many of the gold occurrences within both the *GLDZ* and the *MDZ*. These cross structures are commonly occupied by Proterozoic diabase dikes in the Mishibishu Lake district and to a lesser extent in the Goudreau-Lochalsh district. In addition, the two regionally extensive brittle cross faults which define the boundaries between structural domains within the *GLDZ*, contain siliceous, fault-breccia hosted gold mineralization, but only within that portion of the brittle fault intersecting with the *GLDZ* (Figure 3). These empirical observations suggest that many of the cross structures are ancestral Archean structures that may have played a role in localizing lode-gold mineralization within the regional deformation zones they transect. Subsequent reactivation during Proterozoic tectonism and magmatism serve to obscure the early structural history.

In conclusion, it becomes apparent that the structural style of regional deformation zones is an important control on how and where gold mineralization and associated alteration will occur. The Wawa gold camp exemplifies that within a small geographical area there can be different structural styles, the recognition of which is critical for exploration target delineation and/or ore-body definition.

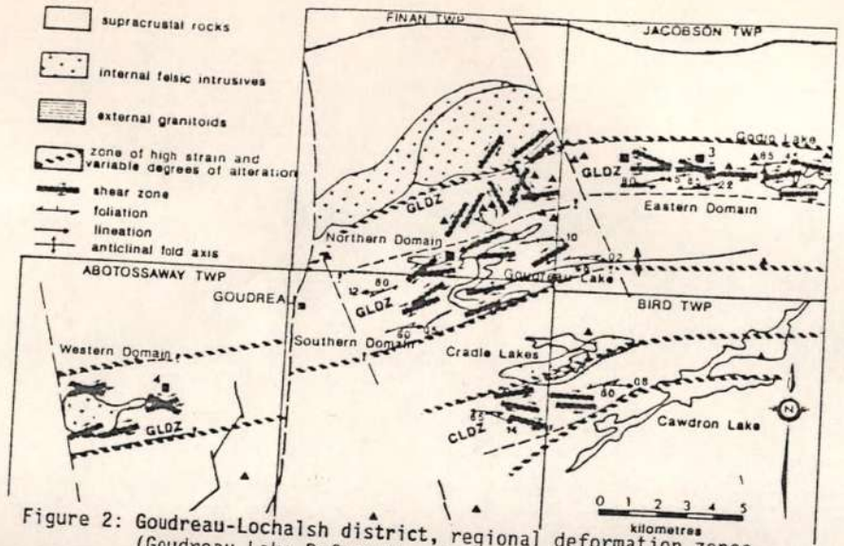


Figure 2: Goudreau-Lochalsh district, regional deformation zones (Goudreau Lake Deformation Zone (GLDZ) and Cradle Lakes Deformation Zone (CLDZ)), structural domains, shear zone orientations and senses of displacement, lineations, and gold occurrences (squares and triangles). (1) Kremzar Gold Mine, (2) Magino Gold Mine, (3) Cline Lake Gold Mine, (4) Murphy Gold Mine.

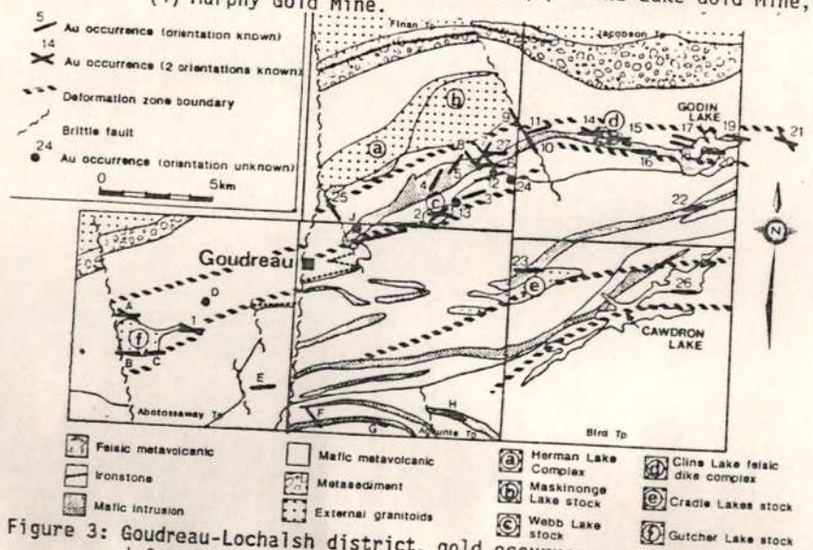


Figure 3: Goudreau-Lochalsh district, gold occurrence orientations, deformation zones, cross structures, general geology, and felsic intrusions.

THE GEOLOGICAL SETTING OF GOLD MINERALIZATION IN THE WAWA GOLD CAMP, ONTARIO, CANADA

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The Wawa gold camp is currently one of the most actively explored areas in Ontario. Located 130 km southeast of the Hemlo gold camp and 225 km west of the Porcupine (Timmins) gold camp,the Wawa gold camp hosts two current producers, three planned producers, several past producers, numerous underground exploration programs, as well as a multitude of surface exploration projects. Located within the Abitibi-Wawa Subprovince of the Archean Superior Province, the Wawa gold camp encompasses both the Michipicoten and Mishibishu Lake Greenstone Belts. Four distinct gold-bearing districts in the Wawa gold camp are the **Mishibishu Lake district**, the **Michipicoten district**, the **Goudreau-Lochalsh district**, and the **Renabie-Missinabie district**.

The supracrustal rocks of the Mishibishu Lake Greenstone Belt consist of mafic metavolcanics and clastic metasediments to the north, and a complex package of felsic, intermediate, and mafic metavolcanics with intercalated chemical and/or clastic metasediments to the south. The belt has been intruded by several large, internal batholiths of variable composition, as well as several high-level felsic stocks. The belt has undergone extensive folding, ductile shearing and late brittle faulting.

The supracrustal rocks of the Michipicoten Greenstone Belt can be subdivided into at least three mafic-felsic volcanic cycles based on whole rock geochemistry and U-Pb age dates of approximately 2900 Ma, 2749 Ma, and 2700 Ma. The intermediate to mafic rocks of the oldest cycle are basaltic to peridotitic komatiite in composition while the two younger mafic cycles are tholeiitic to high iron tholeiitic in composition. The intermediate to felsic rocks of all three cycles are typically calc-alkalic rhyolites and dacites. Each of the volcanic cycles is capped by chemical and/or clastic metasediments consisting of siderite-, pyrite-, or chert-magnetite-iron formations, wackes, siltstones and minor conglomerates. Numerous sill-, and dike-like intrusions of gabbroic to quartz dioritic composition intrude the three volcanic cycles. The Michipicoten supracrustal rocks have been intruded by at least four ages of granitoid stocks (2880 Ma, 2745 Ma, 2720 Ma, and 2660 Ma) of widely varying composition. The Michipicoten Greenstone Belt appears to have been originally a north-facing monoclinal sequence which has undergone regional tilting, folding and faulting. The majority of the supracrustal rocks within both the Mishibishu Lake and Michipicoten Greenstone Belts have been metamorphosed to greenschist grade, while those found in the immediate vicinity of large intrusions are of amphibolite grade.

Gold mineralization in the **Mishibishu Lake district** is localized within regionally extensive, steeply dipping deformation zones which comprise anastomosing, ductile and brittle-ductile shear zones. These deformation zones are coincident with major lithological contacts and include all rock types present within the belt. The deformation zones average several kilometres in length and several hundreds of metres in width. Gold mineralization is associated with pyrite, arsenopyrite, galena, chalcopyrite, and minor pyrrhotite in shear zone hosted quartz veins and sulphide-rich schists. A systematic pattern of alteration flanks the auriferous vein systems. Intimately associated with the veins are sericite-quartz-Fe-carbonate-sulphide schists which grade outward to chlorite-Fe-carbonate-sericite-sulphide schists, which in turn grade into schists of chlorite-calcite-sulphides. This zonation of alteration types is most observable within rocks of intermediate to mafic composition (eg., intermediate to mafic volcanics and mafic intrusions), while being more cryptic within rocks of felsic composition (eg., sediments, felsic intrusions and felsic volcanics). The majority of the gold occurrences in the Mishibishu Lake Greenstone Belt occur within the Mishibishu Deformation Zone (*MDZ*), a 40 km long by 1 km wide zone of intense ductile to brittle-ductile shearing with coincident hydrothermal alteration. Intrusive quartz-feldspar and feldspar porphyry dikes, related to the high-level Mishibishu Lake quartz monzonite to monzonite stock, are commonly associated with gold occurrences within this zone of deformation. There is a spatial relationship between major structures that cross the *MDZ* and the location of gold occurrences. This indicates that the intersection of these structures may have provided a favourable site for gold mineralization.

Gold mineralization in the **Michipicoten district** is localized within an 020°-trending shear zone known as the Jubilee shear system. This system is a 60 m wide zone which dips shallowly at 35° to the east within the sub-volcanic Jubilee stock (2745 Ma) of dioritic composition. Gold mineralization occurs within silicified, lense-shaped bodies, within quartz veins and within breccia zones. Generally the lensoidal bodies and the quartz veins plunge to the southeast and form en echelon systems which step left both in plan and longitudinal section. Alteration associated with these auriferous zones consists of carbonatization (Fe-carbonate and calcite), sericitization, chloritization, pyritization, feldspathization, and biotitization. Additional subparallel shear systems located to the east of the Jubilee shear host similar gold mineralization.

Gold mineralization in the **Goudreau-Lochalsh district** is localized within two regionally extensive, subparallel deformation zones referred to as the Goudreau Lake Deformation Zone (*GLDZ*) and the Cradle Lakes Deformation Zone (*CLDZ*). The majority of the known gold occurrences are located within the 4 km wide by 30 km long, east-northeast-trending, gently arcuate, strata-subparallel *GLDZ*. The *GLDZ* is comprised of numerous systematically oriented, discrete, brittle and brittle-ductile shear zones which can be classified into six groups based on their orientation. The systematic orientation of the shear zones, the consistent sense of shear displacement within shears of similar orientation, the angular relationship between individual shear zones, and the apparent synchronous development of

each shear zone orientation, all seem consistent with features found in Riedel shear systems. Gold mineralization occurs in all rock types in the area (excluding diabase dikes) associated with shear zone hosted quartz vein systems and/or sulphide-rich schists flanking the vein systems. Gold mineralization has a spatial association with felsic porphyry dikes and stocks (eg., Gutcher stock (2720 Ma)), with the contacts of dikes being particularly favourable sites for shearing and gold deposition. Where auriferous vein systems cut mafic volcanics or intrusives an alteration assemblage of biotite, Fe-carbonate, pyrite, pyrrhotite, quartz and minor potassium-feldspar occurs with an outer assemblage of chlorite, calcite, and minor pyrrhotite and/or pyrite. Where auriferous vein systems cut felsic volcanics or intrusives an alteration assemblage of quartz, sericite, pyrite, Fe-carbonate, albite, hematite, pyrite and/or pyrrhotite occurs with an outer assemblage of similar minerals except chlorite replaces sericite as the dominant alteration mineral.

Gold mineralization in the **Renabie-Missinabie district** is localized within brittle-ductile shear zones, of two dominant orientations, within both the supracrustal rocks and the external granitoid terrane. West to west-northwest trending, south dipping shears exhibit sinistral (oblique-slip) shear displacement, as do northwest trending, southwest dipping shears (Callan and Spooner, 1987). The Renabie Gold Mine, the largest producer of gold to-date in the Wawa gold camp (> 1,000,000 ounces), occurs at the intersection of two of these shear structures. These shear structures are developed within tonalites and gneissose trondhjemites of the Wawa Domal Gneiss Terrane, external to the Michipicoten Greenstone Belt. The Renabie, C-Zone and Nuduluma Vein systems all plunge at approximately 55° to the southwest (Callan and Spooner, 1987) roughly parallel to the greenstone-granitoid contact. Numerous smaller gold occurrences are found within other shear structures both within the external granitoids and the supracrustals.

In conclusion, considering the Wawa camp as a whole, it is apparent that structure is of paramount importance in localizing gold mineralization. Each of the four gold-bearing districts within the Wawa gold camp has its own site-specific controls on gold mineralization. Structural styles vary (Heather et al., this volume) from large, ductile-brittle shear systems (**Mishibishu Lake district**) to smaller, dominantly brittle-ductile shear systems (**Goudreau-Lochalsh and Michipicoten districts**). Consequently, host rock lithology and hydrothermal alteration patterns vary from relatively simple (**Michipicoten and Renabie-Missinabie districts**) to complex (**Goudreau-Lochalsh and Mishibishu Lake districts**). However, similar types of alteration are associated with the gold mineralization within all the districts. The structural style of regionally developed deformation zones strongly influences how and where gold mineralization and associated alteration will occur within each of these districts.

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GOLD MINERALIZATION IN THE MURCHISON PROVINCE, WESTERN AUSTRALIA

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INTRODUCTION

Western Australia's Murchison Province is a 95 000 km^2 area of Archaean granite-greenstone terrain which occupies the northwestern part of the Yilgarn Block and includes the important gold mining towns of Mt Magnet, Cue and Meekatharra. From the first discovery of payable gold in 1890 to the present day the area has yielded about 230 tonnes of gold. Between 1983 and 1987 the Geological Survey of Western Australia undertook an extensive investigation of the province to improve our knowledge of its regional geology and crustal evolution, document mineralization and to assess metallogenic controls, most particularly with regard to gold mineralization.

REGIONAL CONTROLS

A new geological map (Plate 2, Watkins and Hickman, 1988) indicates several important links between regional geology and the distribution of gold deposits:

1. Most deposits are located on, or within 1 km of, regional faults and shear zones, some of which extend more than 200 km.
2. Almost all the deposits are situated in greenstone belts, despite the fact that these occupy less than 20% of the province's total area.
3. Deposits generally occur within 2 km of granite-greenstone contacts, and most are located close to post-folding granitoid intrusions.
4. Deposits are concentrated in the upper three formations of the Luke Creek Group.

The close spatial association with faults and shear zones strongly supports the view that these acted as conduits for gold-bearing hydrothermal fluids. The conduits extended through both granites and greenstones, but gold mineralization was concentrated in the greenstones because these provided both the best gold source and the most favourable conditions for gold precipitation (see local controls). On the assumption that fluid movement along the conduits was essentially vertical, and because greenstones generally structurally overlie granites, gold precipitation would occur in the lowest favourable greenstone host rocks.

Because the tectonic and metamorphic environments responsible for the generation of granitic magma and gold-bearing hydrothermal fluids were probably similar, the spatial relationship between gold deposits and post-folding granitoids (Watkins et al., in press) need not

reflect a direct genetic link, and is considered to be largely coincidental.

The concentration of gold deposits in a particular part of the stratigraphic succession results from local controls.

LOCAL CONTROLS

The most important factors controlling the precise location and form of epigenetic gold deposits are ore-fluid composition, pressure-temperature conditions, local structure and wallrock lithology. Ore-fluid composition and depositional pressure-temperature conditions are discussed by Groves et al. (1984). Local structure provided access for ore-fluids and space for deposition, whereas wallrock - ore-fluid reactions largely controlled gold precipitation. If ore-fluids were predominantly of one type it follows that gold deposition would be concentrated in a limited range of rock types. This is the situation in the Murchison Province where most deposits are hosted either by mafic rocks, ultramafic rocks or BIF-chert (Plate 2, Watkins and Hickman, 1988). Where all three rocks occur in close proximity BIF is the favoured host, confirming the importance of an Fe-rich composition in promoting gold precipitation. The fact that structure and rock type are partly interdependent (rock competence and homogeneity influencing local deformation, and deformation subsequently influencing the extent of alteration) probably explains the distinct features of the three main categories of deposit:

1. Mafic rocks, principally tholeiitic basalt and less commonly dolerite, generally host gold deposits in single quartz veins or simple quartz-carbonate vein systems. Ore shoots are narrow (generally 0.5 - 2 metres), long (horizontally) and of moderate though relatively constant grade. Economic gold mineralization is generally confined to the veins, and wallrock alteration (chiefly carbonation, chloritization, K metasomatism and pyritization) is typically restricted to narrow (about 1 metre) zones.

2. Gold deposits in ultramafic rocks, ranging from peridotite to komatiitic basalt, normally occur in shear zones and consist of numerous lenticular and discontinuous quartz veins and stringers in talc-chlorite and talc-carbonate schist. In many areas sills of quartz-feldspar porphyry intrude these units, and are accompanied by marginal carbonation, silicification and fuchsite development. Quartz veins at porphyry-schist contacts, and sulphidic quartz veinlets within the porphyry bodies locally contain medium to high gold values. Extensive low-grade gold mineralization in the ultramafic schists permits large-scale bulk mining.

3. BIF and chert host two main categories of deposit: stratabound gold-bearing sulphide-rich lenses, and erratic high-grade shoots at intersections with faults and quartz veins. In both cases gold precipitation accompanied sulphidation of Fe-rich rocks by ore-fluids moving along the faults (Groves et al., 1984); low background gold contents (generally below 10 ppb) along strike cast doubt on any significant syngenetic gold component. Stratabound orebodies are commonly wide, long and extend to depths of several hundred metres, whereas the narrow shoots are typically short, isolated and sub-economic below the zone of supergene enrichment.

Other types of epigenetic gold mineralization, such as deposits in felsic volcanics and clastic metasediments, are far less common and relatively small, the only exception being Big Bell. Containing more than 100 tonnes of mineable gold, the Big Bell deposit is a stratabound, pyritic quartz-muscovite-K feldspar schist lode within high grade metamorphic rocks, probably representing metasomatized volcanogenic sediments. The deposit is located on a shear zone close to a granite-greenstone contact, and probably occupies a local dilation structure.

Isolated examples of syngenetic gold mineralization associated with base-metal deposits (eg Golden Grove), conglomerate-hosted placer deposits (eg Bonnie Venture), laterite-hosted deposits (eg Mt Gibson) and the numerous small alluvial deposits are described elsewhere.

EPISODES OF GOLD MINERALIZATION

Table 1 places gold mineralization within the framework of the province's Archaean crustal evolution. The main point to emerge is that gold mineralization was not a single event but occurred in stages over about 400 Ma.

Table 1. Gold mineralization during the Archaean crustal evolution of the Murchison Province.

Age (Ma)	Event	Gold Mineralization
ca 3000	Deposition of the Luke Creek Group - volcanics, BIF and clastic sediments.	Syngenetic, with base-metal deposits.
ca 2900	D1: Recumbent folds and thrusts. Granitoid intrusion.	Epigenetic, in D1 shear zones.
ca 2800	Deposition of the Mount Farmer Group - volcanics and clastic sediments.	Placer Au-W deposits in conglomerate.
ca 2650	Granitoid intrusion. Contact metamorphism. D2: E trending upright folds.	Epigenetic, associated with D2 shears and faults.
2650-2600	D3: NNE to NNW trending upright folds. Regional metamorphism (2650-2625 Ma). D4: NNE, N and NW striking wrench faults and shear zones. Post-folding granitoid intrusion.	Epigenetic, associated with D4 faults and shear zones.

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GOLD MINERALIZATION IN RELATION TO POLYMETAMORPHIC EVENTS IN THE VUMBA SCHIST BELT, BOTSWANA

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The Vumba Schist Belt can be described as an Archean greenstone-granite association which has a complex metamorphic and tectonic history and which includes several Au deposits. It is at the western edge of the Zimbabwean (former Rhodesian) craton. Comparative lithological and stratigraphical studies by several authors suggest that the Vumba Schist Belt is a stratigraphic equivalent of the Tati Schist Belt in Botswana and both can be correlated with the Upper Bulawayan Greenstones in Zimbabwe.

The Schist Belt consists of a sequence of rocks of ultra-basic, basic, felsic and sedimentary origin which are highly deformed and intruded by granitoids. The investigation of Litherland (1975) and the working group of the BGR (Hannover) and the GS (Lobatse) demonstrated that the Vumba association is polymetamorphic. This is in sharp contrast to most of the greenstone belts in Zimbabwe, South Africa, Canada, Australia and Brazil.

Whereas the Tati Belt, most of the Zimbabwean greenstones and most of the Archean greenstones studied in other terranes are low to medium grade, the Vumba Belt underwent high-grade metamorphism. This suggests that the Vumba Belt was buried at considerable depths, while the other belts remained in structural highs. The special situation of the Vumba Belt can be explained in terms of its exposed position at the westernmost margin of the Zimbabwean craton. It was influenced to a high degree by the Limpopo Mobile Belt.

M2 granulites were generated in the western part of the belt during initial devolatilization. After a considerable amount of tilting, another less depleted part of the greenstone belt came into an environment of granulitization and a second dehydration event took place, providing fluid for the M3/4 amphibolitization.

The M3/4 metamorphic event reached the amphibolite facies and generated or remobilized a disseminated pyrrhotite and chalcopyrite mineralization which shows a laminated fabric and is paragenetic with hornblende and/or biotite. The high amount of biotite suggests that potassic metasomatism took place during ore formation. Quartz mobilizates cut across the laminae and are folded. If there was any gold associated with this metamorphic and metasomatic event it cannot be proved because of the later M5 event which altered this M3/4 paragenesis. Due to remobilization, the M3/4 gold, even if it is present, cannot be distinguished from the M5 gold.

The tilting continued and in the final stage rock from the greenstone belt that had not previously been affected by devolatilization underwent some degree of devolitization in which the ratio of decarbonatization to dehydration increased relative to the second stage and gave way to the carbon-rich fluids of the M5 mineralization.

The fluids which became mobile during the last event (M5), followed the old F2 (syn M3) shear zones. They were enriched in various elements leached from the available rocks of the Vumba Belt, mainly komatiites. These elements were transported towards a suitable precipitation environment. This environment was provided by a deformed sequence of various rock types in the central Vumba Belt, where the transition from ductile to brittle deformation under greenschist facies conditions was convenient for secondary boiling of the transport medium and resulted in a reaction with the altered wallrock.

The M5 event is characterized by intensive alteration along planes of ductile shear in ultra basic to basic rocks and quartz veining in more felsic rocks, and banded iron formation in which deformation was brittle. The alteration has a typical greenschist facies, characteristics with actinolite, albite, clinozoisite and sericite. Stilpnomelane is sometimes present, whereas tourmaline occurs together with spongeous pyrite and arsenopyrite at nearly all known mine sites. Veinlets of quartz, quartz-carbonate, or carbonate-graphite-tourmaline may contain arsenopyrite, pyrite and possibly some gold, accessory scheelite can be present too. The chemical composition of the various types of rocks in the vicinity of the mine sites in the Vumba Belt clearly shows an alteration pattern. This alteration pattern is somewhat similar to those reported for other greenstone belts.

A distinct enrichment (relative/substantial) can be observed for K, B, Ca, Al, Si, As, Au, Te, W, Sb, Ag, S, H_2O and CO_2.

Arsenic, a well-known pathfinder for gold, was investigated successfully in the center of Vumba to outline shear zones. The amount of alteration and enrichment of certain elements in dependance of the physical and chemical conditions resulted in a sixfold element zonation. Even if this zonation is deduced from only a limited amount of data it seems to be reasonable for zones 3 and 5, which show significant element concentrations. Zone 5 shows anomalous high values for Au, Ag, As, B, Te, W and extremely depleted Hg, whereas zone 3 is highly anomalous in mercury, which seems to form a metamorphic halo around the M5 center.

The mineralized area is restricted to a narrow zone in the center of the schist relic. Metamorphic assemblages of the last M5 event suggest that P-T conditions and availability of fluids were favourable only in this area. Exceptions can only be expected to a limited extent in shear zones that parallel competent layers (serpentinites).

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ENVIRONMENT OF GOLD METALLOGENY IN SOUTHERN INDIAN SHIELD

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The Archaean supracrustal belts (Dharwar schist belts) of southern Indian shield form an important gold metallogenic province with innum erable occurences of gold: only a few form deposits which have contributed about 5% of the total gold obtained from Archaean greenstone belts all over the world. These supracrustal belts comprise in general the following sequence in ascending order: (i) mafic/ultramafic lavas with chemogenic sediments and minor clastics (1) - these occur as highly detached and dismembered linear belts, showing high grade metamorphism/migmatisation and minor gold mineralisation, (ii) a platformal association of orthoquartzite, quartz pebble conglomerate, minor carbonate, metabasic volcanic rocks, banded iron/manganiferous formation- these have large aerial extent, occur only in the western block of the craton and gold mineralisation is minor, (iii) a rift - type of basic volcanic rocks with minor acid volcanic/tuffs, sulphidic metachert and Algoma-type banded iron formation - these occur as sublinear detached belts in the eastern block of the craton and constitute the producing gold belts of the shield accounting for 99% of the country's production and (iv) thick clastic "flysch type" of greywacke-shale, polymict conglomerate and minor volcanics - these occur in the western block of the craton and gold mineralisation is minor. All these lithologic associations are partially preserved as equant to long, linear schist belts of various dimensions i.e., from the scale of an outcrop to a few thousands of square kilometer in a vast sea of migmatite/granitoid gneisses (Peninsular gneiss). A high grade metamorphic belt skirts the craton in the south and the east. Available geochronological data indicate a vast span of 1000 m.y. (3500 m.y. to 2500 m.y.) for the formation of these supracrustals punctuated by three major events (3300 m.y., 3000-3100 m.y. and 2500-2600 m.y.) of Peninsular gneiss formation (2). A major linear N-S trending intrusive granite (Closepet granite, 2500 m.y.) is the divide between the eastern and western blocks of the craton (Fig.1). The schistose as well as the gneissose rocks trend N-S to NW-SE, exhibit three principal episodes of folding (3) and are metamorphosed from greenschist-> amphibolite-> granulite facies in a prograde manner from north to south. A few gold occurrences/prospects are also known in the southern granulite belt which perhaps represent the relics of the supracrustals.

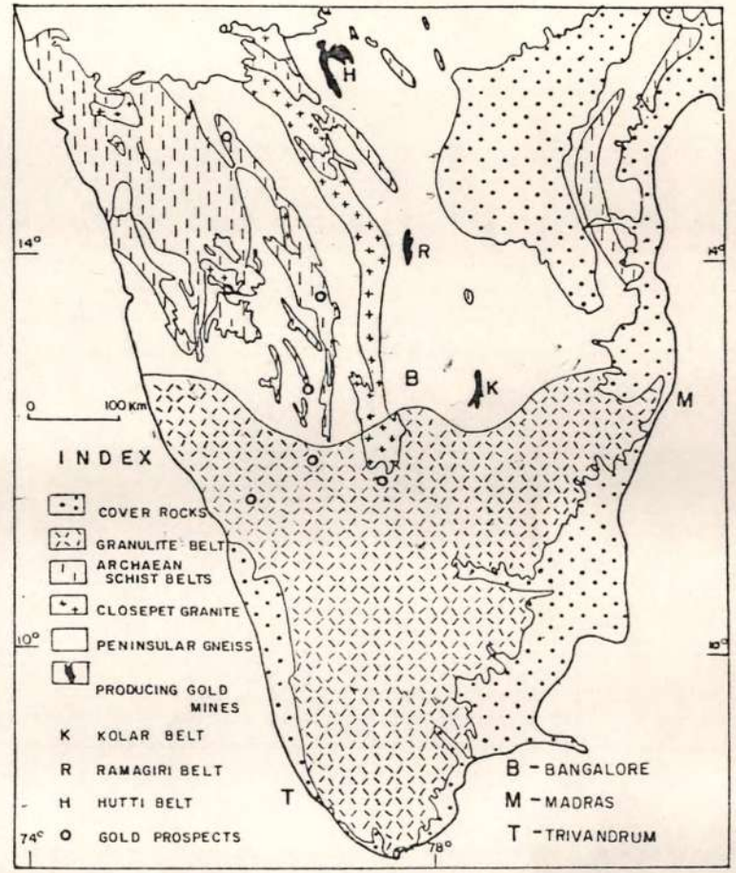
The producing gold mines of the country namely Kolar (>800t. Au), Hutti (> 55t. Au), Ramagiri (> 10t. Au) and many occurrences/prospects are confined to "rift type" of belts in the eastern part of the craton. These late Archaean belts (2700 m.y.to 2500 m.y.)

(4) comprise mostly subaqueous tholeiitic basalts, minor ultramafic sheets, exhalative sulphidic sediments, felsic volcanics/tuffs and immature clastic sediments. The most dominant host rocks are metamorphosed Fe-rich tholeiites and ultramafic schists. Mg-rich basalts and rocks of komatiitic affinity have been identified only in Kolar belt barring all others (e.g. Ramagiri and Hutti). These primitive less evolved lavas (Komatiites) are more prevalent in some of the belts occurring in the western block where gold occurrences are few and far between. Minor gold deposits and occurrences are known in almost all the lithologies (e.g. acid to intermediate volcanics, tuffs, chemical/clastic sediments, sulphidic banded iron formation) represented in the supracrustal belts irrespective of their stratigraphic position. A primary episode of syngentic gold mineralisation is recognised in sulphidic/carbonaceous sediments which is however less important. The epigentic types are the most important and productive ones. These have evolved through processes of syntectonic vein formation and limb shearing during F-2 fold movement which defines the main structural grain of the schist belts; and ductile-brittle shear zones and hydraulic fracturing postdating the F-2 folding event. The mineralised shear zones which transect the regional schistosity at low angle with profound hydrothermal alteration gave rise to all the important deposits (5). Favourable tectonic structures, availability of hydrothermal fluids for large scale ingress and prolonged tectonothermal modifications appear to be the most important controlling factors in localisation of gold ore deposits in the South Indian shield.

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Fig.1 REGIONAL GEOLOGICAL MAP OF SOUTHERN PENINSULAR INDIA



GEOLOGICAL SETTING OF ARCHEAN GOLD MINERALIZATION IN THE ILOMANTSI GREENSTONE BELT, EASTERN FINLAND

PEKKA A. NURMI and PETER WARD

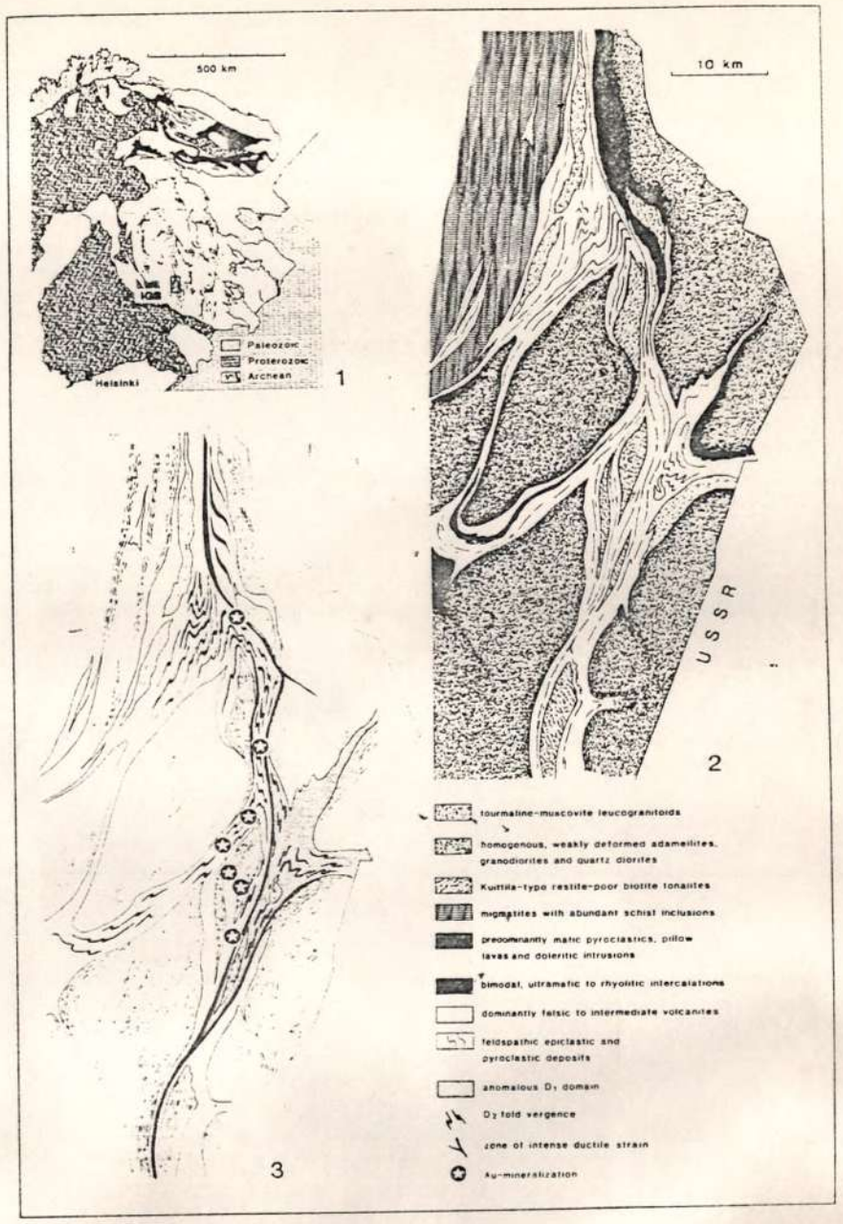
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The Ilomantsi greenstone belt (IGB) forms part of an extensive and typical late Archean granitoid-greenstone association in the eastern Fennoscandian Shield (Fig. 1), and consists of narrow, bifurcating zones exceeding 50 km in length, but seldom attaining 5 km in width (Fig. 2). Recent till geochemical surveys by the Geological Survey of Finland revealed Au anomalies in the eastern branch of the IGB (Nurmi et al., this volume) and have subsequently led to the delineation of the first Archean gold mineralizations of economic potential reported from the Shield (Fig. 3).

The zone of current interest is also lithogically distinctive, consisting predominantly of calc-alkaline dacitic to andesitic pyroclastics, along with their sedimentary derivatives and lesser felsic to intermediate subvolcanic intrusions. Mafic rocks are in general only minor components of the belt, occurring as sporadic tuffaceous deposits, pillow lavas and doleritic sills throughout the more felsic succession. However, an exception to this is a distinct bimodal komatiite - tholeiite - rhyolite association in the northernmost part of the belt (Fig. 2); there is some (structural) evidence that this unit is stratigraphically younger than the bulk of the felsic to intermediate sequence.

In spite of complex deformation and a metamorphism attaining amphibolite facies grade, some degree of stratigraphical coherence remains and primary depositional features are commonly preserved. These indicate terrestrial to shallow water deposition associated with generally coarser detritus and more abundant volcanic deposits in the northern part of the belt, while modal grain size and lithological diversity tend to decrease southwards, reflecting a concomitant increase in abundance of resedimented feldspathic graywackes. So far there is no compelling evidence for mineralization being spatially restricted to any particular primary depositional lithology. (Fig. 2).

The IGB was intruded by granitoids between 2.80 - 2.70 Ga and since Sm-Nd model ages and U-Pb zircon data from sediments indicate deposition during the same time interval and a lack of detrital material older than 2.9 Ga, relatively rapid crustal evolution and deformation is implied. Structural geometry is regionally coherent to the extent that NNE-NE trending strata consistently show dextral F_2 folds and non-coaxial strain indicators whereas N-NW trending zones are conversely sinistral. Anomalies in depositional younging direction (hachured area in Fig. 3), as well as an early differentiation fabric and vein development reveal a more protracted structural history, and illustrate the progressive evolution of deformation, at first characterized by large scale folding and subsequently by localization of strain into discrete shear zones.



Bicentennial Gold 88, Melbourne, May, 1988

Such progressive deformation is compatible the pre- or syn- D_2 intrusion of at least the earliest granitoids at releasing bends in curviplanar shear zones or dilantant sites caused by differential movement between pairs of shear zones. A gradual increase in the vertical strain component as intrusion proceeded is also indicated by steeper lineations and rotated fold hinges adjacent to some granitoids, possibly resulting from diapiric ballooning in the final stages of emplacement.

A close spatial correlation has been observed between Au mineralization, shear zones and the deformed marginal phases of the early, Kuittila-type intrusions (Figs. 2 and 3). These biotite tonalites are typically restite-free, though may contain country-rock inclusions and screens near margins, and are commonly accompanied by quartz-plagioclase porphyry dykes and apophyses. Anomalous Au contents are found sporadically throughout extensive zones hundreds of metres in width and up to several kilometres in length, characterized by quartz - sericite - chlorite alteration of feldspathic pyroclastic and epiclastic protoliths. Pseudomorphing of presumed andalusite porphyroblasts, similar alteration in the porphyry dykes, and Au-bearing shear zones cutting deformed tonalite indicate that regional hydrothermal alteration possibly accompanied and certainly continued after intrusion of the Kuittila-type tonalites. A structural control on the distribution of alteration is also apparent where mineralized shear zones obliquely truncate lithological units.

A number of mineralizations within the belt have proven to be of economic interest, although they are yet to be fully evaluated. The prospect investigated in most detail (by Outokumpu Oy) has been assessed to a depth of 70 m over a strike interval of 500 m with Au contents averaging about 5 g/t from quartz ± tourmaline veins in shear zones up to several metres in width. In common with other mineralized zones throughout the belt, the alteration assemblage includes quartz - sericite ± biotite ± chlorite ± tourmaline ± carbonate. Pyrrhotite, pyrite, arsenopyrite and chalcopyrite accompany native gold and tellurides as both disseminations in altered rocks and within discrete quartz veins and shear zones. However, IGB mineralization is typified by a relatively low amounts of S (usually less than 2%), and a rather erratic correlation between overall S abundance and Au content.

Tonalite-hosted mineralization exhibits a similar alteration assemblage, except that K-feldspar and biotite are characteristic and carbonate is more abundant. However, the mineralization tends to be developed within discrete shear zones and quartz vein systems, of various width, and moreover two distinct types of mineralization have been identified. The earlier phase, typified by Mo - W -bearing quartz veins, is not gold bearing whereas the second type, occurring as more extensive shear and vein systems containing pyrite, pyrrhotite, chalcopyrite, molybdenite, sphalerite, gold and tellurides, but in contrast to mineralization in the schists, is notably lacking in arsenopyrite.

Limited stable isotope data for carbonate from mineralized Kuittila tonalite yields $\delta\,^{13}C$ values in the range -7.2 to -9.6‰, considerably lighter than is typical for Archean gold deposits, and suggests circulating fluids incorporated a distinct non-magmatic component.

METAMORPHIC PARAGENESIS IN TRANSTENSION AND TRANSPRESSURE SITES ALONG THE AU-BEARING DIADEMA SHEAR BELT

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INTRODUCTION. The Diadema Shear Belt (DSB), in southern Pará, is the site of several dozen gold occurrences which are being presently investigated by Multiplic Mineração SA. Structural determinations along threnches and detailed petrographycal, mineralogical and geochemical studies of drill cores of the Main Zone of Anomaly 4 provided the basical data for this paper, whose aim is to explain the several mineral paragenesis within the shear zone environment.

STRUCTURAL GEOLOGY. The DSB forms a S-shaped structure with a general N 40 W trend conjugated with the regional E-W//N 70 W transcurrent faults. The DSB is branched across gabbros, layered peridotites and a metavolcanic sequence of ultramafic, mafic and felsic rocks and banded iron formation which have been preliminary interpreted as a greenstone belt type sequence. The DSB is intruded and bound northwards by the domic Parauapebas granite batolith of proterozoic age and southwards by the tonalitic gneisses of the Xingu Complex. The DSB shear zones are an array of subparaleil to 30º inclined sets of mylonitic and cataclastic zones with thicknesses varying from a few centimeters to one hundred meters. Domains of high ductile deformation are marked by blastomylonites and ultramylonites and show a strong one-direction mylonitic foliation while within the less deformed alternated domains of the protomylonites the foliation show an anastomosed configuration around less deformed nucleii. Mylonitization is also marked by continuous stages of dynamic recrystallization and blastesis of new minerals. Cataclastic bands within the inner portions of the shear zones characterize zones of brittle shear and consequently the formation of banded S-C tectonites. The internal foliation of the mylonitic bands(S-surface) defined through minute sericite and chlorite makes an oblique(around 30º)angle in relation to the cataclastic bands that define the C-surface. S-surfaces are roughly E-W dipping 70º S while C-surfaces have an average N 50º W strike with near vertical dips. Relationship between these surfaces indicate dextral displacements in the interior of the shear zones. Early crosscutting extension veins show intense intrafoliation folding. These veins and other structures such as quartz rods and boudins show lineations around 135º with a 55º to 60º pitch. Using Ramsay's (1980) model, the ductile shear was calculated to be produced by a high angle reverse movement generated by north-south compression. The shear zones above described represent a single deformation event (D_1) only sligthly modified by late inverse faulting with associated kink banding and shear folding related to a D_2 event.

METAMORPHISM/HYDROTHERMAL ALTERATION. Along the shear zones, transpressure and transtension sites suceed one another showing, respectively, prograde and retrograde mineral assemblages in relation

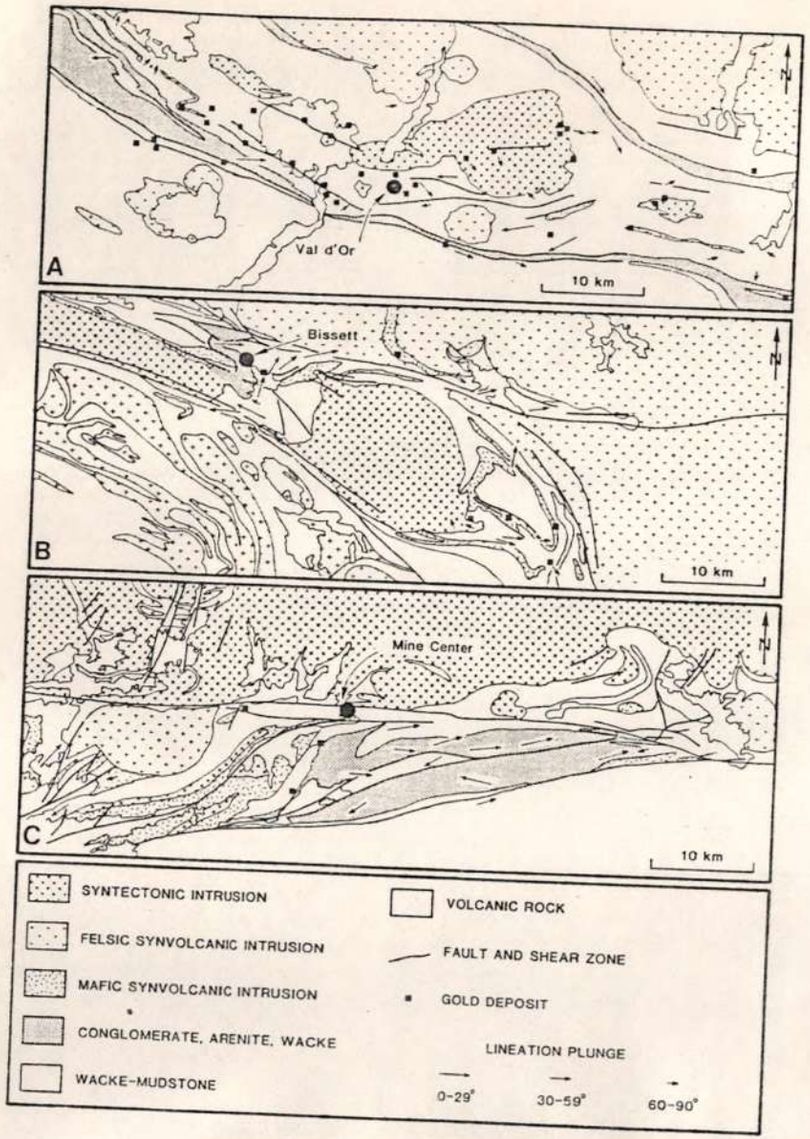


Figure 1: Geology and major structural elements of Val d'Or (A), Rice Lake (B) and Mine Center (C) gold districts of the Superior Province.

tectonic regimes with different proportions of compressive and dextral transcurrent components, MC being the most transcurrent, VD the least, RL having characters of both.

Each district contains gold deposits and occurrences with similar lithological settings, structural associations and scales of hydrothermal alteration; yet VD accounts for approximately 600 t of total gold production and reserves, RL 60 t and MC only 0.6 t.

In all districts, mineralized quartz veins postdate regional folding and occur both in brittle-ductile shear zones and in adjacent extensional fractures. Veins in shear zones are typically ribboned and contain foliated wallrock septa. Slickenlines are common within the vein quartz and are parallel to mineral lineations in the host shear zones. The shear zones themselves are generally characterized by foliation oblique to the boundary, which indicates the sense of shear. Veins in extensional fractures display textures of multiple open-space filling.

Despite similarities in style of mineralization among districts, there are major differences in orientation of the veins. VD deposits are typically associated with high angle reverse shear zones and sub-horizontal extensional veins, whereas MC deposits occur in strike-slip shears with vertical extensional veins and RL deposits have characteristics of both types (Fig. 2). In each district, vein orientation reflects the dominant structural style, transcurrent in MC and compressive with vertical extension in VD (Fig. 2).

The most transcurrent district (MC) has the highest metamorphic grade and the lowest gold content, and the most compressive district (VD) has the lowest metamorphic grade and the highest gold content. The differences in metamorphic grade may well reflect differences in preserved crustal level between the districts, which in turn may relate to differences in gold endowment. In addition, transcurrent tectonic regimes may be less amenable to gold deposition than compressive regimes: vertical ore shoots and extensional fractures of transcurrent regimes would promote upward fluid mobility, whereas episodic seismic failure in steep veins and opening of sub-horizontal extensional fractures in compressive regimes would impede fluid escape and favor gold deposition. If crustal level and structural regime are important factors in determining gold endowment, differences of as little as 2-3 km in structural level may distinguish productive from non-productive gold districts.

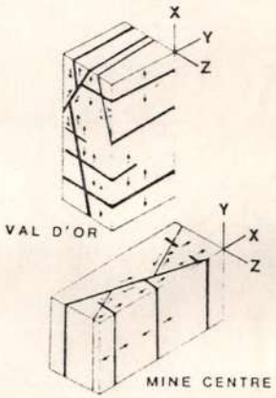


Figure 2: Vein geometry in relation to regional strain in VD and MC districts.

to the regional rocks. In the Main Zone of the Diadema prospect the main gold ore type is hosted by sheared and hydrothermally altered andesites. In less deformed unaltered adjacent zones where original chemical composition and relictic andesite structure are still preserved, the rocks show a chlorite-biotite-oligoclase(An_{23})-carbonate-ilmenite-magnetite-(pyrite) mineral assemblage. This assemblage, outside the domain of the shear zone , is thought to record regional metamorphic conditions where the lithospheric pressure(P_L) should be aproximately equal to the fluid pressure ($P_L=P_F$). In the transpressure sites, where P_L is greater than P_F,the main paragenesis becomes biotite-hornblende-andesine-carbonate-(epidote)-ilmenite-pyrrhotite. Both assemblages when they are submited to transtension conditions, where P_F exceeds P_L, they undergo a typical process of hydrothermal metamorphism that is marked by widespread albitization, sericitization ,chloritization, ankeritization and tourmalinization. Silicification, pyritization and minor fuchsite replacement of sericite generaly take place in the central part of the alteration zone, where gold values may reach 20 ppm. The resulting mineral paragenesis within the transtension sites is thus quartz-albite(An_0)-sericite-chlorite-leucoxene-pyrite. The initial stages of hydrothermal alteration is marked by the disappearance of hornblende which is replaced by chlorite 1(ripidolite) and an increase in the carbonate content. The intermediate stage is marked by albite-carbonate-chlorite-2 (pennine)-sericite assemblages while the advanced stage by the pairs sericite-ankerite, sericite-pyrite, quartz-pyrite and quartz-tourmaline. Monomineralic banding is also characteristic of the advanced stage of hydrothermal alteration where selective mineral separation by pressure solution has taken place as those mineral assemblages are further sbjected to deformation.

MINERALIZATION MODEL. High gold values are invariably associated with the advanced stage of hydrothermal alteration, particularly where the cataclastic bands become subparalell to the mylonitic foliation. When the fluid pressure is built in the interior of the transpressure sites, precipitation of solids take place with a consequent reduction in both porosity and permeability. Fluid migration and hydrothermal alteration can only continue when hydraulic fracturing, caused by built in fluid pressure beyond the strenght of the impermeable wall rocks, restores the fluid flux. In the interior of the shear zones where pulses of hydraulic fracturing repeatedly takes place, the mechanical regime passes alternatively and continuosly from ductile to brittle. As this process is intensified and the dislocation of the shear surfaces is consequently increased, the mylonitic foliation tends to become more and more parallel to the C-surfaces, generating thus the favorable sites for gold deposition.

A COMPARISON OF STRUCTURAL STYLE AND GOLD ENDOWMENT OF THREE ARCHEAN GOLD DISTRICTS, SUPERIOR PROVINCE, CANADA

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The association of lode gold deposits with major faults has long been recognized, but the relationships between deposit-scale setting and district-scale structural evolution are not well understood. Furthermore, the reasons that some major fault zones have no or very little associated gold, and that reverse faulting seems to be important for gold remain unexplained. To obtain new insights on these problems, three areas of equal size, containing major faults and associated lode gold deposits within the Superior Province have been compared. These three areas share similar overall geologic setting, lithological assemblages and style of gold mineralization, but they display significant variations in structural style, metamorphic grade and gold endowment.

The three gold districts, Val d'Or (VD), Rice Lake (RL) and Mine Center (MC) occur at subprovince boundaries and consist of southern domains of meta-turbidites and northern metavolcanic-plutonic domains separated by major faults and fault zones (Fig. 1). In all districts, the volcano-plutonic domains, to which the gold deposits are restricted, consist of narrow belts of volcanic and sedimentary rocks, approximately parallel to major fault zones, which define sigmoids, Z-shaped at VD and RL, S-shaped at MC. The sedimentary belts within the volcano-plutonic domains represent late-stage accumulations of conglomerates and arenites. Metamorphic grade ranges from lower greenschist at VD, upper greenschist at RL, upper greenschist to lower amphibolite at MC.

All three districts contain steep foliations sub-parallel to lithological units and major faults, and stretching lineations which are steep at VD, moderate at RL, and shallow at MC (Fig. 1). Regional foliations and lineations intensify towards steep phyllonitic fault zones at the boundaries between northern and southern domains. Smaller shear zones, both parallel and oblique to the major faults, are common. Lineations in faults and shear zones are parallel to those in strained rocks between the shear zones. The dominant style of fault is high angle reverse at VD, dextral strike slip at MC, and RL is characterized by faults of both types.

All districts are characterized by a component of approximately northerly directed shortening, reflected by upright folds sub-parallel to the structural trend, by the steep foliations, and by high angle reverse faults. These structures have been superimposed by variable amounts of dextral transcurrent shear, as indicated by reorientation of steep lineations toward shallower plunges at MC, or by minor dextral drag-folding along major faults at VD. The structural style of the three districts is therefore best explained by transpressive

HOST ROCK CHARACTERISTICS AND CONTROLS OF GOLD MINERALISATION IN THE SOUTHERN PART OF KOLAR SCHIST BELT, INDIA.

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Gold mineralisation of economic significance is hosted by the mafic and felsic volcanics in the Chigargunta area, in the southern part of Kolar Schist belt, Andhra Pradesh India. These recently discovered prospects lie 30 km south of the famous Kolar Gold Fields, situated in the central part of the Archaean Kolar schist belt (2900 Ma). The mineralisation in this area is of lode type with quartz vein and veinlet system containing minor sulphides (pyrite,pyrrhotite,arsenopyrite, galena and molybdenite) and scheelite with a wide envelop of alteration typical of hydrothermal epigenetic deposits. Gold occurs in stringers or in disseminated form within the quartz veinlets. The gold content varies from 4 to 5 grammes per tonne over widths exceeding 1 metre.

Southern part of Kolar schist belt exposes predominantly meta-volcanic rocks comprising mafic and felsic volcanics. The mafic volcanics represented by metamorphosed basalts, gabbros and minor ultramafics occupy the western half of the belt. The eastern half exposes a felsic rock designated as "Champion gneiss" in the literature. These represent metamorphosed acid lavas, tuffs and metasedimentaries. A narrow band of iron formation of oxide to sulphide facies occur close to the western margin of the belt. The schist belt rocks exhibit imprints of three phases of deformation. Lower amphibolite facies metamorphism is prevalent and is concomittant with F_2 folding.

The mafic volcanics hosting gold mineralisation can be divided into two major types (1) Hornblende schists which are coarse schistose rocks having hornblende and plagioclase as the dominant minerals. Sphene and apatite are accessories. Plagioclase (oligoclase) occurs as twinned polygonised aggregates and (2) Actinolite-hornblende schists, which are massive to schistose consisting of actinolite, hornblende, plagioclase and epidote. Accessories include sphene and apatite. The contact between the two is either sharp or gradational.

The felsic unit hosting mineralisation is a coarse to medium inequigranular rock consisting of porphyroblasts of plagioclase, quartz or quartz+plagioclase in a fine grained quartz-feldspar-biotite-chlorite-amphibole matrix. The prophyroblasts have a crude alignment parallel to the foliation. However, the coarser porphyroblasts do not show any orientation.

Geochemically these mafic volcanics can be divided into (1) Tholeiite basalts and high Mg basalts. This classification is based on the MgO content, TiO_2,K_2O contents of Brooks and

Hart (1974) and also MgO, MgO/Al_2O_3 ratio of A.Y.Glikson (1982). The coarse hornblende schists fall in the tholeiitic field and is enriched in Fe. The fine actinolite hornblende schist (Mg number 64) shows affinity to the high Mg basalts having MgO >9%, MgO/Al_2O_3 >0.6,TiO_2 <0.9%.

The felsic schists characterised by high Al_2O_3 and Na_2O have a rhyodacite composition showing a calc-alkaline trend (K_2O 1.05 - 2.24%). Assuming a similar mantle source for the Kolar volcanics, it appears that from the less evolved basic rocks, as differentiation progressed more evolved melts of tholeiitic composition were generated. The felsic volcanics may be products of differentiation of a tholeiitic magma. Absence of any intermediate rocks in the area also points to the same.

A strong structural control for the mineralisation is noticed in the volcanics. These are defined by zones of high deformation localised in continuous, narrow subparallel zones having a near concordant relation to the host rock schistosity. These brittle-ductile shear zones post date the major F_2 folding and are mainly present along the central part of the belt. The shear zones have a tendency to occur along or close to the contacts of the different litho units. Progressive changes in mineralogy, texture and fabric of rocks are noticeable from the unmineralised host rock towards the shear zones. Mineral aggregates show reduction of grain size and preferred orientation parallel to the shear foliation. As the fabric strengthens towards the centre with progressive alignment and fining, the fabric lines become closer resulting in mylonite. Mineralogical changes include breaking down of feldspar to fibrolite and then to sericite, amphibole to biotite and in turn to chlorite etc. The deformational characteristics of the shear zones indicate that they might have evolved by simple shear deformation.

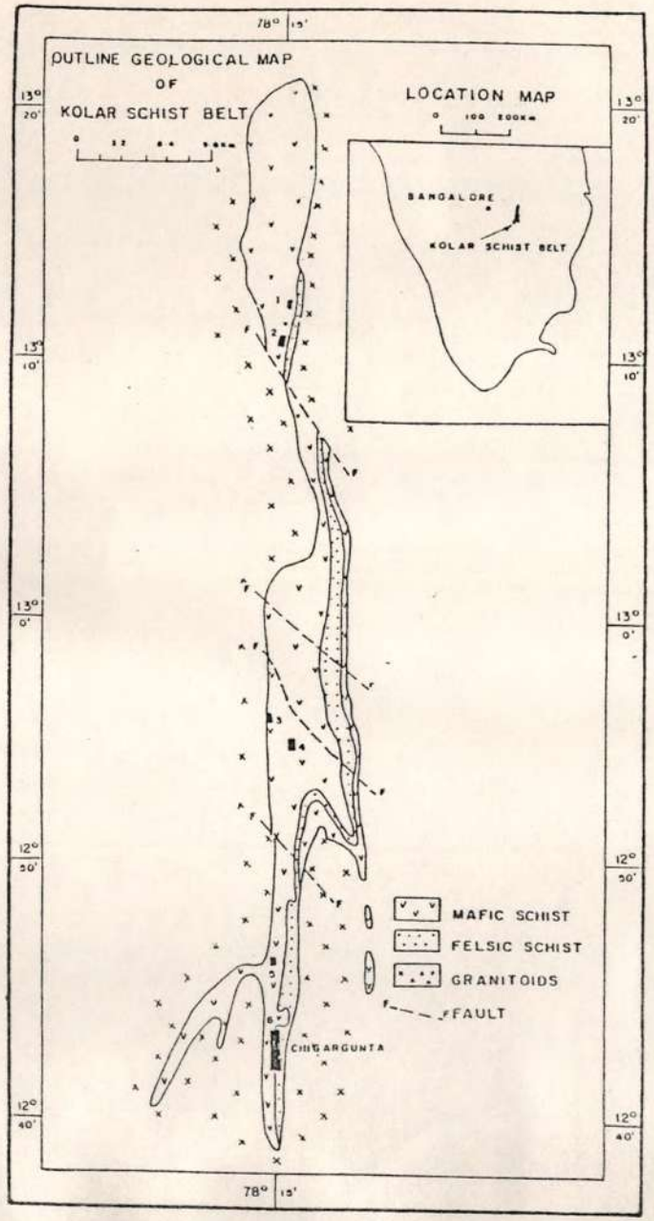
Structural control plays a vital role rather than stratigraphic and lithological controls in the formation of economically significant gold lodes in this Archaean belt.

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CONTRASTING TYPES OF GOLD MINERALIZATION IN THE 3 KM WIDE ARCHEAN KOLAR SCHIST BELT, SOUTH INDIA

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The Kolar gold deposits occur within the Archean, volcanic dominated N-S trending Kolar Schist Belt in the Dharwar Craton of South India. The belt consists of tholeiitic and komatiitic amphibolites formed from diverse mantle sources and forms a suture between two discrete late Archean terranes (Hanson et al 1988; Rajamani et al 1988). Banded iron formation and ferruginous quartzite occur as discontinuous ridges on the western margin of the belt and also as isolated lenses within the belt. In addition, the belt includes on its eastern margin, a unit of schistose felsic rocks known as the Champion Gneiss, which at places is agglomeratic with cobbles of granite, amphibolite and banded iron formation embedded in a fine grained felsic matrix. The belt is surrounded on either side by granitic gneisses.

Gold mineralization, within this 3-4 km wide belt, occurs as both stratiform-type gold-quartz-sulfide lodes and as vein-type gold-quartz-carbonate association. There are major differences between these two, in their geographical distribution, field association, mode of occurrence, mineralogy, geochemistry, gold tenor and Nd isotopes as shown in table 1. Gold-quartz-sulfide lodes occur all along the strike of the belt associated with banded iron formation within LREE depleted komatiitic and tholeiitic amphibolites whereas gold quartz calcite veins are associated with LREE enriched amphibolites which are present only on the eastern part of the belt in close proximity to the Champion Gneiss and also within the Champion Gneiss.

The gold quartz sulfide lodes are stratiform and have variable amounts of sulfides, quartz, magnetite and silicates with deformational, metamorphic structures and textures. Dominant sulfides are pyrrhotite and arsenopyrite present in varying proportions alongwith minor amounts of pyrite, sphalerite, chalcopyrite and loellingite. Epidote, diopside, tremolite, hornblende, cummingtonite, garnet and biotite are the common silicate minerals in the ore. Gold occurs as inclusions mostly within the highly deformed arsenopyrites. There is no correlation among gold content, total sulfide contents and the abundance of arsenopyrite among the lodes. The arsenic content of arsenopyrite in equilibrium with pyrrhotite and loellingite indicates a minimum temperature of equilibration $\sim$500°C, which is in agreement with the metamorphic temperature of the host amphibolites. The lodes have very low abundances of base metals inspite of their higher sulfide contents. Gold concentration is low and variable. REE abundances in general are low and are enriched both in LREE and HREE with strong positive Eu anomaly. REE abundances and the magnitude of Eu anomaly are variable among the different lodes, probably implying differing physical conditions of ore deposition and/or ore fluids. REE abundances do not correlate with gold contents. However, lodes

Table 1. Some characteristic features of the two types of gold deposits in the Kolar Schist Belt

	Gold-Quartz-Sulfide Lodes	Gold-Quartz-Calcite Veins
Host Rock	BIF within Amphibolites	Eastern Amphibolites and the Champion Gneiss
Mode of Occurrence	Stratiform lodes	Fracture filled veins
Mineralogy	Quartz, sulfides, oxides & mafic silicates	Mostly quartz, with variable amounts of calcite, tourmaline, scheelite, albite & biotite.
Sulfide Content	5 - 25 Volume %	Trace (< 1 Vol. %)
Arsenopyrite Content	< 1 - 10 Volume %	Trace
Au Content	1 - 5 ppm	~10 - 100 ppm
Base Metal Content	1 - 300 ppm	1 - 150 ppm
Ni Content	1 - 100 ppm	50 - 250 ppm
Cr Content	1 - 225 ppm	100 - 1200 ppm
REE	Generally low and variable abundances. Concave upwards with positive Eu anomaly.	LREE enriched No Eu anomaly.
Epsilon Nd at 2600 Ma	+ 0.3	+ 2.8
Source of Fluids	Sea water derived hydrothermal solutions.	Metamorphic and magmatic fluids

with higher base metals have higher abundances of REE, whereas lodes with higher arsenopyrite content have lower REE concentrations. These REE patterns are not comparable to those of host amphibolites.However, these are somewhat similar to those of associated banded iron formation. One sample of the sulfide lode has an epsilon Nd of +0.3 at 2600 Ma, which is significantly different from that of the host amphibolites (+2 to +8). This indicates that the REE in the ore were not exclusively derived from the amphibolites.

The gold quartz calcite deposits are fracture filled veins with narrow alteration zones and include fragments of wall rock. The veins show effects of intense shearing. They consist dominantly of quartz with minor calcite, biotite, tourmaline, albite, scheelite and traces of sulfides. Gold occurs in native form in association with quartz. The veins have considerable depth persistance with changes neither in the gold tenor nor in the alteration type and intensity. They have higher abundances of Au, Cr, Ni and W relative to sulfide lodes. Similarly the REE geochemistry is distinctive with high LREE and low HREE abundances and without any Eu anomaly. This REE pattern is rather similar to that of the host amphibolites as well as that of the Champion Gneiss. This sample has an epsilon Nd of +2.8 at 2600 Ma, which is similar to that of the eastern komatiitic amphibolite. Galena samples from the veins analysed by Venkatasubramanian et al (1977) and Chernyshev et al (1980) for their Pb isotopes fall along the trend defined by the K-feldspar Pb from the Western Gneisses by Krogstad et al (1988) on the Pb-Pb diagram. It is possible that the Champion Gneiss magma could have provided the necessary heat as well as fluids for the economically more important gold quartz deposits. Just as the REE, at least a part of the Au may have been derived from the host amphibolites.

The stratiform nature, association with banded iron formation and the absence of extensive wall-rock alteration indicate a syn-sedimentary deposition of gold sulfide ores before metamorphism. Precipitation of auriferous sulfide lodes could be related to exhalation of hydrothermal solutions generated by the interaction of sea-water with seafloor volcanics. The absence of systematic variation in mineralogy and geochemistry among the sulfide lodes in the belt indicates that several exhalative systems were probably responsible for the different lodes in the belt.

On the other hand, the field, geometric, textural and alteration observations on the vein deposits suggest that the entire vein system was open at the same time, probably due to volumetric inflation of pressurized fluids on a massive scale. The presence of significant quantities of calcite and the LREE enriched nature of the veins indicate the involvement of fluids containing a significant proportion of CO_2. The CO_2 contribution to the fluids could be due to amphibolite facies metamorphism of carbonate bearing chemical sediments and/or from the fluids emanating from terranes undergoing granulite facies metamorphism now occuring further south of the Kolar Schist Belt. The gneisses east of the belt have age and isotopic systematics that are similar to those of the charnockite occuring further south (Krogstad, personal communication).

Thus, the two types of gold mineralization in the 3-4 km wide Kolar belt seem to have been formed by completely different processes.

STYLE, CONTROLS AND TIMING OF GOLD MINERALIZATION IN THE LAKE OF THE WOODS GREENSTONE BELT, NORTHWESTERN ONTARIO, CANADA: EVIDENCE FOR A PLUTONIC CONNECTION

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Greater than 95% of the known gold mineralization in the Lake of the Woods Greenstone Belt occurs within 3.5km of syn- to late-tectonic, felsic to intermediate intrusions, which range in size from small stocks and dikes to large batholith complexes located at the margins of the belt (Figure 1). The gold-bearing vein systems are hosted in ductile and brittle permeable shear or fault zones. Some of these were formed during regional, northwesterly directed transpression at approximately 2709 Ma (Stott et al., 1987); however, many have formed in direct response to the emplacement of the granitoid plutons. In some cases the emplacement of the plutons reactivated shears initiated by transpression. The permeable structures are best developed along pre-existing zones of structural anisotropy (ie. early faults, or lithological contacts).

Although gold mineralization is structurally controlled, there is a pronounced lithostratigraphic control. Stratigraphy in the Lake of the Woods Greenstone Belt is complex. The belt is bisected by a major fault (the Barrier Island Fault) across which correlation of stratigraphy is equivocal (Figure 1). Most of the gold occurrences lie north of the fault; nevertheless, stratigraphic sequences north and south of the fault are physically and chemically similar (Figure 1). Over 95% of the known gold mineralization is hosted by iron-rich mafic to ultramafic, komatiitic and tholeiitic rocks or rocks which intrude them (Figure 1). Moreover, six of the eleven past producers in the belt occur within the iron-rich upper cycle of the Bigstone Bay group. As suggested by numerous workers (eg. Phillips et al. 1984), such iron-rich rocks most likely provide a suitable chemical trap for the destablization of gold-bearing bisulphide complexes.

Unequivocal cross-cutting field relationships and detailed petrographic studies, combined with precise U-Pb zircon geochronology, constrain the gold mineralizing event to peak- to

post-peak contact metamorphism, coeval with the waning stages of granitoid emplacement and regional transpression. Gold-bearing vein systems transect and are cut by plutonic rocks which are approximately 2709 Ma, at least 15 million years younger than the youngest volcanic rocks dated in the northern part of the belt. At some locations vein-related alteration overprints amphibolite-facies minerals related to the emplacement of granitoid plutons.

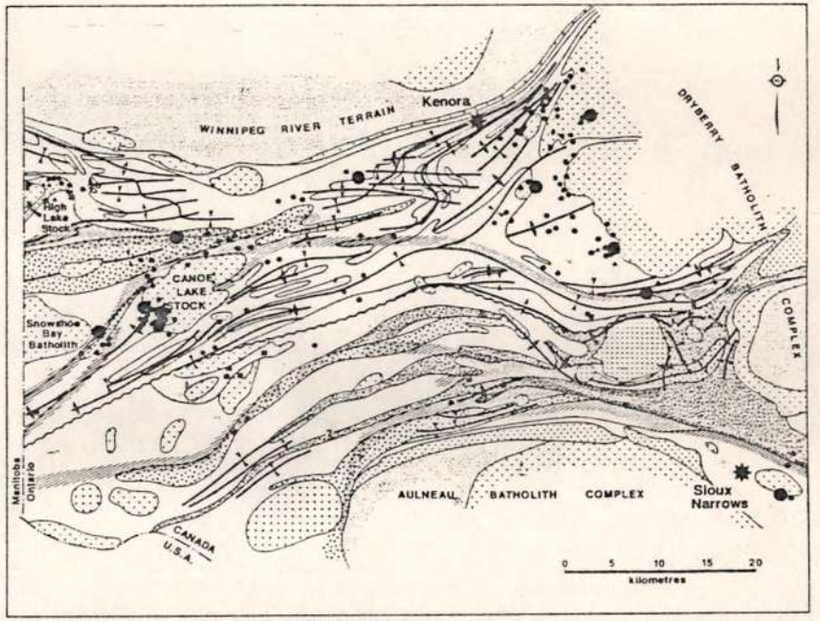


Figure 1. Simplified geology of the Lake of the Woods Greenstone Belt. (N) and (S) in the legend indicate north and south of the Barrier Island Fault respectively.

Petrographic, microprobe, geochemical and fluid inclusion studies of both regional metamorphic and alteration patterns, and gold-related alteration indicate that gold was deposited at pressures of 3 ± 1 kilobars, and at temperatures ranging from 250 to 400°C.

The mineralizing fluid was low in salinity, alkaline to slightly acidic, and generally enriched in water, carbon dioxide, potassium, silica and sulphur. These characteristics are consistent with devolatilization related to contact metamorphism and/or a magmatic source. Most of the gold occurrences in the Lake of the Woods Greenstone Belt occur outside of, or straddle the amphibolite-facies, contact metamorphic aureoles which border late-tectonic intrusions; however, the lack of gold mineralization associated with other contact metamorphic aureoles in the belt, such as that related to the Winnipeg River Terrain, suggests that a metamorphic source alone is unlikely.

Detailed studies in and around the High Lake and Canoe Lake Stocks have shown that gold mineralization occurs within structures which are peripheral to, but which appear to have formed at the same time as, porphyry-style, copper and molybdenite mineralization and associated potassic alteration. The two types of mineralization could not be distinguished on the basis of fluid inclusion studies, except that a larger population of two phase (CO_2 - H_2O) inclusions was observed within the porphyry-style mineralization.

Clearly, the combined temporal, spatial, structural, and analytical evidence indicate that gold mineralization in the Lake of the Woods Greenstone Belt is directly related to the emplacement of syn- to late-tectonic plutons.

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DEVELOPMENT OF GOLD-BEARING STRUCTURES IN THE ARCHEAN: THE ROLE OF GRANITIC PLUTONISM

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In the Superior Province of the Canadian Shield, shear zones can be subdivided into two main groups: 1) major transcurrent and dip slip shear zones and faults which formed along pre-existing zones of anisotropy during a set of northwesterly directed compression events between 2709 and 2686 Ma (Stott et al., 1987); and 2) shear zones within, or marginal to, contact strain aureoles that formed during the ascent and expansion of coeval granitic plutons. Numerous, well documented gold deposits are associated with Group 1 and less well documented deposits are associated with Group 2. We present our observations on the types of structures associated with the latter.

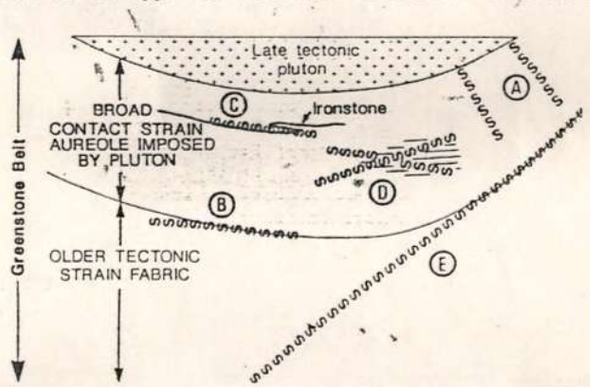


Figure 1. Schematic surface plan of the contact strain aureole and the five major gold-bearing shear zone types (A through E) which result from the ascent and expansion of granitic plutons.

In the Uchi and Wabigoon Subprovinces, some granitoid intrusions have produced broad contact strain aureoles in the surrounding supracrustal rocks (Figure 1). Significant gold mineralization occurs in permeable shear zones or fault zones within, or close to, the contact strain aureoles of these granitic intrusions (Figure 1). The development of many of these permeable zones can be attributed to the intrusive event. Such structures can be subdivided into five types (Figure 1): A) rotational shear or fault zones which strike at a high angle to the pluton margins; B) shear zones defining the outer margin of the contact strain aureole; C) stratigraphically controlled shear zones and associated folds, localized within, or marginal to, units of marked ductility contrast with their adjacent

rocks; D) conjugate shear zones formed at a low angle to the principle schistosity; and E) pre-existing regional structures which have been reactivated.

Type A, B and E shears or faults are developed during the initial doming and continued ascent of the pluton (Figure 1). Types C and D develop as a result of flattening, likely during the expansion of the pluton by continued injection of magma into the core of the pluton.

Examples of these structures include:

Type A: Steeply dipping, narrow shear zones, located at the southwest flank of the Canoe Lake Stock in the western Wabigoon Subprovince, are oriented at a high angle to the margins of the stock. These shear zones delimit wedges of supracrustal rock which were uplifted and rotated away from the intrusion while it was rising. Gold-bearing quartz veins, and silicified, pyritiferous zones occur within the shear zones at a number of occurrences (Smith and Thomas, 1986).

Type B: Auriferous veins occur in a broad shear zone which is located at the outer margin of a contact strain aureole surrounding the Dobie Lake Batholith, in the Meen-Dempster Lakes Belt of the central Uchi Subprovince (Stott and Wilson, 1986). This zone is interpreted as a one of differential displacement separating the subsided and flattened domain of contact strain from the unaffected supracrustal rocks to the south (Stott and Brown, 1986).

Type C: Type C structures occur near Pickle Lake in the Uchi Subprovince where gold mineralization at the Dona Lake Deposit is hosted in a folded, sheared and sulphidized ironstone unit (Cohoon, 1986). This deformation is part of a broad zone of strain within the greenstone belt caused by the emplacement of the Ochig Lake Pluton (Stott and Brown, 1986).

A second style of Type C structure occurs near the southwest flank of the Canoe Lake Stock (Smith and Thomas, 1986). Here, gold-bearing quartz veins of the Mikado Mine are hosted within en echelon flexural shears which formed along lithological contacts. These units are oriented at a high angle to the stock's margin and were folded during the expansion, or ballooning, of the intrusion. Each unit flexed independently, and strain was concentrated along the contacts.

Type D: The Pickle Crow deposits in the Uchi Subprovince occur within the contact strain aureole of the Seach-Achapi Lakes granitoid complex (Stott, 1986). These deposits comprise gold-quartz veins that occur along the length of narrow shear zones. The shear zones strike at a low angle to the schistosity and form conjugate sets. Generally one member of the conjugate set is dominant and hosts the veins (Stott and Brown, 1986).

Type E : The Shoal Lake Deformation Zone trends approximately tangential to, and dips steeply toward, the Snowshoe Bay Batholith, located near the Ontario-Manitoba border in the western Wabigoon Subprovince. The shear zone was initiated during a regional compression event, along pre-existing zones of anisotropy (Smith,

1987). During its ascent, the batholith uplifted the rocks closest to it and the resultant strain was concentrated within the deformation zone. Riedel shears and other gold-bearing permeable structures formed during this stage of deformation (Smith, 1986; 1987).

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THE ROLE OF LAYERED MAFIC/ULTRAMAFIC INTRUSIONS AS HOSTS TO GOLD MINERALIZATION IN THE EASTERN GOLDFIELDS, WESTERN AUSTRALIA WITH PARTICULAR REFERENCE TO THE MOUNT PLEASANT SILL

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Mapping in the Siberia - Ora Banda - Broad Arrow area has established a similar stratigraphy (the Ora Banda sequence, Witt, 1987) to those already described for the Kalgoorlie and Kambalda areas, particularly with respect to the volcanic units. The Ora Banda sequence comprises high-Mg and tholeiitic basalts, overlain successively by komatiitic volcanics, tholeiitic basalt and epiclastic and felsic to intermediate volcaniclastic sediments. This sequence is overlain unconformably by sandstone and conglomerate. D_2 folding of the Ora Banda sequence about NNW-trending fold axes has produced the Kurrawang Syncline and adjacent Goongarrie - Mt Pleasant anticline. Fold axes plunge 10-20° south. The core of the anticline is occupied by a composite granitoid dome. The east limb was attenuated during a major sinistral (D_3) wrench faulting event. D_3 faulting has generated a 0.5-2 km wide zone of intense deformation and carbonation (the Bardoc tectonic zone) which separates the Goongarrie - Mt Pleasant anticline from a similar structure to the east (the Scotia - Kanowna anticline). Strain during D_2, and particularly D_3, was markedly inhomogenous producing high strain zones (e.g. the Bardoc - Broad Arrow synform between the two domes) which anastamose around isolated blocks characterized by low strain (e.g. the Ora Banda block). Weak dextral (relaxation?) wrench faulting and late, dominantly vertical movement (D_4) post-date D_3. Horizontal deformation (D_1, e.g. Archibald et al., 1978) has not been identified in the area. D_2 to D_4 are related to progressive shortening in response to east-west transpressional tectonics.

Komatiitic to tholeiitic layered mafic/ultramafic sills form an important component of the Ora Banda sequence. These include the Ora Banda sill (16-18% MgO), the Mt Pleasant sill (11% MgO) and the Mt Ellis sill (8% MgO), of which only the Mt Pleasant sill is a significant host for gold mineralization. Although this intrusion has hosted only about 7% of total gold production in the Siberia - Ora Banda - Broad Arrow area, it is nevertheless an important host rock at several mining camps, including those described below. Tholeiitic basalts are the major host rocks in the area (56%); various host rocks within the Bardoc tectonic zone yielded about 20% of total gold production.

The Mt Pleasant sill intrudes the Bent Tree Basalt, is approximately 550 m thick and crystallized from a single pulse of high-Mg basaltic magma. Fractionation initially produced a 100 m thick, cumulate-textured zone of peridotite and pyroxenite at the base of the sill. Subsequent fractionation, caused by crystallization predominantly at or close to the floor of the remaining magma chamber, produced an iron-rich, granophyric quartz-gabbro, approximately 50 m below the roof of the sill. Geochemical evidence and the presence of

primary amphibole at the base of the sill, suggest contamination of the melt by alkalis and water from enclosing interflow sediments. Contamination may have had several important consequences, including lowering of melt viscosity which would promote convection and aid fractionation of the melt, and lowering of liquidus temperatures below the roof of the sill, thus promoting bottom-dominated crystallization.

The Mt Pleasant sill shares a number of petrographic and geochemical features with other mineralized mafic/ultramafic sills at Kalgoorlie (Golden Mile Dolerite), Celebration (Triumph gabbro) and Kambalda (Defiance Dolerite), including the development of an iron-rich quartz-gabbro in the upper part of the sill, the presence of primary amphibole at the base of the sill, and flow and pegmatoid textures in the middle to upper part of the sill. The iron-rich composition of the quartz-gabbro in these intrusions promotes deposition of gold from thiocomplexes in hydrothermal solutions and the formation of iron sulphides in wallrocks (Phillips and Groves, 1983). Mineralized sills are distinct from more magnesian sills described by Williams and Hallberg (1973) (e.g. Ora Banda sill) which crystallized entirely from the floor upwards and culminated in felsic granophyre below the roof of the intrusions, and which are generally poorly mineralized. Additionally, mineralization is commonly located at the margins of layered sills because interflow sediments facilitate emplacement of sill-like intrusions and also act as a locus for shearing during deformation.

The Golden Kilometre (GK) and Southern shoot (S) deposits at Mt Pleasant (Chapman, 1987) occur within the low-strain Ora Banda block on the western limb of the Goongarrie - Mt Pleasant anticline. Mineralization is controlled by 270°- and 240°-trending oblique structures with a strong brittle component, and minimal (30 m) displacement. Economic grades are confined to the quartz-gabbro zone of the Mt Pleasant sill, although the structures can be recognized for several kilometres east and west of the mineralized zone. Movement associated with the 270° (GK) structure is sinistral, but movement along the 240° (S) structure is unknown; timing relations between the two could not be determined. Wallrock alteration is similar to that described for the Golden Mile (Phillips, 1986) with a siliceous lode centre and quartz+/-carbonate veins surrounded by an inner 'bleached' zone of sericite-idioblastic pyrite +/-carbonate, and an outer zone of chlorite-carbonate+/pyrrhotite. Mica in the bleached zone defines a weak to moderate fabric but granophyric quartz-feldspar intergrowths are deformed only towards the centres of the lodes. Gold is concentrated in the siliceous lode centres, quartz veins and 'bleached' zone of alteration. Similar oblique structures are mineralized at Lady Bountiful, Grants Patch and Ora Banda, north of Mt Pleasant. The 240°-trending structure at Ora Banda has accommodated a small dextral and north-side-up movement. 270°-trending structures are interpreted as tensional fractures caused by regional east-west compression; 240°-lodes are probably R' structures generated by sinistral (D_3) wrench faulting.

Cashmans-type mineralization, also within the Ora Banda block, occurs at several centres located on a strike-parallel shear zone at the base of the Mt Pleasant sill. Shallowly plunging lineations, especially on quartz veins indicate predominantly horizontal movement. Orientation of quartz-feldspar porphyries intrusive into the shear zone, and S-shaped drag folds in porphyries and sediments at the base

of the sill indicate sinistral movement (during D_3). However, 'post-tectonic' leucogranite east of Ora Banda has been deformed by movement along the shear zone, indicating an extended period of activity, possibly including D_4 movement. Mineralization is associated with quartz veining in the shear zone, and attendant carbonation, pyritization and minor biotitization of the ultramafic base of the sill, footwall sediment and underlying mafic lithologies, mostly basalt. Mineralization is also associated with fracturing and pervasive sericitization and pyritization of porphyry intrusions. In the Christmas Reef area a dilational jog developed where the base of the Mt Pleasant sill enters the closure of the D_2 Kurrawang Syncline. Extensive quartz veining at this locality hosts widespread small gold workings.

Goongarrie occurs adjacent to the proposed northerly extension of the Bardoc tectonic zone, within the high strain Bardoc - Broad Arrow synform. Mineralization is associated with strike-parallel shear zones, and with NW-trending oblique faults, commonly occupied by large quartz blows. Most gold has been produced from basalts and gabbroic rocks of the Bent Tree Basalt, but shear zones at the top and base of the Mt Pleasant sill are also mineralized, with notable copper mineralization accompanying gold in the former position. Strike-parallel shears, commonly localised by interflow sediments, are 20-100 m wide zones of pervasively foliated quartz-chlorite-carbonate+/pyrrhotite schist which enclose anastomosing zones of quartz-biotite-carbonate+/pyrite schist. Gold occurs in the latter alteration assemblage, commonly associated with late quartz-carbonate veins and coarse, idioblastic arsenopyrite. The quartz blows and strike-parallel shear zones are interpreted as dilational features, and principal shear planes, respectively, formed during sinistral (D_3) wrench faulting. Best gold grades tend to occur in extensional regimes in the acute angles between shear zones and oblique faults.

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Topic 2A

ARCHAEAN CASE HISTORIES

GEOLOGY OF THE BARDOC GOLD PTY. LTD. DEPOSITS

BARDOC-DAVYHURST AREA, EASTERN GOLDFIELDS, WA

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Bardoc Gold Pty Ltd operates a 500,000 t.p.a. CIL mill at Bardoc, 50km NNW of Kalgoorlie, on behalf of the joint venturers, Aberfoyle Gold Pty Ltd and Hillmin Gold Mines Pty Ltd. The mill draws ore from three open cuts; two (Excelsior and Zoroastrian) are located at Bardoc, while the third (Lights of Israel) is at Davyhurst, 80km to the NW.

The Bardoc greenstone belt segment forms part of the Norseman-Wiluna Belt in the Archean Yilgarn Block. The area occupies the eastern limb of a regional south-plunging syncline. The major stratigraphic units from base to top are tholeiitic basalt, komatiitic ultramafics, and clastic sediments. The latter correlate with the Black Flag Beds to the south (W.Witt pers. comm.). The apparent stratigraphic thickness is approximately 3km, with some thickening of the sequence due to conformable mafic intrusions. The metamorphic mineral assemblages present indicate upper greenschist to lower amphibolite facies conditions. Foliation and bedding planes strike near north-south, with variable, generally steep dips. Strike slip shearing, particularly at major lithologic contacts, local tight folding and late WNW and NE-trending cross faulting are the main styles of deformation.

The Excelsior deposit, the main resource at Bardoc, is localised in a major regional ductile shear zone developed in sheared mafic-ultramafic komatiitic rocks with minor interbedded shale and felsic porphyry intrusives, bounded to east and west by less altered ultramafics. Due to the intense alteration, much of the host package is now represented by quartz-sericite-carbonate schist with widely varying bulk chemistry. The ore zones are hosted within the Excelsior Shear, which thickens to 80m locally due to the presence of a NNW-trending splay shear off the the main north-south shear. The depositis overlain by a near continuous 1 - 2m thick layer of calcrete. This, and local pisolitic ironstone remnants are enriched in gold, while the underlying 15 - 20m is heavily leached with gold grades well below average. The base of oxidation is generally 30 - 50m, but several of the mineralised shears are oxidised to greater than 100m depth.

The primary gold mineralisation is enclosed by a zone of intense quartz-sericite-carbonate alteration, with plan dimensions of 400 x 150m. The composition of the mica, carbonate, and accessory sulphide and oxide phases is very consistent. The most characteristic phase is a green chromian muscovite (fuchsite) with 0.2% Cr_2O_3.

This is associated with disseminated spinel which approaches chromite in composition. The carbonate, although displaying several textural variants, is uniformly ankeritic dolomite (70% dolomite 30% ankerite). The sulphide assemblage consists of two populations, one disseminated in the wallrock schists, and the other in cross-cutting quartz veins. The former consists of fine grained pyrite + gersdorffite ± chalcopyrite ± ?bravoite ± niccolite, making up 2.5% of the rock. The vein mineralogy in contrast consists of coarse grained, irregularly distributed pyrite + arsenopyrite ± sphalerite ± galena. The bulk of the visible gold and gold-bearing assay intervals are associated with quartz veining, and geochemically there is a strong positive correlation between gold and lead, and weaker gold/tungsten and gold/arsenic correlations.

The Zoroastrian deposit, located 800m west of Excelsior, consists of auriferious quartz veins along zones of brittle fracturing in a 300m thick tholeiitic dolerite (Zoroastrian Dolerite) intruded along the sheared contact between ultramafics and the Black Flag Beds. The dolerite is weakly foliated, locally quartz-bearing and granophyric, and cut by a 30m thick WNW-trending unaltered mafic dyke thought to be related to the late Archean Widgiemooltha dyke suite.

The Main Lode, which contains more than 90% of the defined ore resource, is made up of a series of en echelon quartz lodes up to 2m thick within a 10 - 15m wide zone which strikes north-south and dips 45 - 50°W. The lode zone has been traced over 700m, but economic mineralisation is restricted to the northern 250m. A zone of easterly-dipping sheeted quartz veins which make up a significant portion of the ore is developed in the immediate footwall of the lode zone. The Main Lode and dolerite are terminated in the north by a WNW-trending fault zone with apparent sinistral offset.

The dolerite is generally weathered to 40m depth, with an inferred gold-depleted zone in the upper 15m, and some supergene enrichment below this level. In the primary zone, visible alteration is restricted to within a few metres of the Main Lode, and adjacent to the margins of the footwall veins. The veins consist of quartz (>90%), ankerite, and minor chlorite and graphitic material. Carbonate, chlorite, pyrrhotite and minor sericite are the main alteration minerals in the adjacent wallrocks. The primary sulphide assemblage in the veins is dominated by arsenopyrite with minor pyrite, sphalerite and galena. Gold is generally located along grain boundaries of, or cracks in, arsenopyrite crystals, or with rare aggregates of base metal sulphides. As at Excelsior, arsenic, lead and tungsten values show positive correlations with gold.

Davyhurst is located in the Coolgardie - Mt Ida greenstone belt. The Lights of Israel gold deposit is one of three recently developed open cut mines at Davyhurst. Mineralisation is hosted by a quartz-biotite schist zone developed in tholeiitic metabasalts which have been metamorphosed to the amphibolite facies. Formation of the schist zone and contained gold mineralisation postdates the peak of metamorphism, but predates the last major phase of folding.

Bicentennial Gold 88, Melbourne, May, 1988

The zone strikes NNE, dips to the west at between 10° and 40°, and has been traced along strike for over 1km. In the south, it is truncated by a NW-trending fault, while to the north the zone thins and gold grades decrease.

Highest gold values are associated with quartz-rich lenses in the schist which plunge to the NNW at 20° to 35°. Extensive redistribution of gold has taken place in the upper 15 - 20m of the deposit. Within the main ore zone, oxidation may extend to 60m or more, while in the wallrock metabasalts it is generally around 30m. Primary sulphide content is low, typically 1 - 2% pyrite, with very low levels of base metals, arsenic and tungsten.

GLADSTONE MINE, ZIMBABWE: GEOLOGY, GEOCHEMISTRY AND CONTROLS ON MINERALIZATION.

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Gladstone Mine, Arcturus District, approximately 29km east of Harare, is situated in the southern limb of the Harare Greenstone Belt (Fig.1). Gold mineralization occurs intermittently over a strike length of approximately 12km, in a narrow, northwards-dipping zone of intense deformation. The deformation zone, which is expressed at surface as a 500m-wide negative topographic feature, strikes parallel to the regional east-west structural trend. Country rocks are Bulawayan (c.2700 Ga) massive and pillowed basalts, ultramafic flows and felsic units metamorphosed at lower Amphibolite facies.

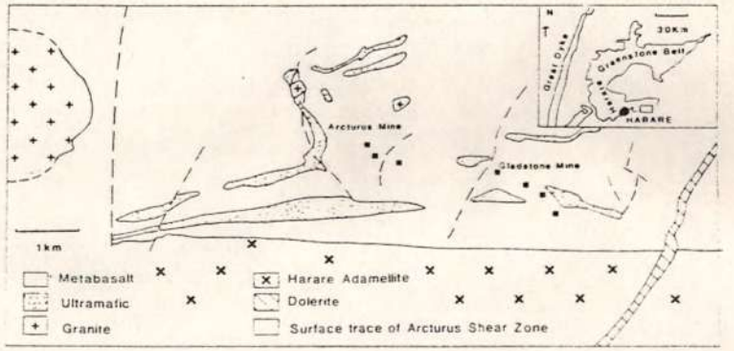


Figure 1.

Gladstone mine includes three types of mineralization;
1. The Gladstone East (GE) orebody is a 1-2 metre-wide zone of disseminated pyrrhotite mineralization hosted by highly strained and altered metabasalts. Visible alteration extends up to 15m into the wall-rocks. The GE orebody is typical of the dominant style of ductile shearing which accompanies mineralization in the Arcturus deformation zone.
2. The Main Reef is a complex quartz vein 150m along strike from the GE orebody, located at the contact of mafic and ultramafic rocks. Only the mafic host shows visible alteration. Sheared selvages of altered wall rocks are abundant within the quartz vein.
3. The Buck Reef is a large, folded and banded, low-grade quartz vein, 50m in the footwall of the GE orebody. The host rocks are ultramafics containing chlorite and randomly oriented tremolite. Little wall-rock alteration is visible.

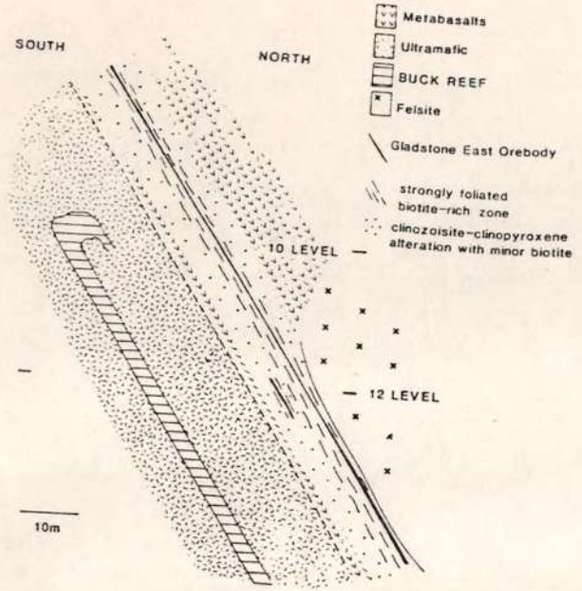


Figure 2. Schematic cross section, Gladstone Mine

Wall-rock alteration in metabasalts: The metabasaltic wall-rocks of both the GE and Main reefs are characterized by strong potassium enrichment which is coincident with increasing strain towards the orebodies. Biotite alteration of hornblende extends at least 15m into the wall-rocks, forming strong biotite-rich partings. The retrogression of synkinematic, poikilitic hornblende to actinolite accompanied the influx of aqueous fluids into the shear zone. Extreme K-metasomatism and replacement of the mafic rocks resulted in sharply defined horizons in which microcline is the principal potassium phase. Such horizons occupy the regions of greatest shearing and contain the highest gold values. Lower grade sections are characterized by a gradational change from a wall-rock mineralogy of hornblende, actinolite, plagioclase and biotite to a biotite-microcline-pyrrhotite ore assemblage.

Concomitant with K (and Ba) introduction from the externally derived fluids, Na, Ca and Sr were removed into the less strained wall-rocks as a result of the replacement of plagioclase by microcline and quartz. Ca metasomatism resulted in the formation of 'bleached' bands of coarse clinopyroxene (Di_{50-80}) and clinozoisite in the wall-rocks of the GE orebody.

The chemistry of the amphiboles changes from the wall-rocks into the orebody. This is most abrupt at the margin of the highest grade zones of the GE orebody (Fig.3). The mineralogical transition from amphibolite wall-rocks to microcline-pyrrhotite orebody is accompanied by a change in amphibole composition from tremolite (50-60) to tremolite (90-94) A 4cm-wide transition zone contains increasing amounts of microcline and pyrrhotite, and increasingly tremolitic amphiboles. In the highest grade sections biotite is absent from the transition and ore zones.

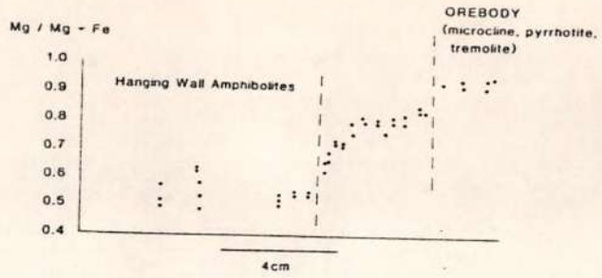


Figure 3.

The loss of iron from the immediate wall-rocks is accounted for by the introduction of sulphur-bearing fluids which stripped iron from the metabasalts to form sulphides. Au-sulphur complexes would be destabilized by this reaction, leading to deposition of gold in association with iron sulphides.

Undoubtably biotite, formed by potassium metasomatism of Fe-bearing amphiboles in metabasalts, enhanced the ductility of these rocks and precipitated the development of shear zones. In contrast, ultramafic rocks within the deformation zone were unreactive to the k-rich fluids and responded to shear stress by deforming in a brittle manner. The three styles of mineralization in Gladstone Mine were therefore the result of the response of different rocks types to the same deformation and hydrothermal event. The Main Reef, which shows biotite-rich alteration and ductile shearing in the mafic hanging wall, and quartz veining as a result of the brittle deformation of the ultramafic footwall, is transitional between the structural extremes exhibited by the GE and Buck Reef orebodies.

TTG(TONALITE-TRONDHJEMITE-GRANODIORITE) TERRANE HOSED ARCHEAN AU-QUARTZ VEIN MINERALIZATION, RENABIE MINE AREA, WAWA, N. ONTARIO, CANADA.

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Introduction, Location and General Geology

The Renabie mine, located near Wawa, N. Ontario, Canada, is an unusual example of Archean Au-quartz vein mineralization because:

(1) Mineralization lies outside the confines of a greenstone belt, being hosted entirely within tonalitic/trondhjemitic marginal components of the areally extensive tonalite-trondhjemite-granodiorite(TTG) material comprising the Wawa Domal Gneiss Terrane (Fig. 1).

(2) Mineralization is significant with past-production/current reserves of 5.5 m tonnes at 6.6 g/t Au and 2.1 g/t Ag.

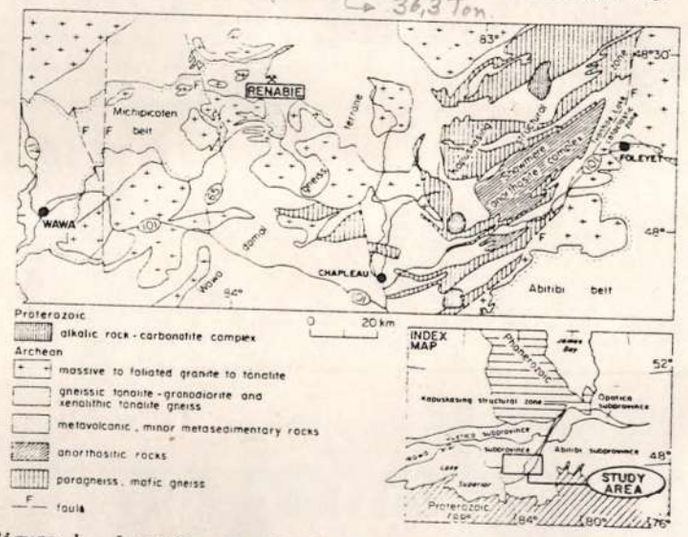


Figure 1. Location map showing regional geology.

Au-quartz vein mineralization is located to the east of a NW trending, steep SW dipping metavolcanic/TTG contact (Fig. 2). The latter shows good intrusive relationships, with local tectonization. A regional metamorphic "S" fabric, concordant with this contact is developed in the metavolcanics and intrusive phases - but with the easterly, tonalitic phase showing qualitatively less strain.

Major vein structures form steep S dipping, E-W trending and steep SW dipping, NW trending associations, both of which crosscut

regional "S" fabric, but are themselves crosscut by late lamprophyre and diabase dykes. Orebodies exhibit steep WSW-SW plunges parallel to the dips of major lithological contacts, may achieve dimensions of up to 220 m by 27 m in horizontal section, and in the Renabie main zone are known to extend to depths greater than 4500'.

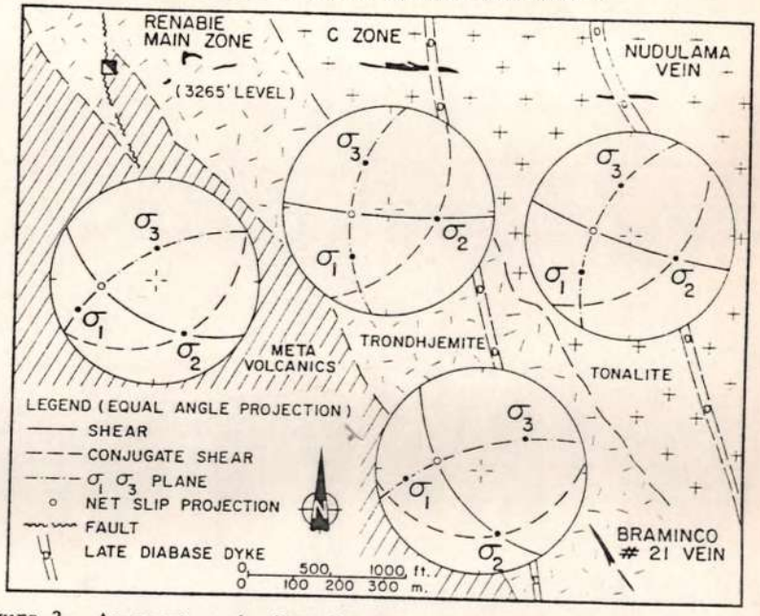


Figure 2. Au-quartz vein distribution and σ_1 orientations for hosting shears.

Structural Control

Au-quartz veins are confined to brittle-ductile shear zones which rotate and crosscut the NW-NNW trending regional "S" fabric and show three dominant orientations; W-WNW and NW trending structures with moderate to steep SW dips, and less well developed SW trending structures with moderate to steep SE dips.

Net shear on these orientations is variably constrained from a variety of kinematic indicators including:

(1) A shear foliation showing progressive rotation and intensification with respect to regional foliation outside the shear zone, reflecting increasing finite shear strain.

(2) Shear fabric relationships including C-S and C-C' fabrics.

(3) A mineral stretch lineation defined by elongate quartzo-feldspathic domains.

Displacement is oblique, reverse, sinistral on all orientations of shear, though in some examples of SW trending structures, displacement may have been minimal or may even exhibit a weak dextral horizontal component. In addition, SW trending structures observed in the structurally complex zone between surface and the 375' level

appear to be folded sigmoidally, defining a sinistral horizontal component of shear, and are displaced in the same sense by later WNW oriented shears. These observations suggest that at least some of the SW oriented structures may represent early tensional veins which opened parallel to σ_1.

Structural analysis (Fig. 2), based on the assumption that given the extremely dilatant nature of the host shears (as evidenced by impressive mineralized widths), then the maximum principle stress (σ_1) is most likely to bisect the acute angle between the host shears and their inferred conjugate orientations, indicates that σ_1 during shear deformation was directed approximately towards the W-SW at a moderately steep dip. This intepretation would;

(1) Account for the interpreted shear displacements.
(2) Suggest that, in the light of the NNW-NW oriented, fairly steeply SW dipping regional "S" fabric, the stress field responsible for shear deformation was significantly reoriented with respect to that in effect during regional "S" fabric development.

Relative Timing of Mineralization and Shear Deformation

A number of features indicate that the shear zone hosted veining and associated mineralization is variably strained, and was thus introduced throughout all stages of deformation. These features include;

(1) The prolate, W-SW plunging nature of cm to m scale, individual quartz lenses comprising the veins, parallelling the plunge of mineral stretch lineations within the host shear.
(2) Minor folding and boudinage of quartz veining within mineralized zones.
(3) The granular, recrystallized nature of the quartz.
(4) Strain features such as brecciation of pyrite, and inequant prismatic or tabular crystal habits exhibited by pyrite, the latter suggesting syn-deformational growth.

In addition, it is the preferred orientation of alteration minerals, in particular sericite, which to a large extent defines the deformation fabrics within shear zones, indicating likely syn-deformational growth. Strain softening processes may also have been involved, as shown by higher finite strains indicated by C and C-C' fabrics in zones of most intense alteration, compared with C-S fabrics in less altered zones. This process would require fluid activity to be synchronous with deformation.

Mineralization Characteristics

Mineralization may comprise massive, white quartz with few other mineral phases and poor Au values, but more typically forms spectacular "banded" veins comprising alternating cm to m scale quartz veins and intensely altered mm to cm scale elongate wallrock foliae, defining a planar fabric concordant with C fabric within the host shear. This geometry is interpreted to be the result of syn-deformational crack-seal processes, with the orientation of mineralized hydraulic fractures being controlled by the anisotropy represented by the C fabric in the hosting shear. Fabric has probably been accentuated by superimposed ductile shear. The elongate, cm scale, fabric

parallel nature of pyrite, carbonate and sericite selvages within the veins may also reflect a primary depositional habit with superimposed shearing. Marked inflation of host shears by iterative fluid injection associated with this crack-seal process has generated impressive mineralized widths. Associated alteration includes extensive silicification, sericitization, carbonatization, pyritization, hematization and anhydritic alteration.

In thin section, mineralization shows variation in style and intensity of deformation. Quartz shows inhomogeneous ductile (plastic) strain with narrow, recrystallized, high strain domains interspersed with broader, coarser grained, lower strain domains. Grains often show weak to moderate elongation, discontinuous extinction, deformation bands and serrated boundaries. In contrast, pyrite, comprising ~1.5% of the vein material, frequently shows a brittle fracture response to deformation, typically occurring as elongate strings of subhedral to anhedral grains.

Chalcopyrite, galena, tellurides and associated free Au (up to ~80 μm) appear paragenetically coeval but together exhibit consistently paragenetically later positions relative to pyrite. Typical habits are;

(1) Rimming pyrite.
(2) Filling fractures within brittly deformed pyrite.
(3) Filling radial facture systems within quartz, with fractures focussed around more competent pyrite grains.
(4) Filling fracture systems in gangue, variably continuous and frequently parallel to subparallel with fabric in the vein.
(5) As solid inclusion trails representing healed, mineralized fractures.

Such features suggest that chalcopyrite, galena, tellurides and Au occupy various brittle dilational sites which developed in response to hydraulic fracture. These sites may represent;

(1) Primary depositional sites.
(2) Secondary depositional sites due to solution remobilization and/or remobilization in the solid state (esp. ductile minerals) over short distances during shear deformation.

Au occurs predominantly as complex intergrowths with tellurides such as altaite(PbTe), hessite(Ag_2Te) and petzite (Ag_2AuTe), also commonly with galena and, to a lesser extent, with chalcopyrite.

Stable Isotope Geochemistry

$\delta^{34}S$ values for pyrite associated with main stage Au mineralization at Renabie are strongly fractionated ($\bar{x}$ = -5.7 ± 0.9 °/oo; 1σ, n = 8), with pyrite depleted in ^{34}S. Main stage anhydrite is correspondingly enriched ($\bar{x}$ = 11.4 ± 0.9 °/oo; 1σ, n = 8). These data, together with the abundance of hematite, reflect the oxidised nature of the system. Possible mechanisms include oxidation of reduced Au-bearing fluids by loss of volatile, reduced species during phase separation.

$\delta^{13}C$ values of carbonate associated with main stage Au mineralization define a narrow range of 1.5 °/oo and a mean of -4.2 ± 0.2 °/oo (1σ, n = 14). $\delta^{13}C$ values for disseminated/veinlet-fill, secondary carbonate from least altered tonalite spatially distant from shearing or mineralization, are closely comparable at -4.7 ± 0.9 °/oo (1σ, n = 6), suggesting a relationship between the fluids

responsible for main stage Au mineralization and more pervasive fluids active within the host tonalite. This is corroborated by the similarity in $\delta^{18}O$ values exhibited by the main stage carbonate ($\bar{x}$ = 8.8 ± 0.8 °/oo; 1σ, n = 14) and the secondary carbonate associated with least altered tonalite ($\bar{x}$ = 8.1 ± 1.2 °/oo; 1σ, n = 6). These fluids may comprise retrograde metamorphic fluids, autometasomatic fluid of magmatic origin, fluids which diffused away from the vein zone or a combination of these.

The range of $\delta^{13}C$ values observed is consistent with magmatic derivation though mixing processes incorporating, for example, carbon derived from metamorphic processes with that of juvenile reservoirs cannot be ruled out. However, natural mixing processes are unlikely to generate the consistent, restricted uniformity of $\delta^{13}C$ data exhibited by Archean lode Au deposits.

THE TECTONIC SETTING AND PLUMBING SYSTEM OF THE GOLDEN MILE, KALGOORLIE, WESTERN AUSTRALIA.

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The Golden Mile, Australia's largest gold deposit (1160 tonnes Au to June 1987), occurs within the auriferous Norseman-Wiluna Greenstone Belt of the Archaean Yilgarn Block of Western Australia. The deposit is located within a narrow uplifted corridor of predominantly mafic-ultramafic volcanics and minor mafic intrusives.

The structure of the Kalgoorlie District (Fig.1) is dominated by early upright megascopic folds (eg. Kalgoorlie Syncline) associated with major north-north-west trending faults (eg. Boulder and Golden Mile faults) which strike parallel to the stratigraphy. The eastern limb and axis of the Kalgoorlie Syncline, a major regional structure, has been sheared-out by the Golden Mile Fault. The Kalgoorlie Syncline divides the Golden Mile into Eastern and Western Lode Systems (Woodall, 1965; Travis et al., 1971). All these early structures have been cross-cut and offset by north-south trending oblique faults which have oblique net slips. Lode-gold and gold-quartz stockwork deposits within the district are spatially associated with oblique faults. Oblique faults also contain extensive haloes of either chlorite-carbonate alteration or gold associated pervasive sericite-carbonate alteration.

The Golden Mile is a complex shear system confined between the Adelaide and Golden Pike oblique faults and developed largely within the Golden Mile Dolerite, and to a lesser extent, the upper Paringa Basalt (Fig.1). The Golden Mile Fault has juxtaposed two 700m-thick blocks of Golden Mile Dolerite at the core of the Kalgoorlie Syncline. These extensively sheared blocks represent the largest body of competent rock observed between the Adelaide and Golden Pike faults. The Adelaide and Golden Pike oblique faults (net oblique-slip displacements ~2.5-3.0km) change to a north-easterly strike and a steeper dip where they are in contact with the Golden Mile Dolerite blocks. Away from the deposit, the Golden Mile Dolerite is far less fractured and sheared despite similar oblique faulting.

The shear system is composed of many brittle zones with 10-2500m lateral and 10-1200m vertical extent and net displacements of 01-600 m. The wide spectrum of shear orientations (Fig.2) has resulted in numerous complex intersection relationships (cf. Phillips, 1986). The brittle shear zones are composed of continuous tabular zones of weakly to unstrained fine-grained gouge matrix and sub-angular clasts. Texturally they range from crush breccias to ultracataclasites. Clast lithologies include host rock, vein material and reworked shear gouge.

An early thermal metamorphic event (M1) and a later low grade metamorphic event (M2) have been recognised at Kalgoorlie. The first, equivalent to the low grade static domain described by Binns et al. (1976), is characterised by mid to upper-greenschist facies assemblages of albite-epidote-actinolite-quartz-ilmenite+-biotite in metabasic hosts and excellent preservation of relict igneous textures. Fine-grained minerals display a granoblastic texture. No foliation/s are associated with this event at Kalgoorlie (cf. Phillips, 1986). The second event involved low grade (sub-greenschist ?) metamorphism, regional (district-scale) cleavage development (S1) and small scale folding. The cleavage (S1) cross-cuts all lodes (cf. Phillips, 1986; Groves et al., 1985), including high-grade "green leader" lodes, and resulted in textural modification of earlier

brittle deformation features. Cleavage development was weak and associated with white mica recrystalisation and minor small-scale folds in metasediments. This second metamorphic event is unkown outside of the Kalgoorlie District.

Regional carbonation (CO_2 metasomatism) in the district converted earlier mid-to upper-greenschist metamorphic assemblages in mafic host rocks to chlorite-carbonate-albite-quartz-rutile-magnetite+-sericite assemblages (Bartram,1969; this abstract). The Golden Mile Dolerite is pervasively chlorite-carbonate altered. Extensive alteration and veining associated with regional carbonation and later cross-cutting lode-gold mineralisation was synchronous with brittle shearing. Regional carbonate alteration and lode-gold mineralisation occur as haloes within and around shears, veins or dilationally brecciated shears. Dilational breccias comprise altered wall rock or gouge fragments cemented by crustiform textured euhedral quartz and carbonate vein-fill. Quartz in the vein-fill exhibits euhedral growth zones and prismatic terminations. Veins and dilational breccias are largely systematic in orientation, implying Pf > minimum compressive stress (sigma-3) + T (= tensile strength) and lithostatic conditions. Pervasive sericite-carbonate alteration was synchronous with lode-gold alteration.

The auriferous lodes form a minor but economically important subset of the total shear population. A lode comprises either a shear or a dilationally brecciated shear, and a sericite-carbonate-pyrite alteration halo (Fig.3). Breccias are a ubiquitous component for about 90% of lodes. Lode breccias are persistent (up to 200 x 200 x 1m), occur within and around the permeable shear gouge, and contain thin branching quartz-carbonate veinlets. Un-brecciated lodes are largely uneconomic silicified shear gouge. Gold occurs primarily as 0.5-20um grains within or marginal to pyrite, isolated in silicate/carbonate gangue, with coloradoite as an infill of lode dilational breccias, fracture infill in pyrite aggregates or as gold-tellurides in microfractures and extension veins.

With the stiff rheology of the Golden Mile Dolerite and the deformation style, strain on the Adelaide and Golden Pike Faults could be dissipated in part by fracturing the confined Golden Mile Dolerite. Zones within the shear system have a pole pattern in stereographic projection (Fig.2) approximating axial compression, consistent with compression approximately normal to the confining Adelaide and Golden Pike faults. Given these orientation and spatial constraints, the Golden Mile shear system appears to have formed in response to stress imposed on the Golden Mile Dolerite by the Adelaide and Golden Pike faults. The Golden Mile shear system can therefore be considered secondary to the confining faults. The orientation pattern and displacement sense on the secondary shears is inconsistent with a "duplex" model if the Adelaide and Golden Pike faults (or the Boulder and Trafalgar faults) are utilised as the bounding structures (cf. Etheridge, 1987).

Upper-crustal elastico-frictional conditions are indicated from the widespread brittle shearing, low strain, open-space vein-fill textures and the episodic nature of shear-displacement and veining. The tectonic setting of the deposit is inferred to have been a shallow seismic zone confined between two major oblique-slip faults (cf. Phillips, 1986). The palaeo-structural setting of the deposit is analogous to modern-day shallow seismic zones where intermittent seismic slip along major fault zones, aftershock activity on subsidiary fracture zones and fluid discharge (Sibson, 1986) are intimately related.

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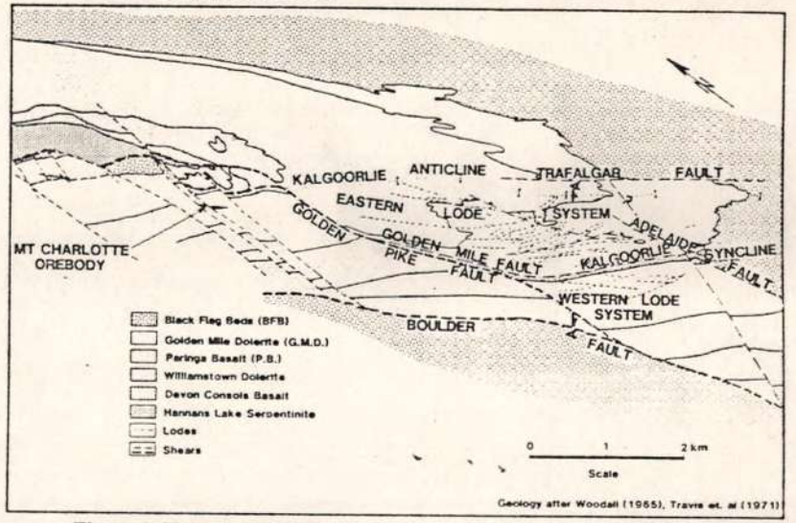


Figure 1. Kalgoorlie District Geology.

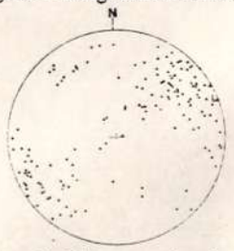


Figure 2. Poles to major shears in the Golden Mile. Lower hemisphere equal area projection.

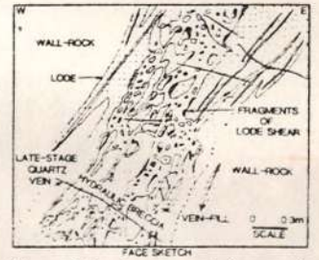


Figure 3. Lode- comprising pyrite-carbonate-sericite altered wall rock (stippled) and quartz vein-fill.

Bicentennial Gold 88, Melbourne, May, 1988

THE CAVE ROCKS GOLD DEPOSIT, YILMIA, WESTERN AUSTRALIA

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The Cave Rocks gold deposit is a medium tonnage deposit located 8km to the west of the town of Kambalda. It is currently being mined via an open pit by Western Mining Corporation's, Kambalda Nickel Operations. The deposit is notable in that it has a rather different style of alteration and mineralisation compared to most deposits in the Kalgoorlie-Kambalda region.

The mine is located within the Yilmia sequence, a belt of mafic and ultramafic rocks within a dominantly sedimentary terrain between Widgiemooltha and Kambalda. Stratigraphy within the mine area is not well-defined; however, the structural sequence from west to east is

(i) Meta-komatiites interleaved with and underlain by high-Mg meta-basalts.

(ii) The Cave Rocks meta-gabbro unit. This unit is some 400-500m thick, dips steeply to the west and is interleaved with shales and wackes which face west. This gabbro has a typical low amphibolite facies assemblage after tholeiitic gabbro, ie hornblende-plagioclase-quartz-chlorite-ilmenite. Igneous textures are poorly preserved.

(iii) Metasediments; shales, wackes and some volcanics.

Mineralisation occurs as fine-grained, (10 to 20 micron) free-gold associated with disseminated arsenopyrite and pyrrhotite in two narrow (10-15m), NNW-trending shear zones (Figure 1). The shear zones occur within the Cave Rocks meta-grabbro.

The shear zones consist of an outer alteration zone with generally well-developed fabric and an inner ore zone with variably-developed fabrics. The alteration halo is marked by the progressive development of fabric towards the ore zone, a coincident decrease in hornblende content and increase in biotite content. Unusually for Archaean lode gold deposits in the area, the alteration halo is also characterised by neoblastic cummingtonite and/or almandine garnet. There are sporadic, low Au values (<2ppm) throughout this zone, generally associated with small quartz veins.

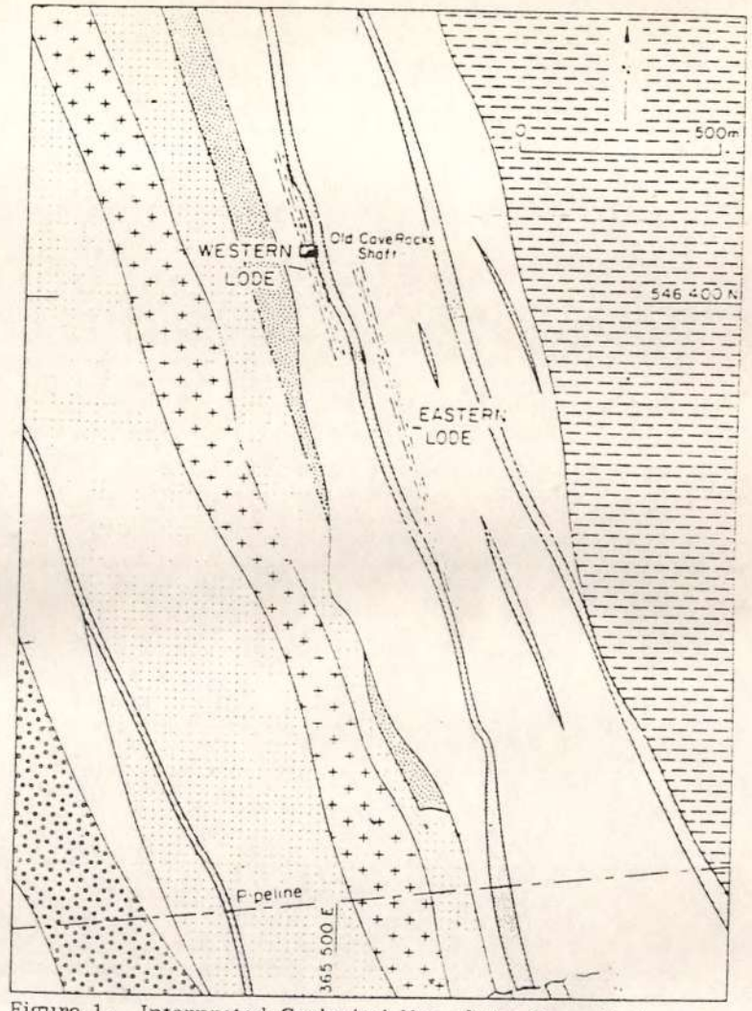


Figure 1. Interpreted Geological Map of the Cave Rocks area after J. Balkau

Undifferentiated Meta-sediments
Thin Meta-sediment Units
Meta-gabbro
Porphyritic Felsic Rock
Low-Mg Komatiites
Moderate-Mg Komatiites
High-Mg Komatiites
Shear Zone

The ore zone is marked by a sharp decline in amphibole content and a gradation into variably-foliated albite-, or chlorite-dominant rocks. Typical assemblages are albite-chlorite-quartz-biotite-calcite-ankerite-pyrrhotite-arsenopyrite-amphibole (pargasite and cummingtonite). Foliation is largely defined by orientated chlorite and/or sulphides in a granoblastic matrix of albite and quartz. Albite occurs as augen where foliation is present, but stumpy euhedral crystals overprint foliation in granoblastic rocks. Cummingtonite occurs as fans or rosettes of acicular crystals between albite-quartz aggregates together with (?) relic hornblende. Veining is not abundant with thin (>3cm), quartz and carbonate veins transecting fabrics. Rare coarse free-gold does occur within veins, but most gold is associated with sulphides disseminated in wallrocks. Gold values range from 1 to 15ppm in the ore zone.

Variation in ilmenite morphology provides a graphic illustration of the progressive change from host rock to ore. Ilmenite boxworks, exsolution trellises after Ti-magnetite, are the ubiquitous oxide phase in the unaltered meta-gabbro. Boxworks become progressively flattened in the alteration halo and their sigmoidal shapes suggest simple shear. Closer to the ore zone ilmenite is drawn into long trains of grains intimately associated with biotite. Little ilmenite is preserved in the ore zone with sulphides being the stable Fe-bearing phase.

Alteration within the shear zones has greatly modified the composition of the meta-gabbros, with MgO and Al_2O_3 lower than unaltered meta-gabbro and SiO_2, Na_2O, W and Au elevated in the shear zones. Essentially all immobile major and trace elements are diluted by added silica, Na and CO_2, whilst variable amounts of Fe and Ca are fixed in sulphides and carbonates.

The deposit is unusual for the Kambalda-Kalgoorlie area in that it is characterised by Na-metasomatism, has cummingtonite and garnet in its alteration halo and contains arsenopyrite and pyrrhotite rather than pyrite. In addition it occurs in low-mid amphibolite facies terrain, a slightly higher grade than most deposits in the region. Fabric evidence suggests that shearing and alteration occurred during retrograde metamorphism, ie destruction of peak metamorphic assemblage. The presence of garnet, cummingtonite and the absence of muscovite suggest retrograde alteration at the greenschist-amphibolite facies transition. The mineralogical differences between Cave Rocks and the more familiar Kalgoorlie-Kambalda deposits may be explained by this relatively high grade retrograde alteration.

THE WESTONIA GOLD MINE - ORE DEPOSITS

SPANNING 2.6 BILLION YEARS

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INTRODUCTION

The Westonia Gold Mine is wholly owned by Australian Consolidated Minerals Limited (ACM). Previously other Companies have twice exploited rich quartz reefs by underground methods for a production of 580,000t @ 19.6g/t.

Westonia is now in its third phase of mining, consisting of a large scale open pit operation and an underground decline scheduled to start in early February 1988.

The mine is situated 300km east of Perth(Figure 1) in the Yilgarn Mineral Field and it was the most westerly of the old major Eastern Goldfields mining centres.

Open Pit Reserves to a depth of 100m were 5.3Mt @ 1.7g/t as at the 31st March 1987. Material is being mined from three geologically distinct ore bodies whose age ranges from Archean perhaps to the present but which are genetically related.

Deep diamond drilling has indicated a fourth potential mineable resource of more than one million tonnes at an expected head grade in the range of 10-15g/t.

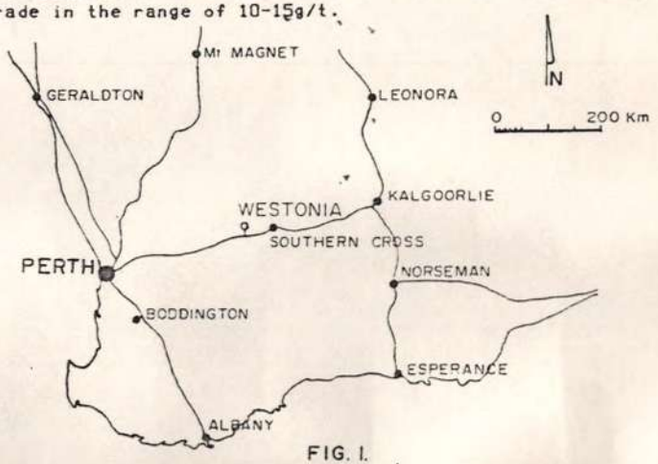


FIG. I.

GEOLOGICAL SETTING

A) ARCHEAN

Westonia occurs towards the north western end of a north westerly-south easterly trending discontinuous greenstone belt of some 100km length. The belt lies sub-parallel to the main Southern Cross greenstone belt and its south eastern end swings easterly almost to join the latter near Edward Find (GEE 1982). (See Figure 2).

In the Westonia area, the belt is about five kilometres wide and consists of a suite of amphibolites, felsic metasediments, felsic and mafelsic gneisses, ultramafics and later stage pegmatites, microgranites and dolerites. Granitic intrusions segment the belt.

B) POST ARCHEAN

The following events (in chronological order) have been recognised at Westonia.

1) An early stage of weathering of a landscape more rugged than the present one.

2) An alluvial/eluvial stage in which a south to north flowing stream system cut an irregular valley and then deposited a basal boulder bed load. The valley subsequently filled with grit overlain by sandy mud and mud. The deposit is known as the Wash and the basal coarse clastic portion hosts the Wash Zone orebody.

3) A continuation of weathering characterised by further iron mobilisation and precipitation in the form of surface Pisolitization of all units, especially the iron rich ultramafic. This surface Pisolitization hosts the Pisolite Zone of mineralisation.

4) Local erosion and stripping of laterite and complementary formation of transported soil.

The Archean and Post Archean geology is summarised in section in Figure 3.

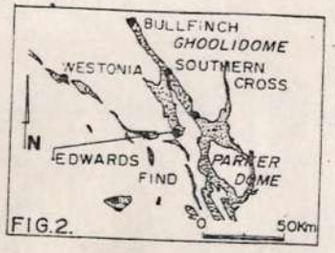


FIG.2.



FIG.3.

ORE DEPOSIT FEATURES

A) GNEISS ZONE

The Edna May Gneiss (EMG) is a tonalite or trondhjemite and has intruded the mafic and ultramafic units. The EMG has an average 45° northerly dip.

The EMG is thought to be emplaced along a major shear. Continual sporadic movement on the shear has initiated reef formation, deformed the reefs, imparted the gneissic fabric to the EMG, has formed a quartz stockwork in the EMG, and subsequently deformed many of the stockwork veins. The primary gold mineralisation is hosted by this set of complex quartz veins and reefs (see Figure 4). The gold, tungsten and sulphides distribution throughout the EMG attests to a primary magmatic origin of this mineralisation. The conclusion is supported by other differences from conventional Western Australian Archean deposits in that the gold is not in greenstone and there is a little carbonate or sulphide alteration. Weathering has caused strong secondary remobilistion of the gold. An average weathering depth of 55m is associated with the following profile.

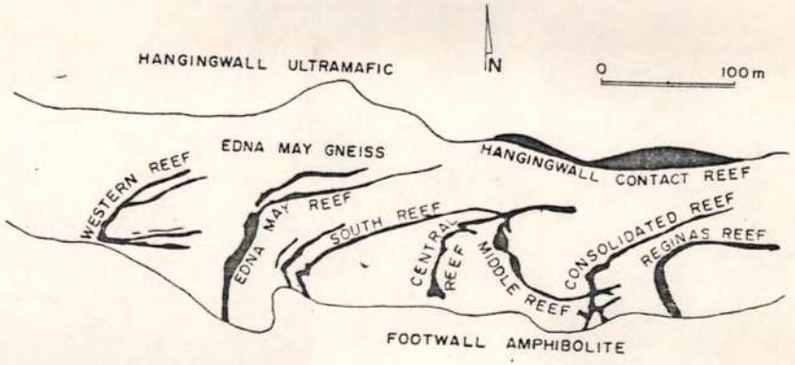


FIG.4 1240m RL LEVEL PLAN.

i) Pallid Zone. Complete kaolinisation of EMG, feldspars, micas or mafics results in a quartz vein-granular quartz-kaolin soft rock, below a thin cemented top. Strong gold depletion occurs in the top 15-20 metres.

ii) Limonitic Zone. Incomplete weathering of the micas and mafics results in a variably limonitic kaolinitic soft rock.

iii) Transitional Zone. This intermediate zone has partial weathering characterised by strong limonitisation and supergene enrichment and the preservation of a gneissic fabric.

B) WASH ZONE

The wash was deposited in a general south to north dipping valley which had a relatively steep westerly side and a more shallow easterly one. The age of the wash depositional event is unknown but is assumed to be Tertiary or Mesozoic.

The basal section is generally the coarsest part of the vertical profile and in grain size varies from grits to boulder beds. The coarse clastics occupy an interval range up to several metres in thickness. They are overlain by a general fining upwards sequence representing the valley fill phase of the sedimentation. The wash probably represents a mixed alluvial/eluvial palaeoenvironment.

The wash can be detected geochemically for at least one kilometre north (palaeodownstream) of the EMG with values up to 0.3g/t over a vertical interval of 1.0 metre being determined. The gold in the wash has been significantly mobilised during weathering. There is now no evident placer mineralisation and a presumed original detrital gold component has been dissolved and then reprecipitated on the iron stains and mottles. Within the quartz boulders and cobbles is often seen a ferruginous core surrounded by a clear rim. Visible gold in the cobbles is almost invariably associated with the limonitic core.

There is as yet no recognised structural reason for the deposition of the wash. Nonetheless, the coincident localisation of the deepest parts of the wash channel, of the highest known gold concentration in the EMG, and of the deepest weathering of the EMG is presumed not to be a coincidence.

C) PISOLITIC ZONE

This zone is hosted by the uppermost 1-5 metres of the lateritic profile. There are three categories of pisolite, each being consequent upon the substrate on which it developed.

i) Footwall Amphibolite. A porous orange high Al low Fe style. Gold content 0.1 to 0.5g/t range.

ii) The Wash/EMG Type. A pink grey orange style high Si and low Fe. Gold content 0.5 to 1.2g/t range.

iii) The Hangingwall Ultramafic Type. A dark brown to purple black pisolite. High Fe content. Gold content 1.5 to 6.0g/t range.

The higher grade mineralisation occurs where the favourable high iron outcrops adjacent to the EMG gold source.

The mineralisation is bounded to the north and west by erosion which has removed the pisolitic upper section of the laterite, and to the south and east by the Footwall Amphibolite substrate and the decreasing gold content of the EMG respectively.

Allowing for the difficulties inherent in gold assaying at these low grades, the pisolite zone mineralisation has proved to be remarkably uniform. It was possible to mine the zone using 25m x 25m or 25m x 12.5m exploration drill hole data for grade control. Mill reconciliation indicates that the exploration grade was understated by only 3%.

THE GEOLOGY OF THE HANNAN SOUTH GOLD MINE, KALGOORLIE W.A.

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INTRODUCTION

The Hannan South deposit is situated 15km SE of Kalgoorlie, in an area of no outcrop, directly south of Hannan Lake. The area is covered by superficial lacustrine deposits and dune sands, beneath which a deeply weathered and leached profile has developed.

Discovered in 1982, the deposit has a mineable reserve of 200 000t at 5.4 g/t Au. Open cut mining commenced in September 1986.

Gold mineralisation occurs within a sequence of thinly bedded felsic volcanics, metasedimentary rocks and high magnesian basalts, which have been intruded by an andesite porphyry sill, (Fig. 1).

Alteration to the west of the steeply east dipping porphyry contact severely impedes identification of lithologies on the basis of mineralogy. The alteration involves silica, carbonate, chlorite and epidote, together with widespread sericitization.

Primary textures are often masked by a well developed schistosity. Banding is recognised in the lode and microfaulting is commonly visible.

GEOLOGY

The geology of the deposit as exposed by mining is described below, (Fig. 2).

Andesite Porphyry (Afap), the western contact is weakly silicified, occasionally pyritic, variably carbonated and sericite rich. Away from the contact the porphyry is massive, generally unaltered and only rarely mineralised. Plagioclase (albite), hornblende and quartz constitute the phenocryst phase in a fine grained, dark coloured matrix. Chloritized and biotitized mafic clasts, some with spinifex textures are common.

Hangingwall Tuff (Aa/Aab), a fine grained bedded/sheared felsic tuff. It is plagioglase rich (albite) and has occasional thin bands of pyrite and arsenopyrite. Low grade ore occurs in the tuff, which is 6 to 10 metres wide. It exhibits a sharp well defined usually comformable contact with the epidote rich rock below.

Epidote Rich Rock - Hannan South Lode (Ae), this lithology hosts the bulk of the gold found in the mine. It is a massive epidote/sulphide rich lens about 140 metres long and 20 metres in maximum width. Both transgressive and conformable upper and lower contacts have been noted and brecciation has been observed on the footwall contact. Metasomatic and hydrothermal alteration have produced a variable mineral composition which includes, microcline (35%), epidote (30%), quartz (15-20%), chlorite-biotite-sericite (5-20%) and opaques (5-50%) plus accessory carbonate, tourmaline and leucoxene. The lode is part compositionally banded and is coarse grained on the eastern side and fine grained and chloritic on the footwall side. Higher grades tend to occur in the coarse grained lode.

Opaque minerals may comprise up to 50% of the rock and more commonly 10-20%. Fine to very coarse grained crystals of pyrite are common, (15%). Magnetite (0-20%) occurs as fine to coarse sub-euhedral crystals. Accessory sulphides observed are, cobaltite bismuthinite, galenobismutite, wittichenite, chalcopyrite, arsenopyrite, gersdorffite and bismuth telluride. Galena and pyrrhotite have also been noted (Schiller, in prep.).

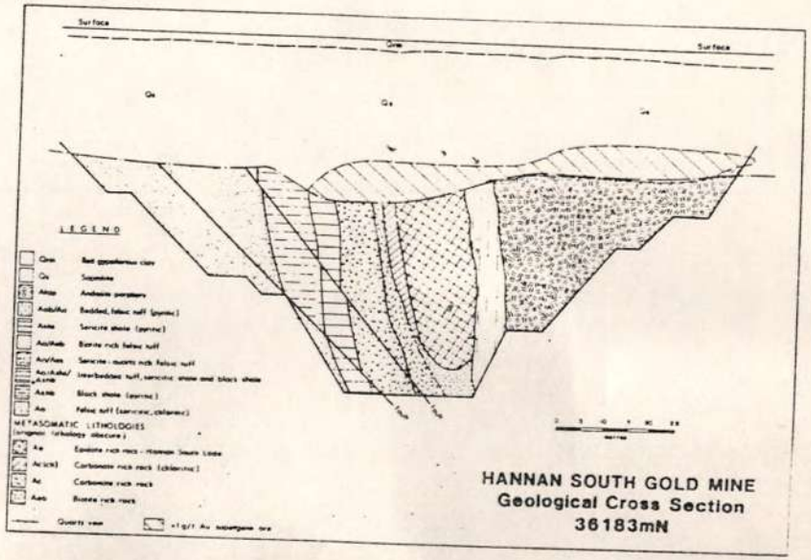


Figure 1: Hannan South Gold Mine Geological Cross Section

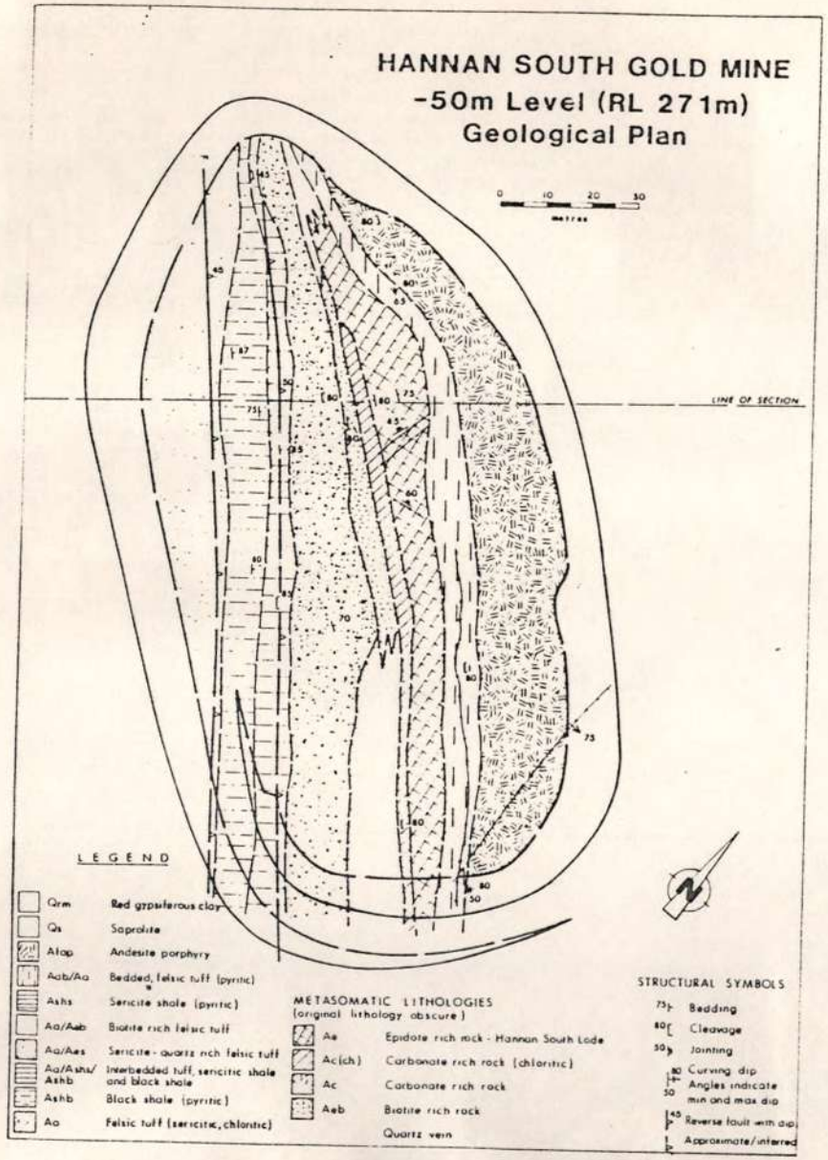


Figure 2: Hannan South Gold Mine, -50m Level Geological Plan

Footwall Tuffs And Sediments (Aa/As), fine grained carbonate and sericite rich schistose crystal tuffs and sediments occur footwall to the Hannan South Lode. They are typically plagioclase (albite) and quartz rich and often sheared. Sericite and carbonate often replace plagioclase and rocks with up to 60% carbonate are present. Variable amounts of chlorite, sericite and muscovite also occur. Thin semi-conformable quartz carbonate veins with free gold are present as are very thin sulphide rich veins containing pyrite, chalcopyrite, cobaltite and arsenopyrite. Rare interbedded black shales and fine grained sediments with graded bedding are found in this unit. Facing derived from graded bedding is inconclusive however it suggests younging from west to east. This conforms with the observations made by Schiller (in prep.).

Black Shale (Ashb), a 2 to 25 metre wide pyritic black shale lens lies approximately 25 metres below the Hannan South Lode. Its dimensions approximate those of the lode, possessing similar maximum widths and both thinning progressively to the north and south.

Footwall to the black shale, fine to medium grained tuffs, felsic tuffs and sediments are found. Carbonate and sericite alteration are still present here in these slightly schistose rocks. Mineralisation rarely occurs in this unit.

STRUCTURE

Intrusion of the porphyry into a regional fault/shear system seems likely. At Hannan South this has resulted in the development of a strong cleavage in footwall rocks. To the north of the pit, a series of reverse faults have been observed trending approximately 320 degrees.

The magnitude of displacement is not yet determined, although these structures may be responsible for termination of the mineralisation at depth.

SUPERGENE MINERALISATION

Intense leaching of the Hannan South Lode and host rocks resulted in the depletion of gold from the present surface to a depth of approximately 20m. Secondary deposition of this gold formed a flat lying supergene zone which blankets the primary ore.

Ore grade mineralisation (>1 g/t Au) is found up to 70m away from the primary ore and minor zones have been found as deep as 40m. This mineralisation was best developed on the weathered to fresh rock interface with the highest grade and most consistent zones found in saprolite overlying fresh andesite porphyry to the north and east of the primary ore. Supergene gold occurred as very thin (5 microns) flat crystals with triangular and hexagonal habit. They were found on fractures in weakly oxidised rock and throughout the enriched

saprolite zone.

The supergene zone is noteworthy with respect to the discovery of the deposit. It was the eastern edge of this flat lying mineralisation which was intersected by a reconnaissance drilling programme which reported an intersection of 2m @ 0.76 g/t Au.

GENESIS

Shearing and alteration as a result of the porphyry intrusion, with possible subsequent re-activiation along shear zones is consistent with mine data. However, the position of the orebody between the porphyry and a black shale unit, must be considered pertinent in the genesis of the deposit. The association of Hannan South mineralisation with regional scale faulting of the same trend as recognised in the Golden Mile cannot be overlooked, and a relationship seems certain. Evidence for a singular structural control is however, lacking.

SUMMARY

The Hannan South deposit remains a relatively discrete discovery, separated from the Golden Mile by some 15km. The felsic tuffs hosting the Hannan South Lode contrast with the Golden Mile Dolerite although the implication of structural similarities is not without foundation.

The relative importance of the intrusive, the tuffs and the black shale, compared with structural considerations remains difficult to ascertain. The orebody lies within the most highly altered and disturbed rocks, consistent with a structural/hydrothermal system of ore genesis. Indeed alteration in the lode is such that identification of the proto-lith hinges largely on geochemistry and extrapolation of stratigraphic data.

Many questions remain unanswered, although current exploration centres on the porphyry contact zone in areas where geophysical data infers structural inhomogeneity.

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A CONCEPTUAL FAULT ZONE MODEL OF A MINERALIZED ARCHAEAN SHEAR ZONE FROM THE MT MARE AREA, PIETERSBURG GREENSTONE BELT SOUTH AFRICA.

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The Pietersburg Greenstone Belt (c.3.5 Ga) is located in the northern half of the Kaapvaal Craton. It lies 50 to 100 km south of the Limpopo Mobile Belt and is oriented sub-parallel to the regional fabric. It is a linear belt generally less than 10km wide that extends for about 100km north-west from under the cover of Proterozoic sediments. The Mt. Mare area of the belt contains evidence for polyphase gold mineralisation, the history of which has been traced through the geological evolution of the area and the role of reworking of pre-existing gold concentrations has been assessed.

Detailed mapping has revealed that the Mt Mare area is a tectonic complex comprised of several litho-tectonic units bounded by faults, fault-related melanges and unconformities. The oldest rock sequence seen in the area is now found as four allochthonous thrust sheets of simatic rocks. These are unconformably overlain by and structurally interleaved with a prograding sequence of upward coarsening cycles of immature alluvial sandstones, conglomerates and debris flows. Field relationships, metamorphic assemblages and whole rock geochemical data suggest that the simatic rocks evolved as an intrusive-extrusive tectono-complex that was pervasively hydrated and carbonated during a period of high-temperature/low pressure metasomatism, that overlapped in time with, or occurred soon after, the igneous evolution of the complex. This metasomatism is similar to that seen in Phanerozoic ophiolites and on the modern ocean floor and caused significant major and minor element mobility that resulted in a low grade concentration of gold (ppb values) in BIF units. The fluid involved in this metasomatism was most likely to have been Archaean seawater that contained predominantly chloride ligands which do not favour the development of economic concentrations of gold. This suggests that concepts of 'syngenesis' should not be used in exploration programmes in the area. Minor structural evidence suggests a period of stratigraphic inversion (D1) that only affected the simatic rocks could have occurred prior to later tectonism.

The simatic rocks were subsequently emplaced as allocthonous units during a period of horizontal shortening (minimum 75% shortening from strain analysis) across the area, probably between about 2.8 and 2.6 Ga. This is the main deformation event (D2) seen in the area and it resulted in significant thrust-related stratigraphic repetition, producing a hinterland-propagating, imbricate fan system. A detailed conceptual model of a progressively developing, mineralised Archaean fault zone has been constructed by interpreting two of the D2 thrusts, the Kuschke and Snymansdrift Shear Zones, as different spatial and temporal levels of one fault zone. The Kuschke Shear Zone represents the lower level of such a fault zone and is marked by an unusual quartz-carbonate-fuchsite tectono-metasomatic fault rock that records a complex history of repeated syn-tectonic fluid migration actompanying cataclasis and mylonitisation. This rock type is interpreted as evidence for a seismic valve by which earthquakes and gravitational instabilities may have been triggered by fluid movement

through the shear zone. One of these periods of fluid movement was apparently mineralising.

Field and microscopic studies of the Snymansdrift Shear Zone, which is interpreted to represent the middle and upper levels of the conceptual fault zone model, have revealed an extended history of progressive D2 deformation, syn-tectonic metamorphism and fluid flow. Higher strain zones within the main shear zone, and whose localisation was strongly controlled by pre-existing sedimentary contacts, are commonly mineralised.

The lowermost parts of the shear zone are characterised by a distinctive tectono-sedimentary melange that began to form early in D2. The lithology is characterised by an abundance of predominantly boudin-like fragments of chert that were produced by the tectonic stratal disruption of a BIF unit to produce a 5km long, by 75m wide, breccia zone derived entirely from spalled fragments of the BIF. The disruption had a unique style, characterised by the brittle-ductile folding of the BIF layers, that was strongly controlled by the initial fine grain size of the sediments, their laminated nature and a difference in response to deformation of the quartz laminae, which behaved in a brittle fashion to produce the boudins, and the magnetite laminae, which behaved in a ductile manner and were reworked in to the matrix of the melange. Original gold concentrations have apparently been downgraded by the tectonism. The extreme dilatancy resulting from the disruption was accompanied a massive influx of carbonate bearing fluids in to the melange.

The lower contact of the melange cross-cuts stratigraphy and is tectonic whereas the upper contact was initially sedimentary and the breccia zone grades upwards without tectonic break in to shales and siltstones and then the overlying coarse alluvial sediments. These sediments contain evidence of "soft-sediment" deformation including other types of stratal disruption and lithological mixing common in more recent melange terranes, mudstone dykes, soft-sediment breccia zones and fold structures. These features suggest sedimentation was occurring above an initially low-dipping active thrust fault and as such the melange and related features probably represent a small piggy-back basin. Furthermore the same sediments can be traced along strike out of the main fault zone where they unconformably overlie the simatic rocks suggesting that sedimentation in the Mt Mare area as a whole was semi-allochthonous.

Continued D2 deformation lead to the steepening and flattening of the original stratigraphy and structural mixing with tectonically introduced lenses of simatic rock and BIF. These significantly different precursor lithologies, although having an initial important control on the type of fault rock formed, had their original textural and chemical differences progressively homogenised during D2 dynamothermal metamorphism. Original simatic rocks underwent significant retrograde metamorphism from actinolite-albite-epidote assemblages to chlorite-quartz-carbonate schists whereas the original sediments were overprinted by diffusive mass transfer and crystal plastic processes and underwent prograde metamorphism to produce chloritoid-bearing quartz-sericite schists. All these schists are correctly termed phyllonites and are extensively strain softened. The shear zone has "equilibrated" the initial rock types at greenschist facies metamorphism (300-450 C, <3-4Kb).

The metamorphism and phyllonite development are a result of significant fluid flow and infiltrative mass transfer within the shear

zone, indeed the rate of fluid influx may have been the rate controlling step in the two processes. However, syntectonic quartz-carbonate-pyrite-pyrrhotite veins attest to episodic hydraulic fracturing and a more forceful passage of fluids through the zone. The veins disrupt the D2 fabric but are commonly transposed parallel to the same fabric. One such episode of hydraulic fracturing occurred late in D2 and resulted in the introduction of tourmaline-arsenopyrite -quartz-gold bearing fluids along one of the higher strain zones within the main shear zone. These fluids travelled upwards from depth and were released in to the middle and upper levels of the shear zone where they passively infiltrated areas of low strain that escaped much of the later D2 deformation and which are the site of most of the ex-gold workings currently being reinvestigated by an ongoing exploration programme in the region. Drill core from the prospects reveals that this period of hydraulic fraturing also became strongly overprinted by the latest increments of D2 and this deformation is effectively downgrading the ore deposit, an important consideration in exploration programmes for shear zone hosted gold deposits.

The shear zones are interpreted as representing different spatial and temporal levels of one shear zone in which a complex hydrothermal "plumbing" system developed (Fig. 1). This system may have been related to granitic melting at depth with fluid migration from the granites triggering earthquakes and allowing rapid fluid movement through the shear zones to a near surface environment. The fluids responsible contained sulphide ligands and hence were more suited to forming economic gold concentrations.

In conclusion, upper crustal reworking of original gold concentrations in shear zones is of subordinate importance to later influxes of fluid (related to granitic or perhaps metamorphic processes) and that a better understanding of the complex processes involved in the progressive evolution of shear zones should be an integral part of any study of shear zone-hosted mineralisation.

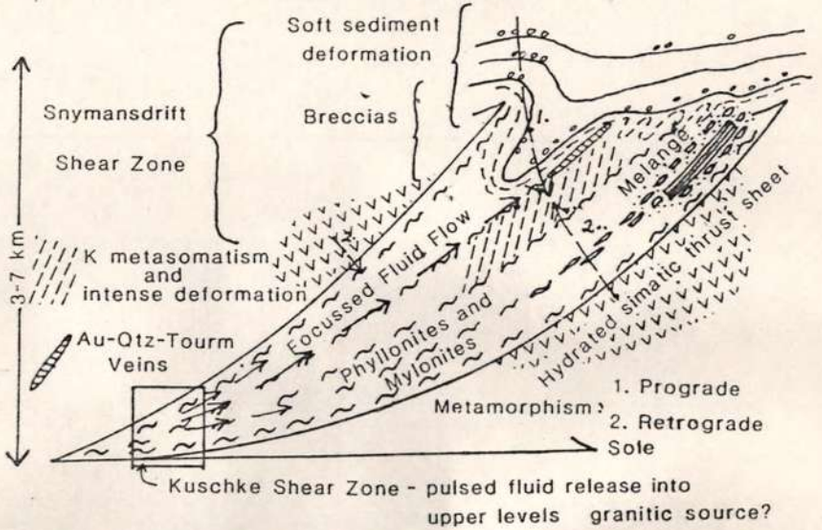


Fig. 1 Conceptual Model of a mineralised Archaean fault zone

GEOLOGY AND GEOCHEMISTRY OF OWL CREEK GOLD MINE, TIMMINS, ONTARIO

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INTRODUCTION

The Owl Creek gold mine lies in the Archean Abitibi Greenstone belt of the Superior Structural Province of the Canadian Shield, 17 km northeast of the city of Timmins, Ontario. The majority of gold mined occurs in the form of inclusions in pyrite in steeply dipping highly strained tholeiitic basalt and carbonaceous shale; however, free gold is also mined from fault-bounded quartz veins.

As of the end of 1985 1,064,072 tonnes of 4.0 g Au/t had been produced leaving approximately 66,000 tonnes of 4.1 g Au/t ore reserves.

MINE GEOLOGY

The four major rock types observed at the Owl Creek mine are tholeiitic basalt, carbonaceous shale, arkosic wacke and mudstone. All rocks have been subjected to lower to middle greenschist facies regional metamorphism.

Basalt: Most of the buff to grey basalt is high magnesium tholeiite that is massive to locally pillowed and intensely sheared. Basalt is intensely carbonatized (ankerite-dolomite; up to 16.7% CO_2) and the grey colour is the result of post-carbonatization addition of carbon. Sericite and pyrite alteration of basalt has also occurred. Most auriferous pyrite is between 0.5 mm and 1.0 mm, and resides in basalt.

Carbonaceous Shale contains as much as 14.8% amorphous carbon and carbon content is highest adjacent to intensely sheared tholeiitic basalt. Carbonaceous shale contains fine-grained disseminated euhedra, nodular and snowflake-like skeletal pyrite, in order of decreasing gold content. Pyrite nodules are either concentrically banded or recrystallized. Both types contain anomalous concentrations of gold, up to 82.7 ppm; however, gold was only visible in recrystallized nodules. This suggests that gold in nodules was concentrated prior to shearing.

Mudstone has a much lower amorphous carbon content (<2%) than shale. Pyrite occurs as disseminated euhedra (<1 mm) and as bands up to 5 cm in thickness which may comprise up to 15% of the rock; both types are virtually devoid of gold.

Arkosic Wacke: Two major exposures, termed the north and south arkosic wackes and a 5 m thick interflow unit within basalt comprise the enveloping sedimentary rocks at Owl Creek. Individual beds range from centimetres to tens of metres in thickness. These are interbedded with mudstone laminae which may be ripped up, indicating overturned stratigraphy which youngs to the south. Pyrite was observed as euhedral cubes up to 10 mm in size. Arkosic wacke contains no appreciable quantities of gold.

Vein Types: Quartz veins in the highly strained rocks exposed in the Owl Creek open pit are; 1) subvertical, 2) south dipping, en echelon tensional and 3) subhorizontal. All three types of quartz veins contain ore grade concentrations of gold.

Subhorizontal quartz veins may be brecciated resulting in subvertical quartzose-breccia veins consisting of angular quartz fragments and a matrix of either chlorite and auriferous pyrite or goethite and chalcedony. The existence of auriferous pyrite indicates that there was a gold precipitating event which post-dated gold-bearing quartz veins.

STRUCTURAL EVOLUTION

A four stage model of structural evolution of shale and basalt is envisaged.

1. Carbonaceous shale and tholeiitic basalt were tilted to a subvertical orientation.
2. Initial dip-slip movement resulted in subvertical faults and discrete high strain zones. Fault-bounded en echelon quartz veins began to form. Hydrothermal brecciation incorporated angular fragments of auriferous pyrite-bearing basalt in subvertical quartz veins.
3. As a result of increased shear strain caused by dip-slip movement en echelon gold-bearing quartz veins were rotated into a subhorizontal position.
4. Subhorizontal quartz veins were brittly deformed and subvertical quartzose breccias were formed. The matrix of these veins contains auriferous pyrite and represents the final mappable phase of gold precipitation.

Development of a heterogeneous deformation zone was responsible for increased permeability in carbonaceous shale and tholeiitic basalt. This deformation zone was the principal conduit for gold-rich fluids and its development controlled auriferous pyrite and gold-bearing quartz vein precipitation at Owl Creek.

ORE PETROLOGY

Gold is most closely associated with pyrite, pyrrhotite, arsenopyrite and chalcopyrite in order of decreasing abundance; however, pyrite represents no less than 95% of the total sulphides present. With the exception of rare euhedral arsenopyrite, all inclusions in gold-bearing pyrite are anhedral. Gold grains occur as isolated blebs in pyrite but may be found adjacent to chalcopyrite inclusions or at grain boundaries between arsenopyrite and pyrite. Gold was not observed as inclusions in arsenopyrite. Altaite was only observed with gold inclusions in pyrite nodules. The very low tellurium levels of pyrite separates from the basalt suggests that there is no genetic relationship between gold in euhedral pyrite in carbonatized basalt and gold in recrystallized pyrite nodules in carbonaceous shale. Therefore gold-altaite associations in nodules may be diagenetic and unrelated to the hydrothermal fluids responsible for precipitating auriferous pyrite in basalt and gold-bearing quartz veins.

MODES OF GOLD OCCURRENCE

Gold was found as inclusions or closely associated with pyrite as:

i) Anhedral blebs in euhedral pyrite, ii) Fracture fillings, commonly with pyrrhotite, in cataclastically deformed pyrite

euhedra; iii) Free gold in quartz veinlets and more rarely in altered basalt; free gold is also present in the chlorite matrix of quartzose breccia; iv) Plated on pyrite euhedra; v) At the boundaries of annealed pyrite grains; vi) In recrystallized pyrite nodules.

Gold grains themselves average 20 µm in size and range up to a maximum of 100 µm; and along with pyrrhotite, chalcopyrite and arsenopyrite give auriferous pyrite a sieve texture. Gold to silver ratios of twelve grains range from 3.3 to 9.4.

SULPHUR ISOTOPE GEOCHEMISTRY OF PYRITE

Sulphur isotope ratios of 28 pyrite samples from Owl creek were measured and the following observations were made.

1) Auriferous pyrite has a distinctive narrow range of $\delta^{34}S$ signatures (+1.8 to +3.5 per mil) which is independent of rock type. These data are similar to those listed by Taylor (1987) for other Timmins camp gold mines such as McIntyre (0 to +6.0 per mil), Dome (+2 to +5.0 per mil) and Hollinger (1.2 to +5.5 per mil). 2) There is no linear correlation between S-isotope signature and gold. 3) A S-isotope range of +1.8 to +3.5 per mil is not exclusively indicative of auriferous pyrite. 4) The wide ranging $\delta^{34}S$ signature of sediment-hosted pyrite make them an unlikely source of S.

CONCLUSIONS

1) Migration of gold-bearing fluids was principally controlled by an east-west strike shear zone through tholeiitic basalt and carbonaceous shale.
2) Dip-slip movement resulted in the development of extension fissures in basalt in which gold-bearing quartz veins precipitated.
3) Field and petrographic studies have outlined four phases of gold precipitation: i) diagenetic precipitation of gold and altaite in pyrite nodules in carbonaceous shale; ii) precipitation of auriferous pyrite associated with discrete high strain zones in basalt and to a lesser extent shale; iii) precipitation of free gold-bearing quartz veins which incorporate angular fragments of basalt and shale carrying auriferous pyrite; iv) precipitation of auriferous pyrite as the matrix of subvertical quartzose breccia veins.
4. The alteration assemblage associated with gold in basalt, the main ore zone, is ankerite-dolomite-sericite-pyrite.
5. Gold is commonly associated with pyrite, pyrrhotite, arsenopyrite and chalcopyrite in order of decreasing abundance. Only gold in recrystallized pyrite nodules in carbonaceous shale is associated with altaite.
6. Auriferous pyrite has a narrow range of S-isotope ratios (+1.8 to +3.5 per mil); however, there is no linear correlation of gold concentration and $\delta^{34}S$ in pyrite.

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GEOLOGY AND GEOCHEMISTRY OF THE BOSSOROCA GOLD DEPOSIT, RIO GRANDE DO SUL, BRAZIL

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The Bossoroca gold deposit is situated in southernmost Brazil, near the city of São Sepé, at coordinates 53 44' W and 30 22' S. It produced 500 Kg of gold between 1900 and 1987. The gold is mostly contained in a quartz vein, varying in thickness from 0.1 to 1.0 m and averaging 0.3m. The average ore grade is 15 ppm Au. The ore is made up of quartz, gold, pyrite, arsenopyrite and magnetite. The gold occurs both as free grains and contained in pyrite. The grains vary in size up to 1 mm and average 100-150 mesh.

The Bossoroca greenstone belt includes the mine and occurs in the western part of the Sul-riograndense Shield, which is the southern extension of the Brazilian Shield. The belt is in contact to the west with tonalitic gneisses and granites of probable Archean age. This "basement" is deformed and the main foliation is parallel to the schistosity in the belt. To the north and south the belt dips beneath Phanerozoic cover, and to the east is thins out almost entirely but is connected to the Passo Feio greenstone belt. The belt is approximately 18 Km in N-S dimension and 12 Km E-W. Younger granites intrude the belt, forming 1-2 Km-wide thermal aureoles.

The Bossoroca Complex is divided into the Arroio Lajeadinho and Campestre Sequences, respectively in the western and eastern parts. The Arroio Lajeadinho comprises dominantly supracrustal lithologies, with some mafic-ultramafic intrusives; it includes serpentinites, magnesiano schists, metabasalts, metagabbros, metaharzburgites, metachert, banded iron formations, meta-tuffs and metassedimentary rocks. The magnesian schists and serpentinites usually occur in zoned bodies. The Campestre Sequence contains the gold mineralization and is made up of meta-volcanoclastic rocks and also meta-arenites, metapelites, metaconglomerates and metachert. Common minerals in the meta-volcanoclastic rocks are quartz, amphibole, plagioclase, epidote, biotite, chlorite, carbonate, sphene, zircon and tourmaline. The meta-arenites are made up of quartz, alkali feldspar, plagioclase and some biotite, muscovite, apatite, carbonates, magnetite, pyrite and chlorite. The metapelites contain quartz, muscovite, magnetite and tourmaline. Graphitic bands are common in the complex.

Detailed studies of the Campestre Sequence show the

superposition of two schistosity-forming events and a later open folding event.

Chemical analysis of 55 host-rock samples from the upper sequence show compositions close to calc-alkaline andesites and basalts as far as trace elements are concerned. In a diagram Zr x Ti, the points straddle the limit of basalts and andesites. In the Zr/TiO_2 x Ga diagram, the points plot mostly in the andesite field but a large number plots in the basalt field. Major elements are typical of calc-alkaline andesites, with some samples extending to basalts and even rhyolites. The trace element composition of the rhyolites is similar to the andesites. All rock types show rather high Na_2O contents (5.0 wt %), low K_2O (0.9 wt %) and correspondingly high Na_2O/K_2O ratios.

REE determinations by ICP on 33 samples of volcanoclastic rocks from drill-cores in the mine show rather flat patterns, with very small enrichment in the LREE, no Eu anomaly. The content of REE is approximately 10-20x chondrite.

Chondrite-normalized REE patterns for three samples of banded-iron formation show contents close to or lower than one, with positive Eu anomaly. This type of Eu anomaly is typical of Archean banded-iron formations.

Grade of metamorphism varies from low amphibolite facies in the west to low greenschist facies in the east. In the mine area, microprobe analyses show that the metamorphic amphiboles are hornblendes (13 wt % Al_2O_3) and that the associated plagioclases vary in composition from albite to oligoclase, typical of transitional greenschist to amphibolite facies of regional metamorphism.

Alteration of the host-rocks in the mine area includes silicification, chloritization, carbonatization, tourmalinization and sericitization. This alteration is responsible for lack of correlation between several geochemical parameters, such as Na_2O x SiO_2, K_2O x SiO_2, TiO_2 x SiO_2, CaO x SiO_2, Zr x SiO_2, TiO_2 x Zr. The gold mineralization is closely associated with the hydrothermal alteration. Primary fluid inclusion in the quartz from the gold-quartz vein indicate homogenization temperatures in the order of 230-320 C.

Several occurrences of gold have been noticed in the Bossoroca Complex in the past few years, and some have developed into small mines. The complex is similar to other greenstone belts as described from several Archean cratons in the world.

EVIDENCE FOR EPIGENETIC Au MINERALIZATION IN ARCHEAN SILICATE IRON FORMATION, LUPIN MINE, SLAVE PROVINCE, CANADA

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Numerous gold occurrences, including the Lupin mine, exist in Archean silicate iron formation (IF) at Contwoyto Lake, Northwest Territories within the Slave Province of the Canadian Shield. As of December 31, 1986 Lupin has production plus recoverable Au reserves of 53,206,600 g Au at a grade of 11.02 g/t. Early studies (Kerswill 1986; Pagham 1984; Franklin and Thorpe 1981) suggested that gold was a syngenetic component of the IF; however, the present study strongly suggests that gold was emplaced along with sulphides relatively late in the deformational history of the IF.

IF in the region is hosted by a thick sequence of highly deformed turbiditic greywackes and mudstones that are metamorphosed to middle greenschist to middle amphibolite grade. The IF forms thin (<20 m) beds within the sequence that are predominantly comprised of grunerite and are sulphide and gold-poor.

The following descriptions are based on detailed examinations of the Lupin deposit and several small-scale gold occurrences in IF. At small-scale gold occurrences, the sporadic distribution of the sulphide and gold mineralization is obviously controlled by quartz veining and is limited to zones of a few metres or less in strike length. At Lupin, much greater continuity of sulphide and gold mineralization is present in highly quartz-veined iron formation over a total strike length in excess of 800 m. Despite the differences in scale, numerous geological and geochemical features indicate that Lupin and the small-scale occurrences formed by the same, epigenetic process and the following descriptions and data are derived from both.

Field observations and petrographic studies indicate that Au is associated with concentrations of pyrrhotite or pyrite, and the arsenides arsenopyrite ± loellingite, which occur in IF adjacent to a specific generation of quartz veins in IF (Figure 1). The veins themselves typically contain from 0.03 to 1.00 ppm Au and comprise strained quartz with little or no sulphide. The quartz veins cut across early isoclinal folds and are associated with the later stages of an Archean deformational event that is coincident, or nearly coincident, with peak thermal metamorphic conditions (King et al. 1988). Mineralization is confined to IF and is not present where the veins cut adjacent clastic sedimentary rocks or impure IF (referred to as pelitic IF) which is comprised of a mixture of clastic and chemical sediment.

A zoned sequence of hydrothermal alteration is developed adjacent to quartz veins in the IF. Immediately adjacent to the veins a calc-silicate lithology is sometimes developed which consists of hedenbergite + quartz ± epidote ± scheelite ± grossular. These zones generally contain from 0.03 to 1.00 ppm Au. Next a zone rich in arsenides with lesser amounts of pyrrhotite or pyrite is developed

that typically contains 5 to 30 ppm Au. Silicate minerals in the arsenide-rich zone include hornblende + quartz ± hedenbergite ± epidote ± actinolite. The next zone is an Fe-sulphide zone lacking abundant arsenides but containing pyrrhotite or pyrite and hornblende + quartz ± hedenbergite ± epidote ± actinolite. The Fe-sulphide zone contains from 5 to 30 ppm Au and hosts most of the Au. With increasing distance from the vein this zone grades into unmineralized IF containing $\leq$ 0.03 ppm Au that lacks sulphides and comprises grunerite + quartz ± minor amounts of magnetite and hornblende. In the transition zone hornblende can clearly be seen to replace grunerite. In some samples textures indicate that the Fe-sulphides replace magnetite and amphiboles. These replacement sulphides sometimes have a banded appearance because they replace preexisting minerals that define banding in the IF. The scale of the complete sequence of zones varies from millimeters to metres about individual veins and in the well mineralized parts of the Lupin mine all of the former grunerite IF has been altered and sulphidized.

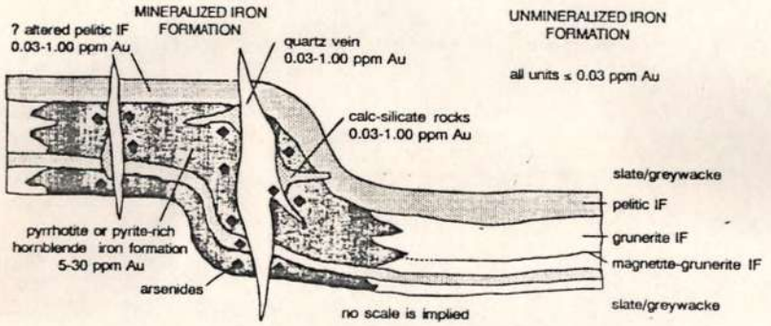


Figure 1. Schematic diagram of the relationships between unmineralized and mineralized IF together with the typical gold values of the lithologies.

At one small-scale occurrence, where the IF is largely comprised of grunerite with little or no magnetite, electron microprobe analyses of coexisting hornblende and grunerite show trends of decreasing X_{Fe} values (defined as Fe/[Fe+Mg]) towards quartz veins as the concentration of sulphides increase. The X_{Fe} values decrease from 0.97 to 0.85. This trend is interpreted to be due to sulphidation of the IF during which S added to the iron formation reacts with iron silicates with high X_{Fe} values to produce iron sulphides and iron silicates with lower X_{Fe} values. At another small-scale occurrence, where mineralization occurs in a grunerite IF with abundant magnetite, there is no change in the X_{Fe} values (0.90 to 0.95) of the amphiboles with sulphide abundance, because most of the iron consumed to form sulphides is derived by the breakdown of magnetite instead of amphiboles. At Lupin, amphiboles in unmineralized magnetite-poor IF along strike from the deposit and within a weakly mineralized part of the Lupin mine have X_{Fe} values of 0.91 to 0.95 and amphiboles in well mineralized samples have X_{Fe} values of 0.83 to 0.90. This trend is also interpreted to be due to sulphidation of the IF.

Whole rock, XRF analyses of samples from Lupin and the small-scale gold occurrences are geochemically similar. Examination of the patterns of the commonly immobile elements Al, Sc, Y, Ti and Zr in the various hydrothermal alteration zones and unmineralized IF shows that only Ti and Zr are immobile, or nearly immobile, in all zones. Mass balance calculations, using Ti and Zr as immobile elements (methods of Gresens 1967 and Grant 1986), suggest that mass increases of less than about 25% occur as the grunerite IF is progressively altered to weakly mineralized IF, Fe-sulphide-rich IF, arsenide-rich IF, and calc-silicate rocks. The different zones are characterized by somewhat different elemental enrichments when compared to the unmineralized grunerite IF precursor. The characteristic elemental enrichments are listed below with the elements arranged from greatest to least enrichment factors with a minimum enrichment factor of 100%:

1) calc-silicate rocks:	W, Au, Sr, As, Ca, S, Al, Sc, La, Pb and Ce.
2) arsenide-rich IF:	As, Au, S, Cu, Bi, Ni, W, P, Co and Sr.
3) Fe-sulphide-rich IF:	Au, As, S, W, Cu, Bi, Sr, Ca and Pb.
4) weakly mineralized IF:	Au, As, S, W and Sr.

Positive enrichment factors for Au, As and S in all alteration zones indicate that these elements are added to the iron formation from an external source. Gains in excess of 100% for typically immobile elements such as Al and Sc in the calc-silicate rocks and the decoupling of these elements from Ti and Zr are strong independant evidence that the calc-silicate rocks are highly altered equivalents of unmineralized IF. In addition, the elemental assemblage of Au, As, S, W and Bi, with low enrichments of base metals, is typical of epigenetic Archean gold deposits regardless of their host lithology (Phillips and Groves 1983).

When the close spatial link between the quartz veining, the calc-silicate rocks, and mineralized IF is considered together with the structural evidence that the quartz veins were emplaced after early Archean deformation, it is certain that the mineralization and alteration is epigenetic. Together the field relationships, mineral chemistry and whole rock chemistry indicate that gold was deposited in IF by interaction between the hydrothermal fluid and the IF wallrock which caused sulphide deposition. This sulphide deposition in turn caused deposition of gold due to the breakdown of gold-sulphide complexes. The hydrothermal fluid caused intense alteration in the IF resulting in enrichments of a typical suite of elements associated with epigenetic gold deposits. The zoned sequence of unmineralized IF to mineralized IF and finally calc-silicate rocks is interpreted to represent increasing water to rock ratios in the alteration of unmineralized IF towards the veins.

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OXIDATIVE, ALKALI-AMPHIBOLE-BEARING ALTERATION AND ITS RELATION TO GOLD IN THE SYENITE-ASSOCIATED LAC SHORTT DEPOSIT, ABITIBI GREENSTONE BELT, QUEBEC, CANADA.

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The Minnova Inc. Lac Shortt gold deposit started operation in 1984 and has produced an average of 55,000 oz (2,000 kg) Au/year at an average grade of 5.4 g Au/tonne. The mine is situated approximately 120km SW of Chibougamau and 350km NE of Val d'Or, two important gold producing mining camps of the Abitibi Greenstone Belt in Quebec, Canada.

The dominant lithologies in the Lac Shortt area are steeply dipping, isoclinally folded mafic flows and volcaniclastic rocks intruded synvolcanically by a complex of pyroxenitic to gabbroic sills and numerous gabbroic dikes. Fold axial surfaces trend NE-SW, parallel to the Opawica Lake Fault, which is considered a major control on ore deposits in this region. The fault is located immediately south of the mine. The NNE-SSW trending Lac Shortt Fault, a steeply north-dipping sericite-dolomite-feldspar-green-mica schist zone, is interpreted to be a branch of the Opawica Lake Fault.

Polymictic diamictites, reminiscent of the Temiskaming Group in the Kirkland Lake area, outcrop south of the mine wihin the fault block bounded by the Lac Shortt Fault to the north and the Opawica Lake Fault to the south. The diamictite comprises angular clasts of mafic lava, banded red and black chert and nodular to lenticular fragments of massive sulphides. The Lac Shortt Main Mineralized Zone (MMZ), a highly altered and deformed zone, lies off the NE end of a small syenitic intrusion in the footwall of the Lac Shortt Fault, and is truncated on its eastern side by the latter Fig. 1). The MMZ contains abundant elongate clasts of syenite, which we interpret to be milled dike boudins. Several small mineralized shear zones splay SSW from the MMZ into the footwall sequence. The MMZ and the Lac Shortt Fault are sharply discordant to lithologic contacts in the footwall sequence. A post-ore, olivine- and phlogopite-porphyry lamprophyre dike, cuts across the ore zone into the hangingwall from the footwall (Fig. 1).

Three alteration facies series are recognized in the mafic rocks of the mine: a hangingwall sequence, a footwall sequence, and a superimposed sequence present in both the hangingwall and the footwall rocks. Alteration is invariably superimposed on the regional metamorphic assemblage, calcite-chlorite-epidote. The mafic crystal tuff in the hangingwall of the Lac Shortt Fault grades from unaltered metamorphic rocks (Fig. 1, 1H) through a zone of

dolomite-sericite (Fig. 1, 2H), to a zone of dolomite-feldspar-quartz-green-mica which coincides with the Lac Shortt Fault (Fig. 1, 3H).

Mafic sills and flows in the Lac Shortt Fault footwall grade from unaltered metamorphic rocks (Fig. 1, 1F) through zones of biotite-magnetite-calcite (Fig. 1, 2F), dolomite-albite-ankerite-pyrite (Fig. 1, 3F) to a zone of dolomite-pyrite-K-feldspar-quartz which concides with the MMZ and mineralized splay faults (Fig. 1, 4F). At least some of the pyrite in the mineralized alteration zones are pseudomorphic after magnetite. The assemblage magnesio-arfvedsonite-magnetite-albite-anhydrite-calcite-apatite (Fig. 1, 5F) is superimposed on the biotite-magnetite-calcite zone of the footwall alteration sequence. It mainly occurs in the footwall SW of the ore zone, below the 100 metre level in the mine. The post-ore lamprophyre dike is pervasively altered into quartz-calcite-dolomite-chlorite-serpentine-talc where it cuts the MMZ and to magnesio-arfvedsonite-magnetite-calcite where it cuts the hangingwall sequence.

There is a relationship between the extent of development of the biotite-magnetite-calcite-bearing alteration facies, the presence of syenite dikes and clasts, and the gold content of the MMZ. The sodic amphibole-bearing alteration appears to be post-ore and shows no spatial relationship to the ore or to major structures in the mine. The juxtaposition of different alteration facies series across the Lac Shortt Fault is attributed to movement along the fault after alteration, although it may also be due to compositional differences in the hangingwall and footwall rock sequences.

Alteration of the syenite is synchronous with the footwall alteration sequence. Unaltered syenite consists of K-feldspar and albite with minor monazite, apatite and quartz. Altered syenite consists of K-feldspar laced with albite, dolomite-albite, haematite and ankerite veinlets. K-feldspar crystal cores are commonly haematized and rimmed by clear K-feldspar which is not in crystallographic continuity with the core. Chemically, the altered syenite shows significant enrichement in CaO, CO2, Au, Ba and Sr relative to unaltered syenite.

Gold-bearing carbonate (calcite, ankerite, dolomite) veins (dikes?), occur at the intersection of the MMZ and splay faults. The veins (dikes?) contain clasts of syenite and are locally monazite-, zircon-, sulphide(pyrite, galena, aikinite)- and magnetite-bearing.

The sequence of events at Lac Shortt (Fig. 2)appears to be : intrusion of syenite, in part into the NE-SW fault system now comprising the MMZ and associated splays; coeval mineralization and brittle-ductile deformation to form the gold ore and associated zoned alteration facies, with the emplacement of carbonate veins (dikes?) late in this event; displacement on the Lac Shortt fault; emplacement of the lamprophyre dike; and formation of the sodic amphibole-bearing alteration. A genetic relationship between the Lac Shortt gold deposit (and similar deposits of the Kirkland Lake-type) and alkalic, carbonatite-associated magmatism, is suggested by: enrichment of the syenites in Ba and Sr; dike-like habit and the occurrence of monazite, zircon and aikinite in the carbonate bodies; presence of a lamprophyre dike; sodic amphibole alteration and association of the deposit with fault-related diamictites.

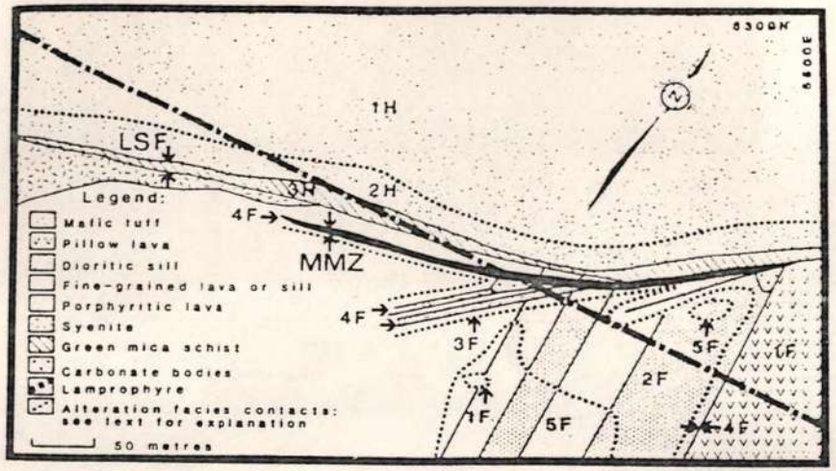


Figure 1. Schematic view of the Lac Shortt gold deposit. See text for explanation.

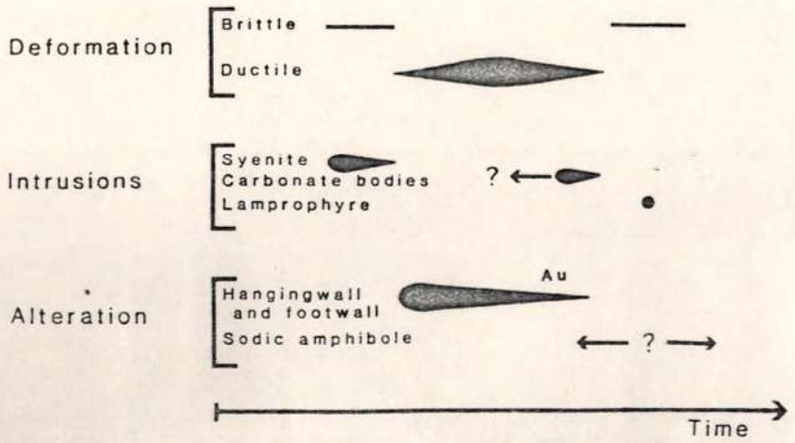


Figure 2. Sequence of events at Lac Shortt.

THE TECTONO-STRATIGRAPHIC SETTING OF THE HEMLO AU-MO DEPOSIT, ONTARIO, CANADA

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The timing of host rock formation and the relationship between mineralization and deformation in the Hemlo Belt, Ontario, have been re-evaluated because of new U-Pb dates and structural analysis. Some previous workers interpreted the supracrustal rocks of the Hemlo area to be composed largely of distal deposits of reworked volcaniclastic material derived from a major volcanic centre, near Heron Bay to the west. A minor felsic volcanic centre near Hemlo, termed the Quartz-Feldspar Porphyritic Complex (QFPC), forms the host rock to the mineralization in the west part of the deposit, and has been dated at 2772 Ma. The Heron Bay volcanic centre, however, has been dated at 2695 Ma. The considerable difference in age between the two volcanic centres suggests that there may be an unrecognized major structural break involving juxtaposed supracrustal terrains of different ages.

With respect to the Hemlo Deposit itself, some workers have interpreted mineralization to be synchronous with deposition of sediments. Others have inferred a direct association between the development of mineralization and progressive dextral shear which has affected all Late Archean rocks at Hemlo. Field evidence, however, indicates that pre-existing deformation structures, unrelated to dextral shear, may have controlled the distribution of mineralization.

The lithological units mapped in the vicinity of the Hemlo mines (Fig.1), are commonly schistose and locally gneissic. Mylonitic zones have also been identified. The QFPC comprises pyroclastic breccia, lapilli-tuff and tuff, derived volcaniclastic sediments, and sizeable subvolcanic porphyries. The structurally upper part of this unit forms part of the host rock to the alteration/mineralization in the east end of the deposit, whereas much of the west end of the deposit is contained within it in a number of zones. The rocks structurally overlying the QFPC are volcaniclastic and epiclastic metawackes and metasiltstones with interlayered iron-calcium-rich rocks referred to locally as calc-silicate rocks. Most of the rocks adjacent to this contact between the QFPC and metasediments are variably altered and mineralized (Au, Mo, As, Sb, Hg, Ba).

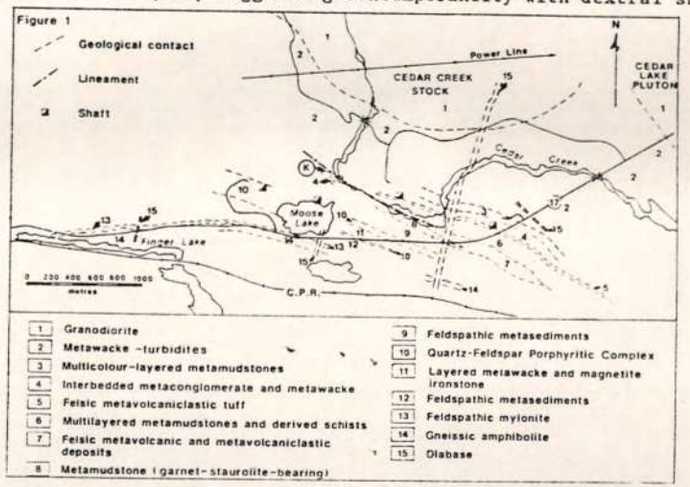
Detailed mapping shows there were at least two deformation events responsible for at least four generations of structures. The deformation history, as presently interpreted, is: 1) Isoclinal folding (F_1) and formation of layer-parallel faults or disrupted zones, possibly by either low-angle normal faulting or thrusting; 2) Very tight to isoclinal folding (F_2), accompanied by development of axial planar schistosity and differentiated layering (S_2), probably associated with sinistral shearing and mylonitization; 3) Weak to intense, locally pervasive, dextral shear, producing mylonites with s-c-c' fabrics, small-scale "Z" folds (F_3) with axial planar schistosity or crenulation cleavage (S_3), quartz rods and overrotated tension gashes, and, in the later stages, layer-parallel breccias and pseudotachylites; 4) Kinking (F_4), and brittle faulting and fracturing, commonly forming conjugate sets at high angles to layering.

A form surface map of the area is shown in Fig.2. F_1 structures have been found at only 3, possibly 4, localities, so their regional distribution and significance are unknown. Only F_2 structures are large enough to show at the scale presented. This generation of folds is regional in distribution. F_3 folds and S_3 fabrics are most abundant within and adjacent to the shear zones, although they too are widely distributed. F_4 structures are small-scale. The southwest limb of the major F_2 fold ('K' in Fig.1) has likely been displaced, because there is no apparent repetition of stratigraphy across the fold axis as exposed on Hwy. 17. However, the magnitude and the sense of displacement of the limb, and the asymmetry of the fold, if any, are presently undetermined. There is a skewness of field observations in favour of cleavage (S_2) clockwise to layering (S_1) throughout much of the area, and a predominance of mesoscopic "S"-shaped F_2 folds. This suggests that the large-scale F_2 folds have "S" asymmetry and were produced during a sinistral shear event.

The main trace of the Hemlo Fault Zone (Fig.2) is a slightly sinuous zone of intense heterogeneous shear, up to 5 m thick, which has deformed gneissic metavolcanics and Mg-rich dikes to produce respectively, phyllonites composed of amphibole+biotite+feldspar+epidote, and those composed of actinolite+talc+chlorite+biotite. The entire Hemlo Fault Zone is likely much thicker and may include the feldspathic mylonite which is adjacent to, and parallels, the main zone. Although the presently recorded kinematic indicators mainly reflect the dextral shear event, locally there is evidence that this may have been preceded by a sinistral shear event. The Hemlo Fault Zone may be the major structural break mentioned previously.

Challenges remain regarding the determination of timing of hydrothermal alteration and mineralization relative to various other geological events. The following place observations into perspective. 1) Intrusion of Plutons and Stocks: Although relatively small-scale folds in granodiorite apophyses and dikes near the margins of the plutonic bodies appear similar to F_2 folds, suggesting pre-F_2 intrusions, the form surface map shows that the trace of the S2 fabric is deformed around, and concordant to, these bodies and their internal fabrics. It is possible that the plutonic bodies post-date some of the F_2 folding event. Numerous dikes, many of which are plagioclase-phyric and granodioritic, are found throughout the area. Most dikes are parallel to S_2 and therefore post-date at least some of the development of S_2. Within zones of alteration, only some dikes are altered, suggesting multiple ages of intrusion. Many dikes show evidence of boudinage (during F_2?) followed by shortening, and crenulation of fabrics (F_3). This indicates intrusion preceded dextral shearing. Most dikes and plutons dated so far were emplaced between 2690-2686 Ma. 2) Regional Metamorphism (a) vs. Hydrothermal Alteration (b): Collectively, previous workers have interpreted: (a) before (b); (a) syn (b); and (a) post (b). There is a possibility that different workers have unwittingly related observations of various metamorphic textures (eg. porphyroblasts) to different generations of structures within zones of different types of metamorphism. Careful surface and underground mapping is imperative to avoid confusion. 3) Deposit Alteration and Mineralization: There are at least 5 types of hydrothermal alteration: potassic metasomatism (microclinization and sericitization); biotitization; carbonatization; tourmalinization; and pyritization. Limited field and geochemical evidence suggests that there are at least two stages of feldspathization; the first of these two appears to be associated mostly with Au. The later, more intense stage appears to be mostly associated with Mo, and

occurs post-S_2. U-Pb ages for rutile and monazite in ore zone units give 2650-2610 Ma, suggesting that a protracted period of hydrothermal alteration post-dated the earlier, regional, amphibolite facies metamorphism associated with granitoid intrusion. This alteration may explain some of the mosaic textures formed in parts of the ore zone. 4) Mineralization vs. Deformation: The highest grade ore in various parts of the deposit has an elongate configuration which plunges toward the northwest, roughly parallel to the orientation of F_2 fold axes and L_2 and L_m lineations in the mines' vicinity . The orebody is not folded about an F_2 structure and is considered to be syn-or post-development of F_2. F_2 and F_3 folds can be recognized in the ore zone. Presently it is not possible to distinguish between two possible cases: 1) that mineralization occurred during F_2 folding and was related to fluids and processes involved in the development of the S_2 cleavage; or 2) that mineralization occurred after F_2 folding, and the mineralizing fluids used F_2-related structures as conduits, perhaps during the dextral shear event. The ore is locally sheared, indicating that at least some shear post-dated the termination of mineralization. Locally, intense alteration is controlled along narrow shear zones, as in the QFPC, suggesting contemporaneity with dextral shear.





GOLD MINERALISATION AT THE MERTONDALE MINE, LEONORA AREA, WESTERN AUSTRALIA

B. W. Nisbet(1), and C. R. Williams(2).

The Mertondale Mine is located 30 kilometres northeast of Leonora in the Mount Margaret Goldfield of Western Australia (Figure 1).

DISCOVERY AND DEVELOPMENT HISTORY

Gold was discovered at Mertondale in March, 1899 by Fred Merton, and in the period to 1911, 88,991 tons were mined from Merton's Reward for a total of 60,524 ounces of gold, an average of 20.8 grammes per tonne (g/t) gold.

In the period 1981 to 1984 geological, ground magnetic and geochemical surveys were carried out by various companies. All work during the period concentrated on the area adjacent to the old Merton's Reward workings.

In December, 1984, Hunter Resources Limited drilled nine angled reverse circulation (RC) holes on several gold anomalies outlined by previous work, resulting in the discovery of the Mertondale 1 and 2 deposits. Following a structural evaluation of the area in April, 1985, a pattern of rotary air blast (RAB) holes was designed to test for shallow-dipping lodes to the north and south of known mineralisation. During this RAB programme in May, 1985, the Mertondale 3 Deposit was discovered in a vertical hole which assayed 7.3 g/t Au from 5-10 metres. RAB drilling recommenced to the north-northeast of the Mertondale 3 deposit in July, 1985. This RAB programme obtained some spectacular intersections, the best being 32.5 g/t gold from 0-15 metres. Subsequent RC and diamond drilling outlined the Mertondale 4 Deposit.

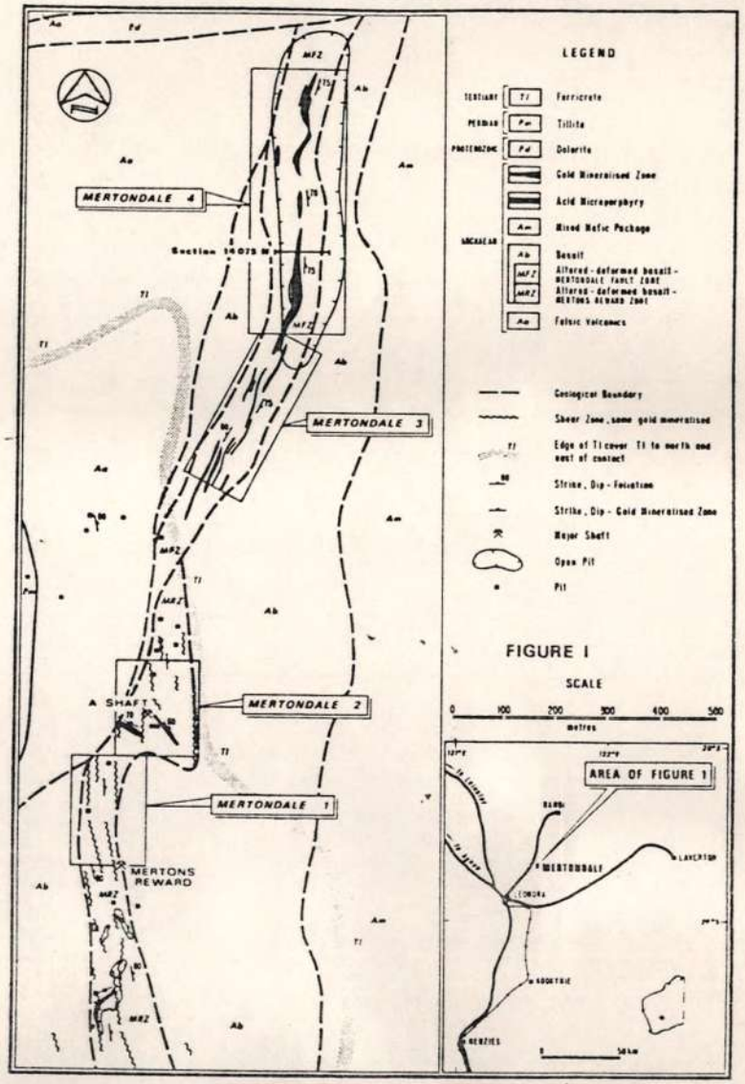
By May 1986 a total of 10,102 metres of RC and 3,710 metres of diamond drilling had been completed at Mertondale 3 and 4 to define the mineralised zone on a 25 by 12.5 m grid. In-situ geologic reserve figures were calculated in May, 1986, and in June 1986 a pre-feasibility study was initiated. A Notice of Intent to Mine was submitted to the W.A. Department of Mines in August, 1986, and a joint venture agreement to treat ore from the Mertondale 4 Deposit was signed with the Harbour Lights Joint Venture Participants in August, 1986.

Stripping of the laterite cap at the Mertondale 4 Deposit commenced in mid-October, 1986, and the first ore was delivered to Harbour Lights in late-November 1986. The first gold was poured on December 22, 1986, some 17 months after the discovery of the Mertondale 4 Deposit. During 1987, 304,054 tonnes were milled from the Mertondale 4 Deposit to produce 41,412 ounces of fine gold.

GEOLOGICAL SETTING

The Mertondale region is underlain by mafic and acid volcanics

intruded by granitoids of Archaean age. In the Mertondale Mine area (Figure 1), a sequence of felsic volcanics, basalts, acid porphyry, dolerite and dunitic ultramafic rocks are exposed. A Proterozoic dolerite dyke intrudes the Archaean sequence north of the Mertondale 4 Deposit. Permian glaciogene rocks up to 70 m thick cover part of the area and ferruginous hardpan up to 5 m thick forms an extensive surficial cover.



MINERALISATION

Four gold deposits have been delineated at Mertondale (Figure 1). The Mertondale 1 and 2 Deposits are located in the vicinity of the old Merton's Reward workings and represent extensions of this mineralisation. The Mertondale 3 and 4 Deposits are contiguous over a 900 m strike length, commencing 700 m north-northeast of the Merton's Reward main shaft. Mertondale 3 and 3 are covered by up to two metres of barren hardpan and both deposits represented totally 'blind' exploration targets.

The Mertondale 4 Deposit is owned 66.3% by Hunter Resources Limited and 33.7% by the Harbour Lights Joint Venture Participants. A probable in situ ore reserve of 1,013,000 tonnes at 4.8 g/t gold has been calculated for the Mertondale 4 Deposit. The Mertondale 3 Deposit is the subject of a joint venture between Hunter Resources Limited (50.6%), Strategic Minerals Corporation N.L. (23.39%), Climax Mining Limited (24.69%), and prospectors (1.25%). A probable in situ ore reserve of 284,000 tonnes at 2.5 g/t has been defined at this deposit. Drilling of the Mertondale 1 and 2 Deposits is currently too widely spaced to define reserves.

Significant differences exist between the style of gold mineralisation at the Mertondale 1 and 2 Deposits (Merton's Reward Style) and the Mertondale 3 and 4 Deposits (Mertondale Fault Zone Style).

Merton's Reward Style

Two types of mineralisation are recognised:

(1) Shear Lode Mineralisation

This type consists of steeply dipping bodies, usually less than 1 m thick, dipping parallel to the local foliation. These lodes are continuous along strike for 50-100 m, and they usually grade at greater than 30 g/t gold. The lodes are highly foliated parallel to their dip and strike, with abundant quartz-carbonate veinlets parallel to foliation. Gold mineralisation is usually associated with 5-10% finely disseminated pyrite-arsenopyrite in a sheared sericitised-carbonated basalt.

(2) Intershear-Lode Mineralisation

This type consists of narrow, flat (0-40 degrees) to moderate (60 degrees), east to northeasterly dipping quartz veins, from which most of the gold at Merton's Reward was mined. These veins attain a maximum thickness of 40 cm, and are contained within a highly carbonated, pyritic alteration halo up to 12 m thick. The vein selvedges contain up to 20% pyrite, 5% arsenopyrite, and 90% ankerite and/or siderite. Gold is typically concentrated in the central quartz veinlet (usually assaying greater than 30 g/t gold), but the selvedge may average up to 8 g/t gold.

Intershear lodes can be up to 40 m wide along strike and are usually bounded on their eastern and western sides by shears and/or shear lodes. In some cases intershear lodes overprint shear lodes, and it is probable that the two developed contemporaneously.

Mertondale Fault Zone Style

The Mertondale 3 and 4 Deposits are located within a strongly sheared zone of variably carbonated and sericitised rocks known as the Mertondale Fault Zone. Within the shear zone a number of units can be recognised, representing varying degrees of carbonation, sericitisation and shearing of a basalt parent lithology.

Drilling at Mertondale 3 and 4 has outlined a series of steep easterly dipping, locally overturned and folded lenses of gold mineralisation over a strike length of at least 900 m. Mineralisation has been subdivided into three zones: A Zone, B or Main Zone, and C Zone (Figure 2). B Zone is intimately associated with a silicified albite microporphyry and adjacent massive and schistose, intensely carbonated and sericitised basalts. Generally the strongest mineralisation is in the altered basalts in the hanging wall of the porphyry. The A and C Zone lenses occur in the footwall and hangingwall respectively of the B Zone mineralisation and are associated with strongly silicified and/or pyritised carbonated basalt. These lenses are generally smaller than B Zone lenses, and are more erratically distributed both along strike and down dip.

All mineralised zones contain pyrite and arsenopyrite, generally present as fine grained crystals up to 1-2 mm in diameter in elongate clusters parallel to the foliation. Locally the sulphide content is up to 30% by volume, although most lenses average between 5 and 10% sulphides.

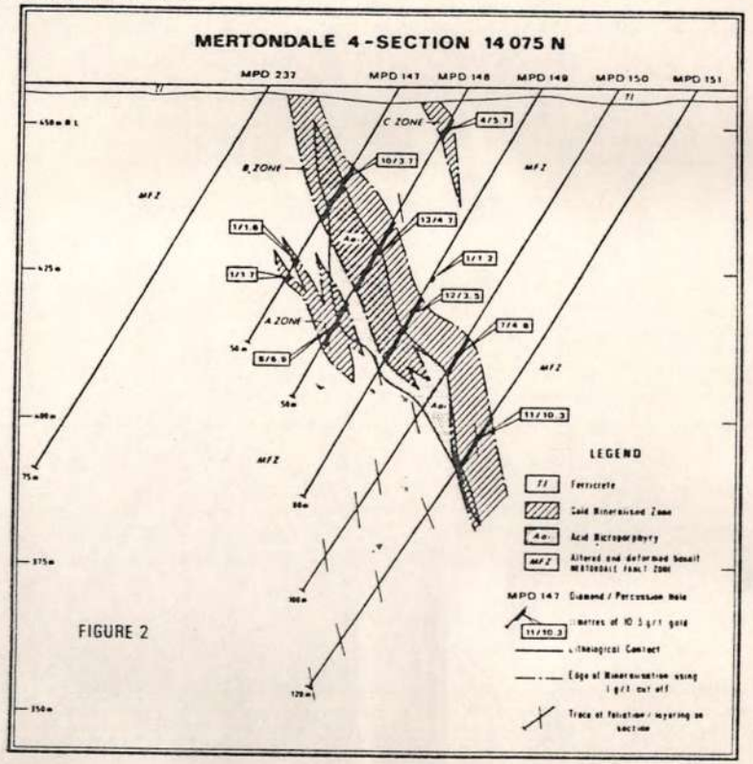


FIGURE 2

Alteration

The mineralised zones at Mertondale show varying degrees of carbonate, potassium and silica alteration, as well as erratically

distributed pink haematite alteration. Carbonate alteration is pervasive within the shear zone which hosts the Mertondale 3 and 4 Deposits, and forms a distinct alteration zone up to 200 m thick within which the mineralised lenses occur. At the Mertondale 1 and 2 Deposits alteration is largely restricted to selvedges a few metres thick on either side of the narrow quartz veins which were mined.

STRUCTURE

At Mertondale 1 and 2, mineralised areas are generally bounded by steeply dipping, strongly foliated zones a few metres thick which parallel the local foliation. These represent zones of intense shearing, and are regularly spaced 20 to 40 metres apart in a zone 50 to 150 m wide. Although the rocks in the shears are highly strained, metabasalt between the shears is generally only moderately or weakly foliated, exhibiting relatively low strains. This sheared/mineralised area is shown as the Merton's Reward Zone (MRZ) in Figure 1.

At the Mertondale 3 and 4 Deposits, a package of mineralised and altered basalt and microporphyry about 100 m thick is highly foliated and has been highly strained. This is the Mertondale Fault Zone, which corresponds to the MFZ unit in Figure 1. A strong foliation or cleavage developed in the sheared and mineralised rocks of the Mertondale Fault Zone is parallel to the strike and dip of the microporphyry-basalt contact and the shear zone.

The Mertondale Fault Zone is considered to be a strike-slip fault with sinistral sense of movement. Strain in the Mertondale Fault Zone is much higher than in the Merton's Reward Zone, and structurally the two zones have significant differences. It is probable that the two zones are contemporaneous, but that the Merton's Reward Zone is a splay fault or a structure related to a regional jog in the Mertondale Fault Zone in the vicinity of Merton's Reward and the Mertondale 3 and 4 Deposits.

INTERPRETATION AND GENESIS

Gold mineralisation at Mertondale is located in the Merton's Reward Zone and the Mertondale Fault Zone, and the most highly altered and gold-mineralised rocks are always associated with strong deformation. It is considered that alteration, deposition of the gold and sulphide mineralisation, and deformation in the Merton's Reward and Mertondale Fault Zones were coeval.

THE GEOLOGY AND GEOCHEMISTRY OF GOLD-ANTIMONY MINERALISATION IN THE KWEKWE GOLDFIELD, ZIMBABWE.

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INTRODUCTION

The Kwekwe goldfield covers an area of 80 km2 and has been Zimbabwe's single largest gold province. Since 1892 more than 180 tonnes of gold and 4500 tonnes of antimony concentrates have been produced from 40 gold and gold-antimony mines. The goldfield is situated within the Bulawayan Upper Greenstones succession c 2700 Ma, the c 2800 Ma Kwekwe tonalitic gneiss, that contains earlier Sebakwian meta-volcanic and sedimentary remnants, and the Kwekwe Ultramafic Complex (Fig.1). The greenstone terrain is dominated by tholeiitic lavas with minor intercalated pillowed and agglomeratic units, the other major lithology is jaspilitic iron formation consisting of discontinuous bodies, with alternating thin chert and quartz-hematite bands, and rare magnesio-siderite meso-bands (Nutt et al in prep.). Serpentinised enstatite peridotites and pyroxenites comprise the bulk of the Kwekwe Ultramafic complex, which forms a 2 to 5 km wide intrusion cutting into both the greenstone belt and the adjacent gneiss.

The tectonic history is dominated by a regional compressive event that folded the greenstone belt into a northerly trending syncline and is associated with steeply dipping, northerly-striking shear zones with lineations indicating dip-slip movement. Where these shear zones cut across the Kwekwe Ultramafic Complex the dominant lithologies become magnesite rocks and silicified serpentinites. Regional metamorphism is generally lower greenschist facies, as indicated by abundant chlorite in the mafic lavas.

MINERALISATION

An Au-As-Sb vein-type mineralisation occurs throughout the area. The Globe and Phoenix Mine is the largest gold deposit of this type where a series of quartz carbonate veins transgress altered gneissic tonalite, serpentinites and magnesite-rich units. The vein system shows zoning with increasing stibnite, galena and boulangerite with depth. Pyrite and arsenopyrite are largely confined to the wall rocks. The adjacent BD and Primrose mines contain stibnite-bearing quartz-filled fissures cut by later, barren ankeritic veins. Both have distinct "payshoots", and the BD gold-antimony ore abruptly faded out approximately 270 metres below surface although the vein persisted at least another 100 metres. The antimonial veins of the Primrose Mine are cut by a later, steeply dipping auriferous shear zone, the Lion "reef" containing abundant pyrite and arsenopyrite. The alteration of the vein type ore in the Primrose Mine is controlled by the host rock; granitic hosts have abundant mica whereas the mafic and ultramafic varieties have minor white mica and more common ankerite. Fuchsite has only been identified from the Lion "reef".

The Indarama, and Anzac mines, hosted by tholeiitic lavas are situated 9km further north. They comprise shallow dipping veins and shear zones. Both have S-C fabrics indicating reverse movement and mineral lineations in parts of the Indarama ore zones indicate dip-slip to oblique slip movement directions. The ore assemblages are dominated

by veins rich in stibnite and minor berthierite, enclosed in pyrite and arsenopyrite-rich wallrocks. Fuchsite occurs within the bleached wall rocks as dark green sharply defined localised patches.

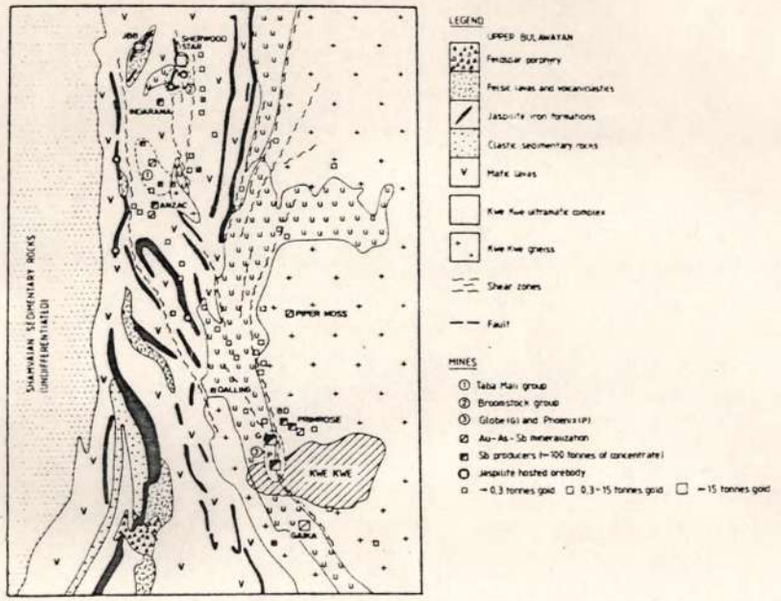


Fig. 1 Geology, and distribution of mines in the Kwekwe goldfield.

Gold deposits hosted by brecciated jaspilitic iron formations form the second major ore category. The largest deposit, the Sherwood Star, consists of shattered jaspilite enclosed in mafic and talc-carbonate or fuchsite schists. The nearby Broomstock group is hosted by similar rock types; the ore comprises disseminated generally fine-grained pyrite and arsenopyrite, replacing the both the hematite-rich and magnesio-siderite carbonate bands and extending outwards from thin, sub-horizontal quartz stringers containing minor gersdorffite and tetrahedrite. These ore-related veins cut across earlier carbonate-cemented brecciated jaspilite, with coarse cubic pyrite and only sub-economic gold concentrations. The iron-formation orebodies are surrounded by ankerite + muscovite + quartz schists which contain sub-economic gold concentrations. S-C relationships and mineral lineations, in these schists, show steep reverse movement directions. These schists occur as part of the major set of shear zones, and where mineralised contain pyrite and arsenopyrite, with minor galena and sphalerite. Fuchsite is present as an alteration product.

Lead isotope compositions (Table 1.) have been obtained for 10 deposits from the Kwekwe. Use of a lead isotope model, based on the isotopic and zircon U-Pb ages for massive sulphide deposits in the western Superior Province yields model ages of 2977 to 3013 Ma for the 6 most primitive analyses. These include the Piper Moss, Blucher, and BD deposits. Leads from the Golden Pheasant, Ardpatrick and Broomstock have model ages of 2755, 2599 and 2583 Ma respectively.

For 10 of the analyses, the calculated source values (mu) of 9.882 to 10.324 are significantly higher than those values for the Yilgarn Block (9.284 - 9.665) and the Superior Province (8.630 - 9.211). In comparison their high source mu values are compatible with

data obtained from other Zimbabwe gold deposits (Kramers and Foster 1984), and from deposits in the Canadian Wabigoon sub-province(Sage et al 1987) and the Norseman area of the Yilgarn Block (Browning et al 1987). The generally invoked and most reasonable explanation for such leads in that they have been extracted from or reflect the recycling of materials from long-lived upper crustal sources.

Table 1. Lead isotopic data for the Kwekwe goldfield.

Locality	206/204	207/204	208/204
BD	13.590	14.964	33.270
BD	13.429	14.893	33.023
BD	13.450	14.910	33.092
Blucher	13.360	14.858	32.900
Broomstock	14.023	14.980	33.690
Cactus ♦	13.599	14.894	33.343
Globe and Phoenix	13.577	14.916	33.234
Golden Pheasant	14.291	15.474	33.056
Piper Moss	13.294	14.789	32.737
"Kwekwe area" *	13.353	14.816	32.830
"Kwekwe area" *	13.357	14.822	32.849
Ardpatrick	14.266	15.234	33.673

* : Re-analysis of samples obtained by Robertson (1969).
♦ : Situated 12km south of Kwekwe.

Electron microprobe analyses of fuchsites from the alteration haloes of some of the mines all show a low Na content, a variable degree of phengitic substitution and a limited amount of Cr and V substitution (Table 2). Within this framework the Broomstock micas are mostly Na deficient, and also the most phengitic, with upto 3.66 atoms per Si formula unit. Cr contents are variable, with up to 2 % Cr2O3 at the Indarama Sherwood Star and Broomstock. The Na low contents a indicate a high K+/H+ ratio in the mineralising fluid.

Table 2. Fuchsite analyses from some Kwekwe gold deposits.

Element	Indarama	Broomstock	Sherwood Star	Monti Cristo
SiO2	48.50	53.88	46.37	49.09
TiO2	0.30	0.09	0.05	0.08
Al2O3	33.99	33.63	32.59	34.31
Cr2O3	0.84	1.01	2.14	0.03
V2O3	0.11	0.07	0.08	0.04
FeO	0.83	1.42	0.84	1.46
MgO	1.07	1.33	3.46	1.00
MnO	0.02	0.01	0.01	0.03
CaO	0.15	0.06	0.11	0.06
Na2O	0.29	0.17	0.33	0.32
K2O	9.93	10.01	7.32	9.55
Number of cations based on 11 oxygens.				
Si	3.183	3.517	3.111	3.213
Al tet	0.817	0.483	0.889	0.787
Al oct	1.807	1.867	1.686	1.855
Cr	0.043	0.054	0.113	0.002
V	0.006	0.004	0.005	0.002
Ti	0.015	0.005	0.003	0.004
Fe	0.045	0.078	0.047	0.080
Mg	0.105	0.132	0.363	0.098
Mn	0.001	0.000		0.002
Ca	0.011	0.004	0.008	0.004
Na	0.037	0.022	0.043	0.041
K	0.836	0.832	0.627	0.797
Number of analyses	16	17	5	3

Abundant pyrite and arsenopyrite, in the vein walls of most orebodies indicate the deposition of gold in response to the sulphidisation of Fe-rich minerals. Late stage development of stibnite in the veins is possibly in response to decreasing fluid pressure. The common muscovite + carbonate + quartz alteration assemblages and the enhancement of Au, As and Sb in most orebodies is suggestive of metamorphically derived hydrothermal fluids, which is supported by a paucity of nearby granitoid intrusions contemporaneous with the mineralisation. The association of mineralisation with thrusting indicates fluid generation during late Archaean compressional tectonics. Initial fluid movement was up the almost vertical shear zones. More brittle deformation during continued horizontal compression produced the later sub-horizontal fractures in the Indarama and Broomstock orebodies. The widespread carbonate alteration indicates CO2-bearing fluids that, in the Broomstock and Globe and Phoenix orebodies may have preceded the main gold deposition event.

The lead isotopic data indicates lead (and probably gold) were derived from the passage of fluid through either older crustal material or re-working of earlier Archaean rocks, in this instance the Kwekwe gneiss and included Sebakwian remnants. The high mu character for all leads from this and other Zimbabwean goldfields suggest formation of Zimbabwean greenstone belts in ensialic rifting environments.

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GEOLOGY OF THE LANCEFIELD GOLD DEPOSIT

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B.J. Goss (Western Mining Corp. Ltd.)

The pre-mine size of the Lancefield gold ore-bodies is estimated to have been 6.17 million tonnes at 8.57g/t Au, containing 1.78 million ounces (52881kg.) of gold.

Gold mineralisation at Lancefield is hosted by two sets of interflow sediments within a basalt flow sequence consisting of successive zones of komatiite, magnesian tholeiite and tholeiite flows. At the base of the basalts is a peridotite breccia which progressively transgresses the lower basalt flows and lode-hosting sediments to the south. The basalt sequence dips 30-50° east, close to a granite margin and is at upper greenschist metamorphic facies.

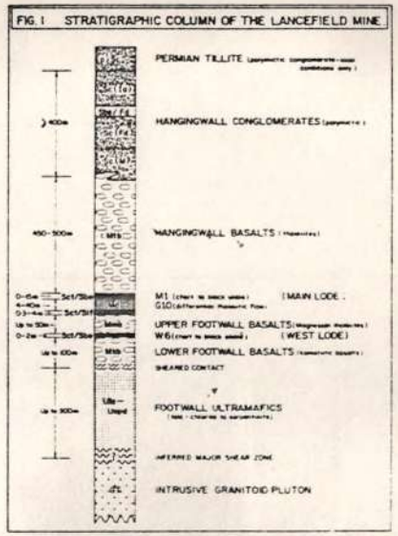
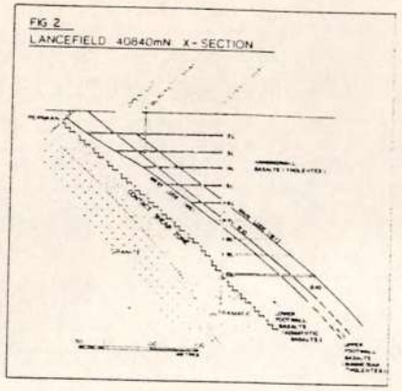


FIG. 1 STRATIGRAPHIC COLUMN OF THE LANCEFIELD MINE

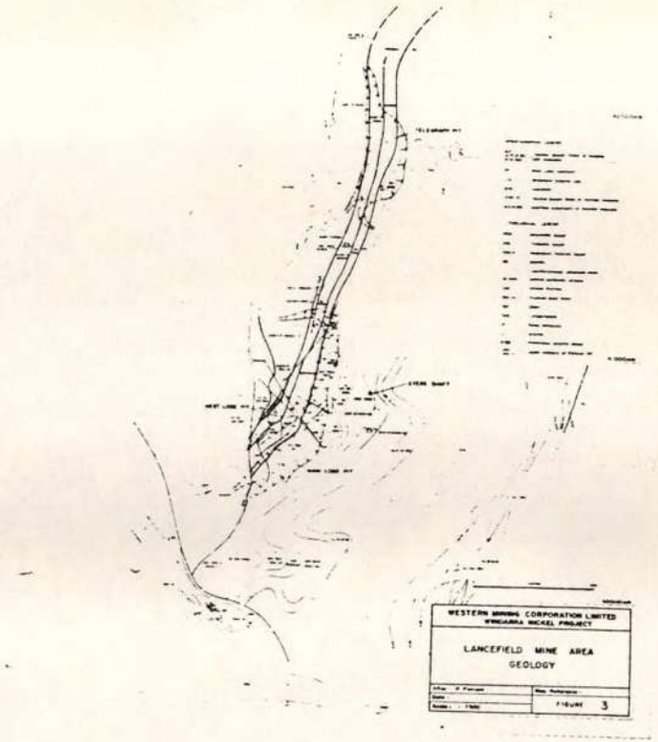


The Main Lode is hosted by the most prominent interflow sediment, a black sulphidic chert and shale horizon 0 to 8 metres thick, located on the contact between an underlying massive differentiated tholeiitic basalt flow and overlying pillowed tholeiitic basalt flows. Locally, a second sediment is separated from the main horizon by a few metres of basalt. The West Lode, in the footwall to Main Lode, is hosted by cherts and basalts, 0.5 to 2 metres thick, at the contact between underlying komatiitic basalts and overlying magnesian tholeiitic basalts. An iron formation 0.5 and 1 metre thick, located between the two lode horizons at the contact between the magnesian tholeiites and the massive differentiated tholeiite flow, is not known to be ore-bearing.

Ore zones in Main Lode are sulphidic carbonate-silica cherts and bleached basalts with carbonate-quartz veins. A pyrite-arsenopyrite association which tends to contain the higher grades and an ore-grade pyrrhotite - arsenopyrite association are present. Gold is contained in sulphides, with up to 1000ppm Au in arsenopyrite.

Basalts associated with the lodes are extensively hydrated and carbonated, with development of chlorite - carbonate - quartz bearing assemblages. Sericitisation with bleaching and sulphidation (sometimes with ore-grade Au) is restricted to 0.2 - 2m zones above and below the lodes.

Near the southern pinchout on the transgressive ultramafic contact, the lode horizons are warped into a broad antiform, plunging down-dip, with the second order sub-horizontal folds.



The gold grades within the Main Lode are controlled by a subtle interplay of factors:

1. Proximity to the southern pinchout of the hosting sediment on the ultramafic contact, with a narrow low grade zone close to the pinchout, followed by the main high grade zone along strike.

2. Proximity to the main antiform with highest grades along the crest on the south side.

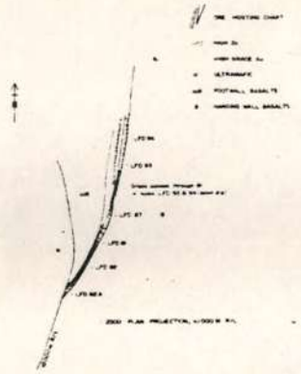
3. Proximity to sub-horizontal folds, with higher grades on the down-dip sides of antiforms/up-dip sides of synforms.

4. Deformation and composition of the hosting sediments; high grade lode is hosted by sulphidic chert and bleached basalt and (particularly where pyrrhotite dominant) is heavily deformed, with gold-bearing sulphides controlled by deformational fabrics. Lower grade areas are less deformed and more shaley.

High grade West Lode is localised close to the pichout of that sediment horizon on the ultramafic contact.

In the Deeps ore zone of Main Lode (where there are locally two sediment horizons), Cu and Zn are zoned in the lode-hosting sediments with higher values (1,000-10,000ppm Zn, 100-1,000ppm Cu) near the top of each horizon, consistent with a sea-floor hydrothermal origin for the sediments. High grade Main Lode ore is slightly discordant to stratigraphy, running from the footwall basalt on the south margin progressively through the sediments and intervening basalt into the hanging wall basalt to the north.

FIG 4 SEMI - SCHEMATIC PLOT OF HIGH - GRADE Au vs Zn ZONING LANCEFIELD DEEPS ORE ZONE



The high grade Au lode is considered to be epigenetic, formed in an interflow sediment of relatively favourable iron-rich composition where it takes up favourable structural orientations close to a pinchout against ultramafic rocks.

POSSIBLE MULTI-PHASE MINERALIZATION IN CONCORDANT AND DISCORDANT GOLD VEINS, DOME MINE, SOUTH PORCUPINE, ONTARIO

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Since its discovery in 1909, the Dome Mine has produced 400 tonnes of gold from over 40 million tonnes of ore. It is the largest operating gold mine in the Porcupine camp, and existing reserves ensure its survival into the mid 1990s. Gold has been mined from a variety of ore types in a block over 2.5 km long, 1.2 km wide and 1.4 km deep.

The ores are hosted in regionally metamorphosed greenschist facies Archean volcanic and sedimentary rocks. Attention is focused on two structurally and morphologically different types of gold vein; one concordant, the other discordant. These veins are exposed together in several active stopes, the latter clearly cross-cutting the former. The possibility that gold mineralization occurred in at least two phases is therefore being investigated. Microprobe and major and trace element analyses have been undertaken to define the geochemical characteristics of these two vein types in order to establish their similarities and differences. This work assesses possible relationships between vein types, with particular reference to mechanisms of gold transport and deposition.

Metavolcanic rocks consist of pillowed and massive tholeiitic flows with thin tuffaceous interflow units at several stratigraphic horizons in the succession. The first vein type is concordant with this metavolcanic sequence and forms layers within the tuffaceous strata. These veins can also be traced along strike into laterally conformable polymictic metaconglomerates, metagreywackes and slates. At first glance, these concordant veins appear to belong to one of two discrete mineral assemblages. The most economically important veins are composed of ankerite + quartz + pyrite +/- sphalerite and range in thickness from a few centimeters to over 2 m. Thin veins extend laterally for only a few meters, but major ones, 20 of which have been mined, persist for up to 500 m. Compositional layering defined by alternating ankerite- and quartz-rich laminae is occasionally present. Microscopic free gold is common, but visible gold is rare. Concordant veins of the second assemblage are of lesser importance. They contain quartz + tourmaline (dravite) + pyrite +/- pyrrhotite and are 5 to 10 cm thick. These exhibit excellent compositional layering, defined by laminae of tourmaline up to 2 mm thick within the prevalent quartz. Microscopic gold is included within pyrite and gold concentrations of up to 350 ppb have been recorded in the veins. Closer examination of both the ankerite + quartz and quartz + tourmaline veins reveals them to represent end-members of a variable vein mineralogy. Veins of the first assemblage have been traced continuously into those of the second along a drift. This transition occurs entirely within the metavolcanic succession.

The second vein type is an en echelon set of discordant, lenticular quartz veins which transect the first, concordant type. They contain milky quartz, up to 5% pyrite with or without pyrrhotite, chalcopyrite, sphalerite, and coarse ankerite as an accessory gangue mineral. Veins range from 5 to 30 cm thick and are usually less than 5 m long, with a vertical extent of 2 to 5 m. Coarse, free gold is common, and microscopic gold occurs within pyrite grains. A higher content of sulfide minerals generally indicates better gold grades that can exceed 30 ppm. The metavolcanic wallrock is moderately carbonatized and often contains parallel, weakly mineralized quartz stringers.

Field observations and geochemical data suggest that the concordant veins are auriferous chemical sedimentary beds. This is apparent in one drift where an ankerite vein is traceable continuously into laterally equivalent black slate. Both have undergone tectonic

ductile deformation, but primary structures are still visible. This ankerite vein has a basal pyrite layer, overlain first by a tourmaline and then by a very fine-grained quartz layer. These in turn are overlain by ankerite containing two discrete pyrite bands similar to the basal one. The black slate contains numerous 1 to 3 mm thick carbonate layers which show soft sediment deformation overprinted by the tectonic deformation. Both vein and slate contain over 1 ppm gold. The black slate is also anomalously high in Ni, Cu, Co, Zn, and W. Gold values in the ankerite vein persist for several tens of meters along strike from their interesctions with the thin, cross-cutting, clearly epigenetic gold veins. The latter are thus an improbable source for gold in these chemical sedimentary strata.

Rare earth element analyses of both ankeritic and tourmalinitic concordant veins yield results consistent with an Archean seawater source. Both are relatively depleted in heavy rare earth elements and exhibit positive europium anomalies.

In several places, laminae within these chemical sedimentary rocks also contain textures indicative of brittle deformation. Laminae are broken, rotated, and in places fragments have been moved a few centimeters. Small veinlets of quartz and ankerite originate from within these chemical sedimentary strata and cross-cut the foliation in the metavolcanic wallrock. It seems reasonable that prolonged deformation and concurrent thermal metamorphism would result in generation of larger cross-cutting quartz veins.

Microprobe analyses of gold grains from all vein types reveal distinct differences in gold to silver ratios. Gold grains in ankeritic veins consistently contain just over 91% gold and approximately 8.5% silver, whereas gold grains in tourmalinitic ones consist of 80 - 82% gold, 17 - 18% silver and detectable mercury (0.5 - 0.7%). Discordant quartz veins contain gold grains composed of 89.5 - 91% gold and up to 10% silver. These results indicate consistent and significant differences in the composition of gold grains between the two end-member varieties of concordant veins. Also, there are differences, albeit less distinct, between the concordant and discordant veins even in samples taken only a few meters apart. Such differences do not support the hypothesis of a single episode of gold mineralization for all vein types.

From the field relationships and geochemical study, two distinct types of gold-bearing lodes have been identified. Their structural setting, lateral and vertical extent, mineralogy, and geochemical characteristics are quite different. Geochemical analyses of the concordant veins indicate their chemical sedimentary nature, and variable gold to silver ratios within these rocks are not readily explained by epigenetic processes. However, facies variations along strike in chemical sedimentary strata, well known in many exhalative deposits, may account for them. The internal structure of these chemical sedimentary rocks indicates that they have been tectonically and perhaps diagenetically deformed, sometimes resulting in penetrative veinlets, of similar but coarser mineralogy, cross-cutting the flanking country rock.

The discordant, clearly epigenetic quartz veins formed in en echelon sets during the later tectono-metamorphic event. The gold to silver ratio of gold within these veins is similar to that in the ankerite + quartz-rich end-member of the chemical sedimentary rocks, but is intermediate between that of the two concordant vein end-members. This may be an expected result if the discordant veins formed, as suggested, by tectono-metamorphic remobilization from a combination of these two end-members. Further investigations are in progress to assess the role of remobilized gangue and metallic minerals in forming these veins.

ARCHAEAN VOLCANIC AND SEDIMENT HOSTED GOLD MINERALISATION IN GADAG GOLD FIELD, KARNATAKA, INDIA.

U.S.REDDY, C.CHAKRABARTI & W.K.NATARAJAN

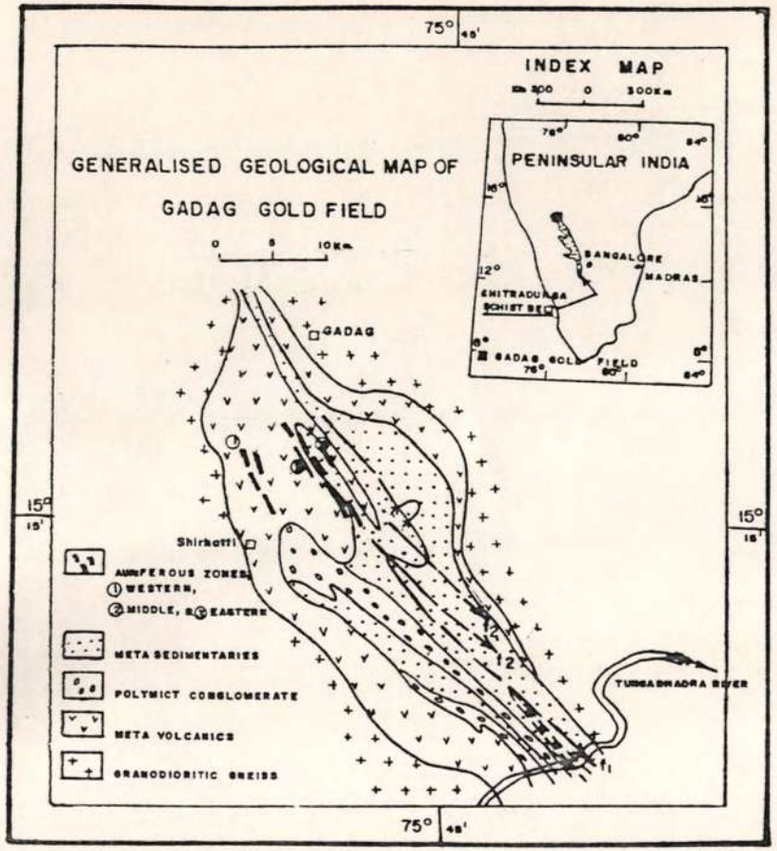
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The Gadag gold field occupying an area of 120 sq.km lies in the northern part of Chitradurga greenstone belt of middle to late Archaean age. This supracrustal belt belonging to the Chitradurga Group of Dharwar Supergroup (1) (2600 to 2400 Ma.) consists of an interbanded sequence of mafic to felsic volcanics with thick piles of metasedimentaries and is surrounded by granodioritic migmatite gneiss.

In Gadag gold field, the metavolcanics are represented by quartz prophyry, rhyodacite to basaltic andesite. These are overlain by a thick pile of metasedimentaries (argillite-arenite-arkose-greywacke suite of rocks, banded iron formation, impure limestone and polymic-tic conglomerate). Ultramafic schists are present along the eastern margin of the belt. Basaltic andesite, the major unit of metavolcanics is tholeiitic in chemistry and exhibits pillow structures. Thin intercalations of carbonaceous schist are occassionaly present. The metasedimentaries show a variety of primary structures and a critical study of them indicated depositional conditions of tidal flat to pro-deltaic, fluviatile environment with low to medium hydrodynamic energy regime. Two sets of basic dykes (dolerite/gabbro) trending NNW-SSE andENE-WSW transect all the rock formations.

The general trend of bedding(S_0) in the sedimentaries is NNW-SSE with dip varying from 20-50^0, towards ENE. The regional trend of schistosity both in the metavolcanics and metasedimentaries is more or less parallel to S_0. The rocks have been folded into regional tight overturned to isoclinal overturned folds (f_1) with the axial plane trending NNW-SSE and dipping at about 50^0 towards ENE (2). The gold field proper forms a part of the normal low dipping (25-40^0) western limb of one such overturned synforms. The second deformation which is mainly coaxial, produced a set of mesoscopic folds (f_2) and fracture cleavage followed by a third phase of deformation (f_3) evidenced by puckers and warps with their axis trending almost east-west. The rocks have been subjected to green schist-lower amphibolite facies of metamorphism.

Three distinct auriferous zones designated as Western, Middle and Eastern zones, occur along a system of structurally dilatant, ductile-brittle shears which are parallel or sub-parallel to the regional trend of the axial plane schistosity formed by f_1 folds. They dip towards east at 25 to 45^0.



The western zone, hosted by basaltic andesite is characterised by quartz and quartz-carbonate veins with prominent wall-rock alteration like sericitisation, chloritisation, albitisation and carbonatisation. The lode zones carry disseminations and stringers of arsenopyrite, pyrite, chalcopyrite, pyrrhotite and sphalerite. Scheelite occurs in association with quartz-calcite veins only in this zone. Feeble gold mineralisation is also noticed along narrow 'enechelon' shear zones within quartz porphyry bodies. The shear zones are marked by well developed foliation and contain veinlets of quartz with profuse arsenopyrite.

The Middle zone of mineralisation located about 5 km east of the Western zone occurs both in the metavolcanics and metasedimentaries but in close proximity to the regional litho-contact. This zone which is the most prominent of the three, has a strike length exceeding 10 km. It is characterised by intensely brecciated

quartz-carbonate veins. Quartz veins are of more than one generation and the mineralisation is associated with the smoky quartz of first generation. The auriferous zones occuring within metasedimentaries are marked by feeble wall-rock alteration with narrow zones of chloritisation, sericitisation and kaolinitisation. In the auriferous zones, the sulphides occur as disseminations and stringers and include pyrite, pyrrhotite, arsenopyrite and chalcopyrite. In the Middle zone, confined to the metasedimentaries, narrow auriferous quartz veins occur along tension fractures developed during f_3 deformation. They vary in width from 5 to 20 cm and trend in a general ENE-WSW direction with steep dips.

The Eastern zone is located about 3 km east of the Middle zone and is hosted entirely by metasedimentaries (chert and argillite), which are intensely carbonatised. The auriferous quartz occurs as veins and veinlets within sericitised zones over limited strike lengths. Sulphides (pyrite and arsenopyrite) are sparsely distributed.

Gold occurs in native state in quartz veins and is of the order of 5 to 10 microns in size. It also occurs as inclusions within pyrite and as 'droplets' in arsenopyrite. There is no lithological control as the mineralisation occurs in various lithounits namely, basaltic andesite, quartz prophyry, argillite, arenite, arkose, greywacke and banded iron formation of Algoma type. Gold mineralisation is epigenetic and is mostly shear controlled with remobilisation taking place during the second fold (f_2) movement with the ore-shoots forming at the intersection areas of early and late folds.

The ore bodies in the different prospects presently being explored vary in strike length from 200 to 800 m and in width from 0.5 to over 6 m. They are of medium size with 3 to 5 grammes of gold per tonne.

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THE GEOLOGY OF FAIRVIEW GOLD MINE, BARBERTON, SOUTH AFRICA

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INTRODUCTION

Fairview Gold Mine is one of the four major producing gold mines within the 3,3 to 3,5 Ga Barberton greenstone belt. Since mining commenced in 1886, 49950kg of gold and 1628kg of silver have been produced from 5,05 million tons of ore (1987).

REGIONAL GEOLOGY

The Barberton Greenstone belt is the largest and best preserved Archaean volcano-sedimentary sequence in the Kaapvaal Province. The Barberton Sequence consists of a lower volcanic unit (Onverwacht Group) which is overlain by sediments (Fig Tree and Moodies groups). A wide range of granitoids varying in age from 2,6 to 3,5 Ga surround and intrude the sequence. The belt has been subjected to numerous phases of deformation and generally exhibits regional greenschist facies metamorphism .

MINE GEOLOGY

The mine is situated in an intensely deformed area some 3km from a ~3,3 Ga intrusive tonalitic pluton. Lithologies from all three groups that constitute the Barberton Sequence occur within the mine. The Onverwacht Group is represented by sheared and altered metavolcanics that are overlain by a banded chert (Zwartkoppie Formation). The metavolcanics, which are crudely stratified, commonly contain preserved spinifex textures. Typically, grey talc-carbonate and quartz-carbonate schists are overlain by green fuchsitic quartz/carbonate schists. This is followed by a black, grey, white +/- green banded chert which is commonly capped by a thin (5cm - 20cm) unit containing spheroids (1mm - 2mm diam.). These spheroids are interpreted as accretionary lapilli. This sequence is conformably overlain by greywacke, shale and minor interbedded cherts of the Fig Tree Group. Feldspathic and calcareous quartzites of the Moodies Group have been structurally emplaced adjacent to the other two groups. The mine area is intruded by pre-mineralization age feldspar-quartz porphyry dykes, and post-mineralization age dolerite dykes.

Structurally the mine is situated on either side of the steeply dipping (50°) Sheba Fault which separates two major refolded synclines (namely the Eureka Syncline to the north and the Ulundi Syncline to the south). Steeply dipping (60° - 70°) overturned Moodies Group quartzites occur within the Eureka Syncline while Fig Tree Group greywackes and shales and lesser Onverwacht Group metavolcanics and cherts occur within the Ulundi Syncline. The Onverwacht Group lithologies are isoclinally folded and occur as anticlines immediately above the Sheba Fault. Granite diapirism and the resultant refolding of the synclines resulted in the development of strike-slip shears and cross-cutting fractures which host the ore bodies.

MINERALIZATION

Two distinct ore types occur within a ~500m wide zone on either side of the Sheba Fault. Refractory sulphidic ore occurs in the Ulundi Syncline while free milling quartz vein hosted ore occurs in the Eureka Syncline.

Refractory sulphidic mineralization constitutes the bulk (~85%) of the proven ore reserve. Ore mined to date has an average grade of ~10 g/t Au. Mineralization is found within a steeply dipping (50° - 75°), anastamosing shear system that parallels the stratigraphy in the Ulundi Syncline. The shear system, which generally occurs in greywacke and shales, is closely associated with and also penetrates one of the tightly folded isoclinal Onverwacht Group anticlines. Disseminated, auriferous pyrite and arsenopyrite mineralization is confined to well defined ribbon-like shoots within the shear system. Shoots have limited lateral dimensions (~60m) and extensive depth extensions that have been traced to 1 500m below surface. Mineralization is most intense within the shear but does extend outwards into the host resulting in average mining widths of between 1 and 2 metres. Quartz and carbonate veining is found within the mineralized shears. The host rock is intensely sericitized and carbonated on either side of the shear.

Free milling, quartz vein hosted mineralization is found in near-vertical, cross-cutting fractures in the Moodies Group quartzites of the Eureka Syncline. The blue-grey quartz veins, which are commonly paired, occur within the more siliceous, brittle, quartzite units. The veins vary in thickness from 10cm to 200cm and have strike and depth extensions of up to 150m and 500m respectively. Mineralization is confined to tabular, steeply plunging shoots within the vein. Gold mineralization generally occurs within the vein but may penetrate the adjacent silicified host rock. Only minor pyrite and arsenopyrite is associated with this ore type.

GENESIS

Two models based on the origin of the ore fluids (metamorphic or magmatic) are considered. The structural control and great depth extension of the mineralization together with the distinctive alteration and metal associations support a metamorphic replacement model for the origin of the ore deposit. The genetic significance of pre-mineralization feldspar-quartz porphyry dykes and the possible magmatic source of the ore fluids still has to be assessed.

DISCOVERY AND DEVELOPMENT OF A NEW GOLD PROSPECT AT CHIGARGUNTA NEAR KOLAR GOLD MINE - A MODEL FOR PRE-CAMBRIAN GOLD EXPLORATION IN PENSULAR INDIA

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ABSTRACT

India has a long tradition in hard rock mining for gold. The century old gold mine at Kolar Gold (KGF) has been one of the most prolific gold producer in the world. The mines situated in the Kolar schist belt, covers a strike length of 100 kms. from North to South. So far 790 tonnes of gold has been recovered. In recent years due to steep fall in grades and difficult mining conditions the gold out put has drastically reduced. Present production in the country is about 1.9 tonnes.

The high ruling prices and the widespread occurrence of favourable geological milieu in the country has prompted intensification of exploration activities for gold. Several Pre-Cambrian greenstone belts in the peninsular India have become centres of intense exploration. The two National agencies, Viz. The Geological Survey of India (GSI) for preliminary exploration and Mineral Exploration Corporation Limited (MECL) for detailed exploration are involved in the location and development of New Gold Prospects. The North and South extensions of the Kolar Mining block was accorded exploration priority to locate extensions of known zones and parallel ore bodies as well as location and development of New Gold mines in the vicinity. The Chigargunta prospect, 30 kms south of Kolar Mines has proved to be a viable deposit. Favourable geomorphological conditions, good exposures and shallow ancient workings permitted stright forward surface geological techniques comprising of detailed geological and structural mapping coupled with shallow trenching followed by shallow drilling. GSI's preliminary surveys recognised two promisi ng prospects. Chigargunta and Mallappakonda in close vicinity, estimating 4.10 million tonnes at 4.7 g/t Au. and 0.68 million tonnes at 4.3 g/t Au. respectively.

Whereas, in the northern Parts, due to thick soil cover and surface dumps extensive use of surface geophysics and multi-element geochemistry was used but, with limited success.

The MEC, is conducting detailed exploration and exploratory mining in the Chigargunta - Mallappakonda prospect to provide stable data base for feasibility studies. It is recognised that exploratory drilling alone has its own limitations in assessing extreamly heterogenous primary gold ore bodies. Therefore, a judicious blend of detailed geological studies and close spaced sampling with under ground mine development, surface and underground drilling formed the exploration strategy. The work plan comprised of close spaced ...

infilling boreholes drilled at 50m x 50m (at shallow levels) and 100m x 100m (at deeper levels) grid centres upto 300m. depth. Two or three level mine development upto 60 or 100m. depth; integrated evaluation of surface, mine and borhole geological and assay data by both conventional and by modern computerised data processing; Ore mineralogy and its impact on ore beneficiation and treatment; extensive bulk samples testing to confirm grade and gold recovery characteristics; geostatistical evaluation of exploration data and computation of minable reserves and grades. Besides, the impact of other essential linkages such as geohydrological conditions, geoengineering properties of rocks, environmental inventory etc. were also studied.

The main theme of exploration has been the appreciation of Macro and Micro structural controls, shoot geometry, grade distribution etc. Geophysics and Geochemistry did not contribute significantly.

The mine development for systematic and close spaced sampling was necessitated by high 'Nugget' componant in variance, short range of spatial correlation and low concentration of values and high degree of reliability demanded for investment evaluation. Variographic studies and block estimates by Krieging have been attempted to quantify the nugget variance and to facilitate short and long term mine planning. So far insitu geological reserves of 2.1 million tonnes of ore with +5 g/t Au at Chigargunta and 0.77 million tonnes of 2.36 g/t at Mallappakonda have been established. Feasibility studies have been carried out and exploitation of the deposits is under consideration.

Based on the fund of data available, an integrated exploration moderl has been built for exploration in other greenstone belts in Peninsular India.

At the stage of preliminary exploration the accent is on robust str ight forward geological studies comprising of large scale detailed geological mapping and shallow trenching followed by test drilling. Multi-elemental geochemistry and geophysics can be used mainly to complement direct geological methods. The Macro structural control being ductile shears and gold being associated with sulphides, the surface resistivity and IP surveys may help in locating concealed auriferous zones. GSI is now exploring in Hutti, Gadag, Ramagiri, Kempinkota, Ajjanahalli and other locations.

MEC is engaged is detailed exploration in selected blocks in Hutti, Gadag and Kolar green stone belts as well as in Kempinkote. The accent is on generation of stable data by a combination of close spaced drilling and 2 or 3 level mine development for total geological evaluation. Integration of borehole and mine sample data, shoot geometry, ore mineralogy and grade distribution, geostatistics, ore body modelling, bench scale pilot plant studies on ore beneficiation and recovery tests, geotechnical, geohydrological and environmental studies provide total information on the ore body and all other essential linkages leading to the technoeconmic feasibility studies. Continuous interaction among exploration and exploitation groups and periodic mid-course analysis of exploration risks ensure continuous readjustments of priorities and programmes.

It can be concluded with confidence that the broad exploration model proposed with subtle changes to accomodate deposit characteristics, will succeed in giving much needed phillip to achieve increased gold output in the country.

MICROSTRUCTURAL AND STRAIN RELATED CONTROLS TO GOLD PRECIPITATION IN ARCHAEAN SHEAR ZONES - RENCO GOLD MINE IN THE LIMPOPO BELT, ZIMBABWE.

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The mineralisation at Renco Gold Mine is mainly restricted to anastamosing mylonite zones occuring in a large elliptical body of enderbitic granulite. This lies in the granulite facies gneisses of the Northern Marginal Zone of the Limpopo Belt, a region whose tectonic history includes major shearing and uplift along thrust faults, and where repeated cycles of partial melting have played a significant role in the development of the gneisses.

Four main mineralised mylonite zones have been recognised at the mine. Generally these are about 1m wide and trend approximately NNE. Field based studies clearly indicate a strong sense of structural control in the siting of the ore bodies. Pyrrhotite, chalcopyrite, gold and bismuth are the main ore minerals, although minor amounts of molybdenite, maldonite, bismuth-sulphuro tellurides and an early generation of porphyroclastic pyrite are also present. The mylonites are the result of intense shearing along zones within the enderbite, and have a similar, albeit slightly retrograde mineralogy. The microfabric shows evidence of multiple deformation events occuring under different external stress regimes and at different crustal levels. Repeated reactivation of movement across these reef zones has resulted in the deformation of the silicates and, at some later stage, the plastic deformation and subsequent recrystallisation of the sulphides.

Detailed investigation of the reef structure and fabric has allowed a preliminary subdivision of the mineralisation into three styles. Firstly there are areas where shearing and mineralisation is largely restricted to a single plane which rarely reaches 1m width. The fabric of this indicates extremely high strain within this zone, resulting in the formation of ultramylonitic lithologies. Although these lithologies are mineralised, gold grades are sub economic due to the high strain environment in which the precipitation of gold is not favoured. Locally this style may be modified by gentle folding.

Less frequently, the shearing occurs in an array of anastamosing shears to form a multiple strand reef. Each of these strands may be up to 3m wide, greatest widths being achieved in areas of reef intersections, and comprise less mylonitic rocks which indicate a lower strain environment. Compared with the single strand reef of high strain, these show much higher concentrations of gold as well as increased width, and are therefore of considerable economic interest. Using this approach, the gold distribution can be related to the strain state of the reef, with higher concentrations in areas of lower strain. Structurally, this domain has the morphology of anastamosing shears

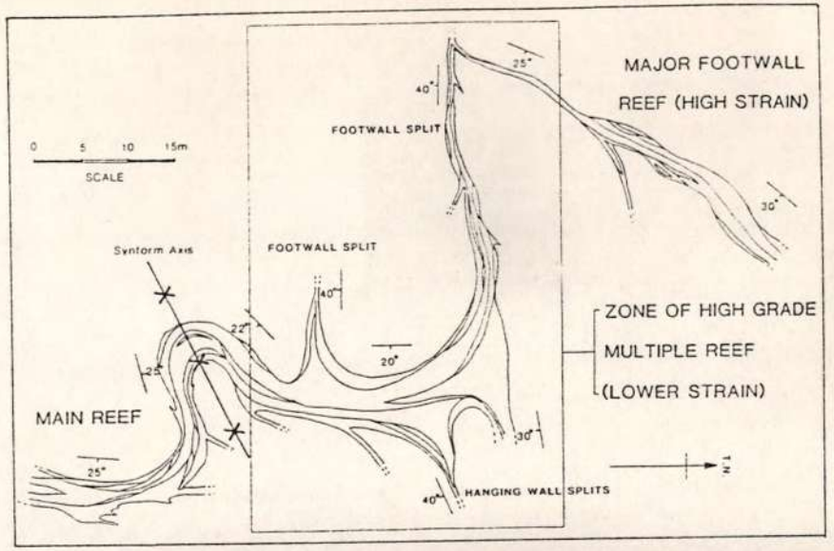


FIGURE 1. Underground plan of a section of Renco Mine showing the structural style and large scale strain distribution.

between the terminations of two sub parallel, stratigraphically distinct shear planes (Fig 1), and may be analogous to the jog systems found in strike-slip zones.

The third structural style occurs in the southern section of the mine. Here multiple strand reef occurs, but this has been modified by intense folding, locally resulting in isoclinal structures.

Investigation of the microfabric has revealed that the reef has undergone deformation in both the quasi-plastic regime (to form mylonites) and the elastico-frictional regime (forming cataclasites). The plastic deformation has resulted in the straining and subsequent dynamic recovery of the quartz into relatively coarse (200-300 micron) grained mosaics, and the straining of feldspar porphyroclasts. Locally these have also recrystallised at grain margins to form classic core and mantle relationships. Plastic deformation also gives rise to a fabric of ultra fine grained quartz and biotite (20 micron), which forms a matrix to feldspar porphyroclasts. It is not possible to distinguish the chronological relationship between these two styles, and it may be that they are different responses to the same externally applied stress field.

Cross cutting and clearly postdating the plastic deformation are various microstructures of cataclastic origin. At least three major types can be recognised. Transecting the quartz mylonites are sub millimetre scale veinlets of quartz cataclasite where the deformation is dominated by tectonic grain size reduction with little or no neomineralisation. In other places, similar sized veinlets of cataclasite show considerable mineral re-equilibration at mid to lower greenschist facies conditions to give an assemblage of quartz - orthoclase - albite - chlorite - calcite with associated sulphides and gold (Fig 2). These veinlets can be clearly identified as derivatives of a quartz - andesine - biotite mylonite through which a mineralising fluid passed during brittle failure.

Finally, a similar mineralogy occurs as the result of millimetre scale pervasive fluid influx into mylonites guided by microfractures. All the gold which has been located thus far occurs in microstructures of cataclastic origin. Gold precipitation therefore occurred relatively late in the genesis of the reef system. It would appear that the brittle deformation is concentrated in the lower strain multiple strand reef, where enhanced fluid flow may be expected.

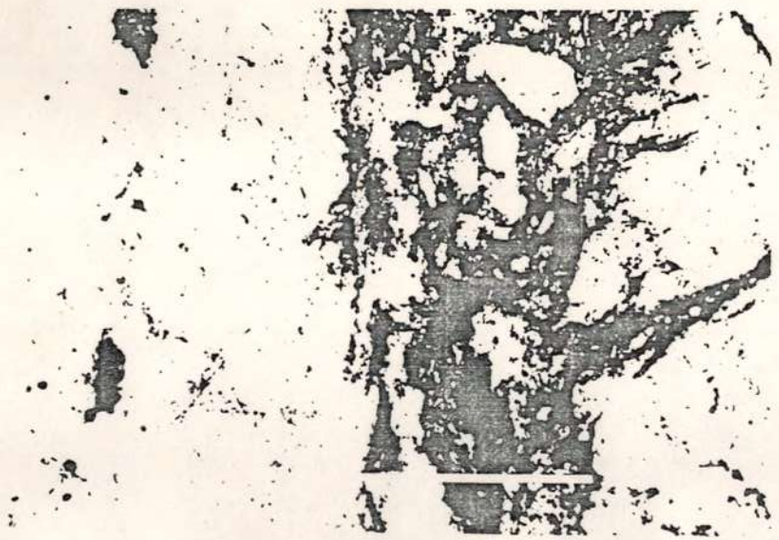


FIGURE 2. Photomicrograph illustrating the transgressive nature of highly retrograde cataclasite veinlets. Scale bar = 3mm.

GOLD MINERALIZATION IN THE MAZOWE AREA, ZIMBABWE - AN EXAMPLE OF THE CYCLE OF GOLD IN ARCHEAN GREENSTONE BELTS

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INTRODUCTION

The **Harare-Bindura-Greenstone Belt** produces approximately 1.7 tons of gold annually from three major gold-mining centres and several small workings. These three mining centres are:
- the Arcturus-Gladstone Area,
- the Mazowe Area and
- the Shamva Area,

all of which represent geochemically and mineralogically different styles of gold mineralization in geologically different terrains. Thus they provide an excellent opportunity to elaborate the different conditions of formation and to discuss possible mechanisms of gold enrichment.

The **Mazowe Area** which hosts three gold deposits of different genetic origin was chosen in order to elaborate the connections between greenstone belt evolution and the formation of gold deposits. Small-scale geochemical sections together with detailed mineralogical descriptions across the orebodies at all mines under discussion exemplify the distinctly different alteration pattern. They provide good indicators of the physico-chemical features of the mineralizing fluids and the conditions of ore-deposition.

OBJECTIVES OF STUDY

The main objectives of the project can be defined as follows:
1) Classification of stratigraphy, tectonic evolution and petrology of a greenstone belt (here the Harare-Bindura Greenstone Belt) that can be assumed to be representative of many greenstone belts on the Zimbabwe Craton.
2) Analysis of the geochemical and isotopic evolution of the greenstone belt with emphasis on REE and LIL-element distribution and Pb- and Rb/Sr-isotope systematics.
3) Explanation of the modes of formation of the different types of ore that occur in a representative section of the greenstone belt by means of mineralogical and geochemical investigation.
4) Unravelling the different physico-chemical conditions that caused the deposition of gold and accompanying elements in the different types of mineralization.
5) Summary of the different modes of formation and interpretation of their genesis in the light of the geochemical and geological history of the greenstone belt evolution.

RESULTS

The following results were obtained:

1) The stratigraphic succession is made up of granite-gneiss-basement (apx. 2.8 Ga), followed by apx. 2.7 Ga old metagabbros, amphibolites and metatholeiites, exhibiting close affinities to N-type MORB (Arcturus Formation). The gabbros can be regarded as partial-fusion products of a three-times enriched primordial mantle. The metatholeiites at the top of the sequence can be explained as partial melting products of the gabbros.
   This mafic sequence hosts a number of gold-quartz-vein deposits (Stori's Golden Shaft Mine), characterized by distinct wall-rock assemblages (see table 1) and element distributions.
2) The mafic unit is followed by apx. 2.6 to 2.5 Ga old felsic volcanic units with intercalated BIF and a conspicuous sedimentary massive pyrite body (Iron Mask Formation). Trace element characteristics indicate that the Iron Mask Formation represents an Archaean equivalent of modern active continental island arcs, whereas the felsic volcano-sedimentary Mount Hampden Formation shows similarities with modern oceanic island arcs. The Iron Mask Formation represents the partial melting products of the mafic Arcturus Formation in its footwall. Mineralogical and geochemical constraints account for a subduction zone mechanism that led to the formation of andesitic to rhyolitic volcanics. These volcanics host subeconomic stratiform gold-sulfide-impregnations.
   During the peak of regional metamorphism this assemblage was deeply burried and subsequently underwent further partial melting processes that generated granodioritic and tonalitic magmas (Jumbo Intrusive Complex). These magmas intruded the overlying greenstone belt sequence and altered it contact-metamorphically.
3) This granodiorite (Jumbo Granodiorite) and the closely associated porphyries (Jumbo Porphyry) host a number of quartz-pyrite-gold vein deposits. They are characterized by Bi-sulfide-galena-gold assemblages as well as high temperature Bi-Te-sulfosalt-pyrite assemblages.
   Reducing Eh-conditions and acidic pH-conditions prevailed during the deposition of the mineral assemblages (+gold). Three different temperature regimes of formation could be identified due to the different ore-mineral assemblages that occur at Mazowe Mine, ranging between 400-450°C to temperatures lower than 273°C (table 2).

Tab. 1: Wall rock alteration assemblages

Mine	Hostrock	Primary Assemblage	Alteration Assemblage
Iron Duke	calc-alkaline meta-volcanics	qtz-plag-musc-bio	qtz-ser-chlorite-carb-po
Stori's Golden Shaft	Metagabbro+ Amphibolite	plag-opx-amph	chlorite-talc-carb-epi-titanite
Mazowe	Granodiorite + Porphyry	qtz-plag-musc-bio	qtz-ser-chlorite-py

Tab. 2: Temperature ranges and mineral assemblages, Mazowe Mine

System	Low Temperature assemblage	High Temperature assemblage	Temperature (C°)
Au-Bi	Maldonit+Bi	melt	241±1
Bi-S	Bismutinite+ Bi	melt	270
Bi	Crystal	melt	271.5
Cu-Fe-S	Pyrrhotite+ Chalcopyrite	$(Cu\text{-}Fe)_{4+x}S$-solid solution	334±17
Bi-Pb-S	Cosalite	Galenobismutinite+ Lillianite	425±25

GENETIC MODEL

The geochemical model, envisaged for the genesis of the different types of gold mineralizations in the Mazowe Area of the Harare-Bindura Greenstone Belt can be explained as follows:

1) The amphibolites and metagabbros at the base of the greenstone belt sequence contain apx. 15 to 19 ppb Au. Their partial melting products (felsic metavolcanics) range between 20 and 200 ppb Au. Particularly high gold concentrations occur at the base of the massive pyrite layer, close to the former water-rock interface (0.3 to 0.6 ppm Au). In that primarily gold enriched environment subrecent supergene redistribution and enrichment led to the formation of a workable gold deposit (Iron Duke Mine).
2) The massive pyrite body at Iron Duke Mine, which is presently worked for sulphur, is almost free of gold (apx. 1 ppb Au).
3) Partial melting of the greenstone belt assemblage during regional metamorphism led to fractionation of sulfide and silicate melts as well as fractionation of hydrothermal fluids that leached and transported gold under high temperatures, neutral to slightly alkaline pH-conditions and neutral to slightly oxidizing eH-conditions.
4) These saturated solutions followed decreasing temperature and pressure gradients along old dilatant zones both in the granodiorite, its felsic volcanic and sedimentary hostrocks and the mafic metavolcanics. The provision of protons in the course of wallrock alteration led to a drop in pH, which together with falling temperature and pressure forced the solutions to precipitate its metal-contents.
   Thus gold was enriched to concentrations between 5 and 2000 (!) ppm in quartz- and pyrite-veins (Mazowe Mine).

IMPLICATIONS FOR THE EXPLORATIONIST

On the basis of these results a potential exploration target should fulfill the following requirements:

1) Background values of gold in the country rock should be enhanced.
2) Host rocks should be of calc-alkaline or mafic volcanic composition.
3) Metamorphism and/or late igneous activities must provide the necessary temperatures and pressures.
4) Wallrock alterations in connection with linear structures in rocks that fullfil condition 1), 2) and 3) are further indications for secondary gold enrichment.

LENNOX MINE, MASHAVA ZIMBABWE: A CONSANGUINEOUS ASSOCIATION BETWEEN QUARTZ-GOLD VEIN IN METAVOLCANICS AND QUARTZ-PYRRHOTITE REPLACEMENT LODES IN INTERLAYERED BIF

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Recent classification schemes and exploration models for Archaean gold deposits in Zimbabwe (Foster and Wilson,1982;Foster, 1937) do not explore their genetic criteria under the 'general', but fundamental concept of hydrothermal mineralisation within a deformation zone (see Colvine et al,1984) or utilise the most comprehensive structural synthesis on Archaean granitoid-greenstone belts based on the Zimbabwe Craton (Coward et al,1976,Coward, 1979). The classification dichotomy highlights vein/shear type deposits as separable from BIF and volcaniclastic hosted gold deposits,the latter, where formation was largely attributed to syngenetic processes either in an axial zone of a proposed late Archaean rift or during felsic volcanism and related clastic sedimentation (Foster, ibid).

However, at Lennox Mine, Mashava, there are contrasting, but juxtaposed mineralisation styles that demonstrate the consanguinity between epigenetic BIF-hosted gold mineralisation and the vein/shear type deposit occurring in mafic metavolcanics. A combination of dextral, inhomogeneous simple shear followed by a bulk inhomogeneous flattening strain history is well constrained for the diverse, yet syntectonic mineralisation styles on the mine. The en echelon Quartz Reef system supports a positive dilational model for fluid ingress, with source external from vein host rock (Ramsay and Huber, 1987).

BIF of the Algoma-type occur in c.3.5 Ga Sebakwian rocks of the Mashava greenstone enclave in which the Lennox deposit is situated. Banded varieties of diopside-hornblende-grunerite-magnetite quartzites occur within a regionally metamorphosed succession of hornblende- actinolite schists, metagabbro, metakomatiites including garnetiferous biotite schists and para-amphibolites (Fig.1).

The mine sequence (some 150 metres of mafic metavolcanics with 2 interlayered BIFs) dips steeply (75°E) and is flanked in the structural footwall (F/W) by a 200m-thick synvolcanic metagabbro,but a major metapyroxenite-metagabbro intrusion occupies the northern portion in the H/W. The F/W metagabbro contains a gold prospect in a quartz-shear associated with sericitization,carbonatisation and minor pyrrhotite-pyrite mineralisation, but the H/W mafic/ultramafic body intrudes and apparently post dates BIF hosted mineralisation on 6 level (Fig.1).

A finite strain fabric $S_1 \parallel S_2$, commonly a differentiated layering in amphiboles -epidote-feldspar- quartz schists is over printed at high angles by S_2-shears marked by quartz veinlets, epidote and porphyroblastic?twinned actinolite. A post S_2 retrogression to chlorites and pennine is recorded in both S_1,S_2 amphiboles and garnets.

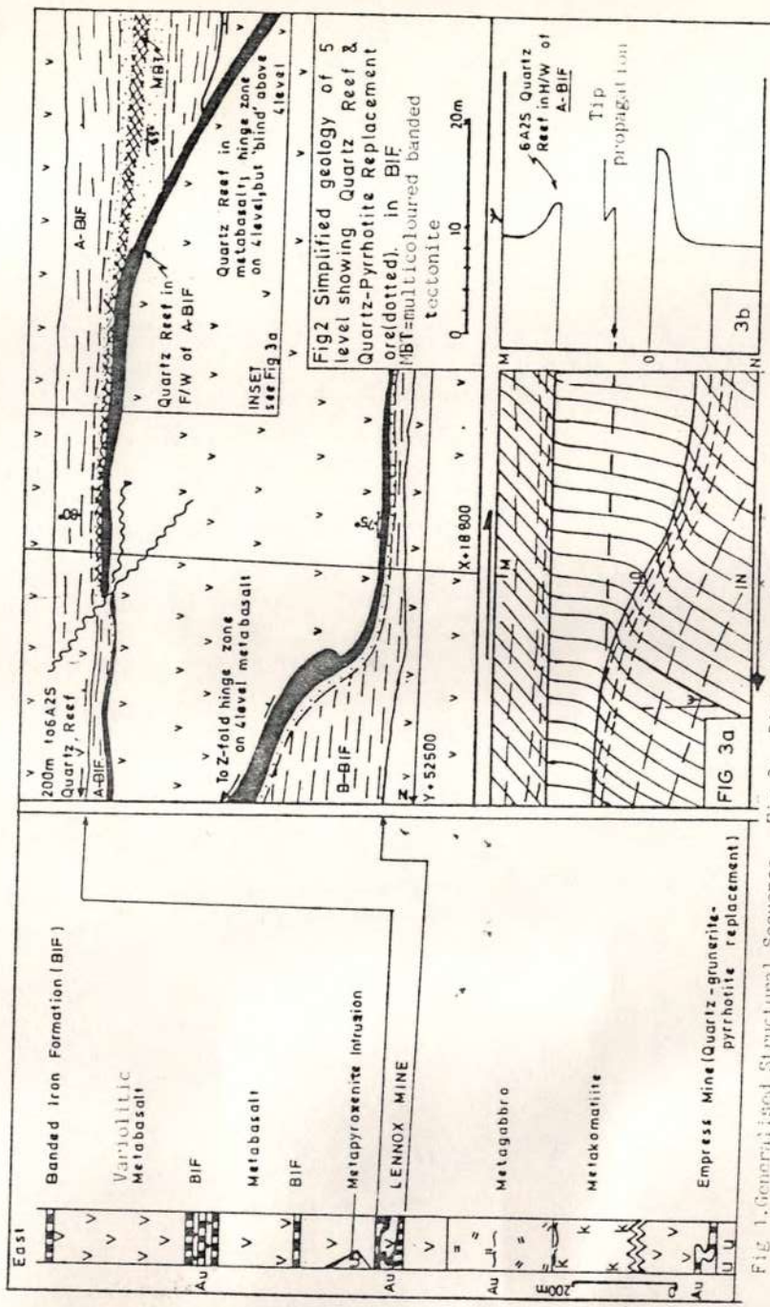


Fig 1.Generalised Structural Sequence across Lennox Mine.

Fig 3a. Distortion of strain and strain fields induced by sigmoidal geometry of A-BIF mound in a ductile shear zone otherwise undergoing uniform simple shear. Slope of marker lines, Ψ, reflects intensity of straining γ (Sibson,1979).

In south section of the mine, a south plunging (20-60°), Z-asymmetric Quartz Reef occurs in narrow (10-35m) mafic metavolcanics that separate the 2 BIFs, termed A-BIF (0-20m),and B-BIF (Fig 2). The limbs of the Z-fold are directly traceable into F/W of A-BIF and H/W of B-BIF where the Quartz Reef is co-extensive with quartz-related, magnetite- destructive sulphidation (Plate a), and hydrothermal bleaching (Plate b) in BIF. On 4 level, a 'blind' en echelon Quartz Reef is developed in the same host, 50 metres south of the main Quartz Reef hinge zone but the second set extends only 70 metres down to below 5 level (Fig.2).

Of significance in mine exploration is the observation that the structural siting of the Quartz Reefs in mafic metavolcanics correlates in detail to a sudden thickening in both A and B-BIFs (Fig.2) but A-BIF in particular. In addition, the magnitude and direction of the plunge of the Z-fold of the Quartz Reef is largely congruent to the pitch of the ellipsoidal BIF-hosted replacement mineralisation. The Quartz reef contains low sulphide (pyrrhotite, pyrite), visible to microscopic gold and an irregular selvage of dark hornblende associated with slivers of pyrrhotite or pyrite.

However, on a mine scale (total mineralised BIF strike of about 550 metres including central and north sections), it is the hydrothermally bleached cherts (Plate b) that define the ore'channel'. In these areas, the black coloured cherts (due to magnetite dissemination) in barren oxide A-BIF are bleached or replaced by a multicoloured banded tectonite (MBT) consisting of green, grey and white banded quartz-rich rocks whose association with bands of pyrrhotite was previously ascribed to syngenetic banding (Gilligan,1984).

In both central and north sections, distant from the Quartz Reefs, the MBT is centrally developed within A-BIF and is flanked by less bleached envelopes of strong quartz-pyrrhotite ± chalcopyrite replacement mineralisation (Plate a and b). These envelopes commonly feature boudinaged quartz-veins and account for bimodal gold peaks separated by lower values (1-3g/t) over the axial MBT. Where the Quartz Reef limb forms F/W to A-BIF (Fig.2), the MBT occurs above the Quartz vein, but is separated from barren oxide BIF by typical quartz-pyrrhotite ore (averaging > 5g/t Au) which in Plate (a) is associated with a contemporaneously pyrrhotised sheath fold. The fold is indicative of high strain (R_{xz}>10:1) in a ductile shear zone (Ramsay and Huber 1987).

Mineralogically, besides quartz, the MBT contains variable proportions of diopsidic clinopyroxene-hornblende-actinolite-grunerité, discontinous bands of turbid cream spessartine-pophyroblastic almandine garnets, minor calcite, magnetite, and disseminated pyrrhotite preferentially developed in relict black cherts. (In B-BIF, in north section, the association of pegmatoidal diopside-quartz-pyrrhotite - calcite is reminescent of skarn-type mineralogy, but the assemblage contains low gold values (3 g/t) compared to quartz-related sulphidation of oxide facies of the same BIF).

The association of sulphide-garnet-amphibole-diopsidic clinopyroxene in the MBT suggests both metamorphic reaction and Ca-metasomatism (±S±Mg ± CO_2± Au) at upper greenschist to lower

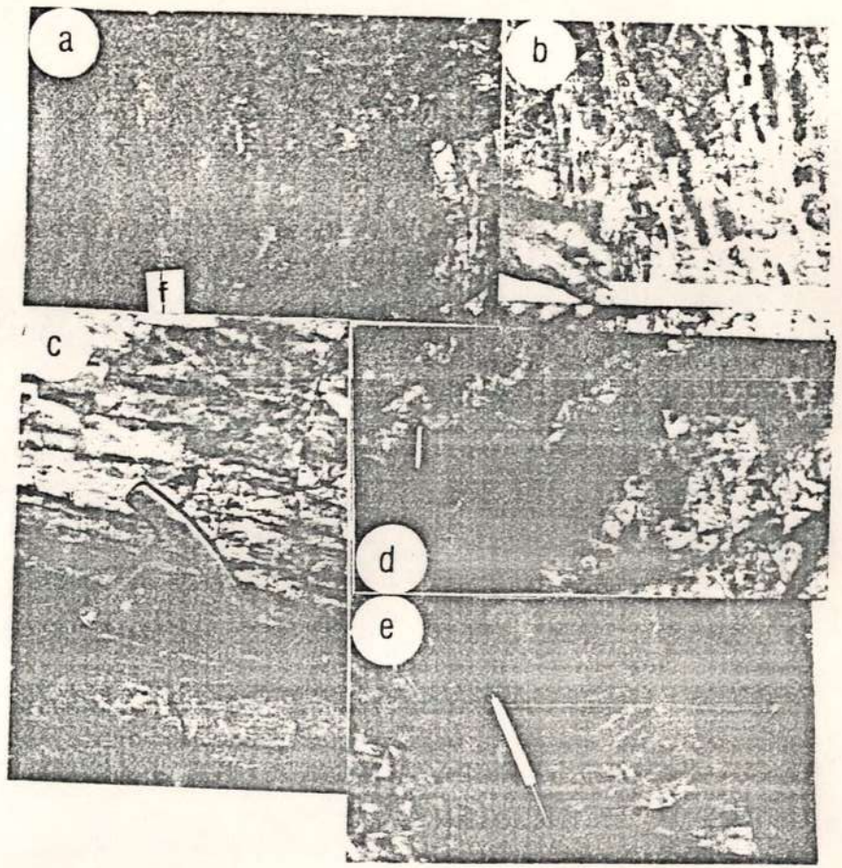


Plate (a). Vertical section looking south in 5A4S Top Sublevel. Typical quartz-pyrrhotite sulphidation ore to the right of mylonitic fracture(f), barren oxide BIF to the left. Note the pyrrhotised "closed loop" sheath fold whose geometry is diagnostic of bulk inhomogeneous flattening strain history, but excludes an inhomogeneous simple shear strain history (Bell, 1978).

Plate (b).Extensive bleaching of dark magnetite-chert assemblage, to form a multicoloured banded tectonite, commonly flanked by Plate (a)-type ore.

Plate(c). Laminated Quartz Reef showing inclusion banding characteristic of incremental hydraulic fracturing and mineral precipitation.

Plate (d). Folded minor quartz veins in a foliated zone above an antiformal Quartz Reef body; 4A4S section.

Plate (e). Breccia-vein (centre); early grey quartz containing mafic inclusion, but veined by white quartz.

amphibolitic facies metamorphism. Only minor quantities of metamorphic reaction silicates occur in barren BIF. The lateral zonation in A-BIF mineralisation summarised above together with occurrence of sulphides and metamorphic silicates is unlikely evidence for disequilibrium isochemical metamorphism of stratiform precursors, as implied by studies elsewhere (Stanton, 1986). The zonation could be explained as a widening of the shear zone following the onset of deformation hardening in the MBT, causing less deformed margins to acquire rapid strain rate (Cobbold 1977).

Three factors, namely the structural siting of the Quartz Reef adjacent to a sigmoidal stratigraphic mound in A-BIF, the size of the Quartz Reef which is comparable to the magnitude of the A-BIF heterogeneity, and en echelon folds that die out along their axial planes indicate that the initiation of the Quartz Reef was controlled by a localised mechanical anisotropy (see Platt, 1983) but passively amplified into folds, kinematically (Berthe and Brun 1980).

Fig.2 is a schematic representation of the physical basis for the perturbation of strain and strain fields induced by the geometry and competence contrast of A-BIF, assuming uniform simple shear. Strain compatibility constraints require that locally intensified shear (γ) and rates of shear strain ($\dot{\gamma}$) must develop adjacent to the BIF body and strain departs from simple shear. Both aspect ratio of BIF lithology and competence contrast will determine the resulting stress amplication that often leads to complex brittle-ductile shearing, thus facilitating episodic fluid ingress (Sibson, 1979) and incremental mineral precipitation.

An alternative formulation of the variation in local strain gradients is to consider the primary role of the stratigraphic mounds in BIF lithologies and spatial variation in horizontal distance between interflow BIF as creating an initial lozenge-shaped heterogeneity in competent metabasalt (Fig.2) that promotes the formation of conjugate sets of ductile shears under an imposed flattening strain regime. Orebodies or dilatant zones are then localised in zones of high strain flanking the metabasalt 'pod' (Fig.2).

Although dextral inhomogeneous simple shear probably initiated and folded the Quartz Reef tension gashes, later deformation of the shear zone walls (tips of tension gashes) probably occurred under non-plane strain. The closed loop of the sheath fold in Plate (a) not only indicates vertical bulk extension, but is also geometrically characteristic of bulk inhomogeneous flattening strain, and excludes an inhomogeneous simple shear strain history (Bell 1978, Fig.13).

In summary, features characteristic of progressive deformation in a ductile shear zone (D2 deformation) are indicated for the juxtaposed BIF-hosted replacement lodes and auriferous quartz vein in mafic metavolcanics at Lennox Mine. The interaction between finite strain and anisotropy in the form of a locally complex BIF stratigraphy has been modelled. Other features presented in photographs demonstrate similarity with features observed in many other deposits in varied lithologies, worldwide. Consequently the diverse epigenetic mineralisation styles appear consanguineous only under a framework of structurally controlled mineralisation in a

shear zone undergoing non-coaxial simple shear and bulk innomogeneous flattening strain history.

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GEOLOGY OF THE CUIABÁ GOLD MINE, QUADRILATERO FERRIFERO, MINAS GERAIS, BRAZIL.

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The Cuiabá Gold Mine is situated in the northern part of the Quadrilátero Ferrífero, in the state of Minas Gerais, Brazil.The rocks are of Archean age metamorphosed in the greenschists facies. (Dorr II, 1969). The mine is one of the largest gold depostis of the Quadrilátero Ferrífero, with reserves of 70 metric tons of gold (Vial,1988).

The lithologic units are from botton to top:

.Carbonate quartz epidote plagioclase chlorite - light green schist locally with pillow structures (metandesite) intercalated with black graphitic phyllite (metapelite).

.Quartz carbonate chlorite sericite . dark grey schist with feldspar and graphite (metapelite) alternated with quartz carbonate sericite - brownish schist (rhyodacitic meta-tuff).

.Banded iron formation (BIF) hosting gold-bearing sulfide orebodies.

.Black graphitic phyllite (metapelite).

.Quartz carbonate sericite - brownish schist (rhyodacitic meta-tuff) with intercalation of black graphitic phyllite.

.Tremolite chlorite epidote quartz - dark green schist exhibiting pillow structures (metabasalt).

.Quartz carbonate sericite graphite - dark grey phyllite (metapelite) with interlayers of quartz sericite chlorite carbonate - light gray phyllite (rhyolitic meta-tuff).

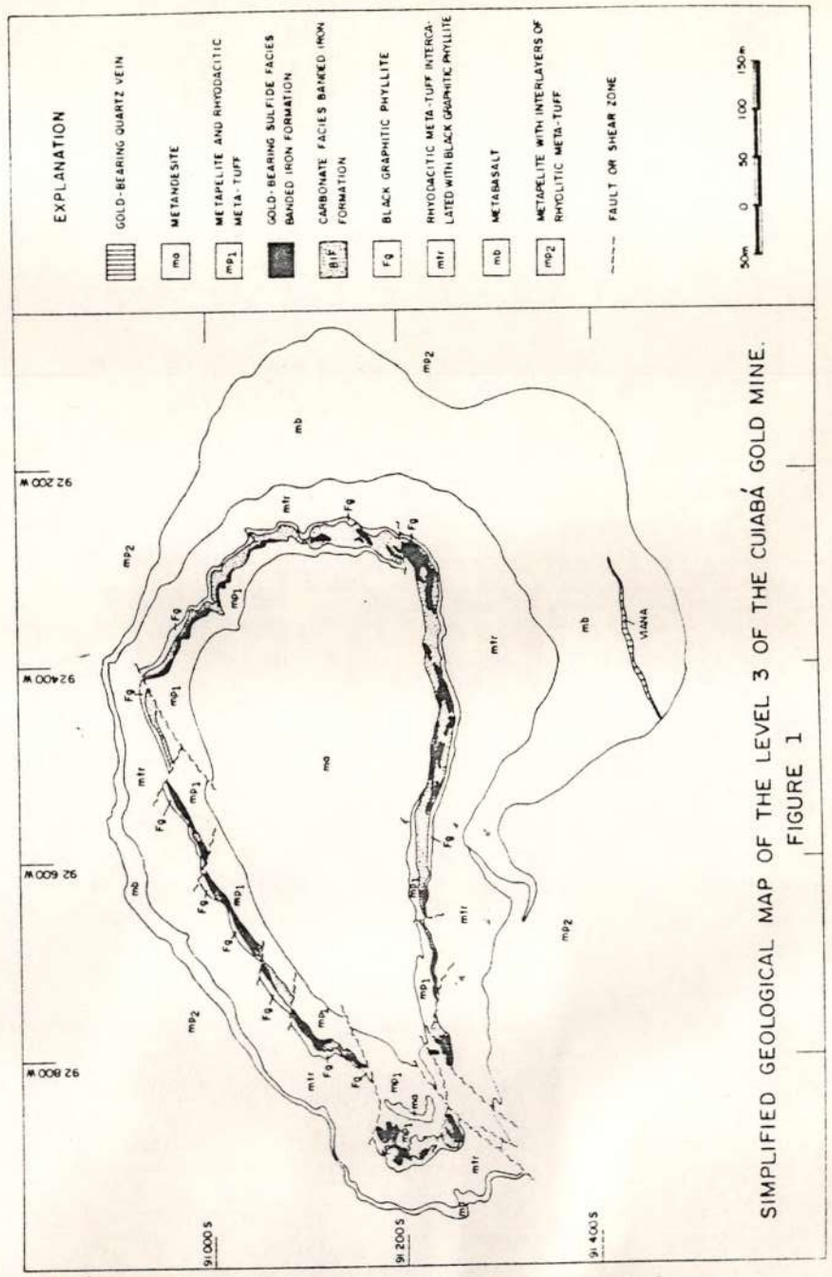
The BIF is well laminated and shows sulfide and carbonate facies in equal proportion. Oxide facies BIF is not present in mine. The ore bodies are stratiforms. They are the sulfide-rich BIF with horizontal section of 50 to 900 m^2 and distributed along a bed 1400 m long and up to 20 m thick.

The Cuiabá Gold deposit was affected by three deformative events. The earliest deformational event (D_1) produced tight folds and intense transposition. S_1 foliation and shear zones are nearly parallel to the bedding (S_0) . The macrostructure is an anticline of this event, with inverted north flank and BIF bed presenting lace shape (Fig.1).

The second event was the most remarkable in the area.It produced anisopaque isoclinal folds. S_2 has atitude of N 50°-60° E/34°-46° SE and L_2 S 54° - 78° E/26° - 40° . Faults developed during D_2 event have atitude ENE/50° SE and WNW/50° SW. The fold axe L_2 is parallel to a mineral stretching lineation. In comparison with the variable orientation od L_1 and S_1 the orientation of S_2 and particularly L_2 is relatively constant regionally.

The third event D_3 is identified by a fracture cleavage striking N 28° W and dipping NE at 83° and a crenulation lineation plunging S 10°W - S 29° E at 25°- 57°. It is represented by gentle folds.

All of the structures can be projected in depth along L_2 and the orebodies show continuity down this lineation. There are eleven orebodies in the mine, sometimes separated by D_2 faults.



SIMPLIFIED GEOLOGICAL MAP OF THE LEVEL 3 OF THE CUIABÁ GOLD MINE.
FIGURE 1

The main structure of the deposit can be alternatively interpreted as a mega sheath fold developed during a progressive deformation which could explain the paralellism of fold axes L_2, mineral lineation and the elongation of orebodies.

The ore is composed of quartz, carbonate and sulfides. Pyrite is the main sulfide, followed by phyrrhotite and arsenopyrite. Ocasionally there are sphalerite, chalcopyrite, marcassite, magnetite, graphyte and rutile. Sulfide-rich BIF presents two types of ore, with first type being well banded and composed mainly of very fine grained pyrite and seconde being massive sulfide and dominated by coarsely crystalline pyrite. Massive sulfides occur in the highly deformed areas and are richer in gold.

The intense fracturing produced locally by D_3 event in the BIF puts sulfide and carbonate beds in contact generating a mosaic structure in some orebodies.

Gold grains are usually smaller than 60 micra, occuring in inclusions and along fractures of both types of pyrite. Gold normally contains up to 30% of silver.

Another type of gold ore appear in the mine. A gold - bearing quartz vein enclosed by a zone of silicification, sericitization, carbonatization and chloritization in the metabasalt (Viana orebody).

The sulfide orebodies are interpreted as syngenetic followed by intense recristallization and only local gold remobilization. They show continuity down the lineation L_2 for at least 1500 m, giving to the orebodies styloid or blade shapes.



FIG 02 - LOCATION OF CUIABÁ GOLD MINE

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The Metallogenetic Model of Jinchangyu Gold Deposit in Archaean Greenstone Belt, Hebei Province, China

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Jinchangyu Gold deposit is located in Hebei Province approx. 150 Km NEE from Beijing.Geotectonically, this deposit is occurred in a mobile belt between the northern boundary of North China Platform and it's adjacent hercynian geosyncline. This mobile belt controls the distribution of a series of Archaean greenstone belt gold deposits in metamorphic hydrothermal type in Northern China.

This granite-greenstone belt is composed of oval-like trondhjemite, tonalite in different sizes, and intercalated greenstones distributed in it.The greenstones and granites are of fault contact.This greenstone belt is composed of ultramafic,mafic and sialic volcanics and less amount of clastic sedimentary rocks subsequently from the bottom to top. It's metamorphic grade reached granulite-amphibolite phase, aged 3.5 b.y.b.p.

This region has undergone the Qianxi movement (3 b.y.b.p.). The rocks were folded in E-W trend and metamorphosed up to amphibolite phase mainly, partly might reach granulite phase. Fuping movement happened on 2.5 b.y.b.p., thus formed the ductile shear zones and imposed tight folding in N-S trend. These ductile zones were the sites of a series of retrogressive dynamic metamorphic zones, and occurred the earliest concentration of gold mineralization in this period; the author classified this deposit as "dynamic metamorphic hydrothermal type gold deposits"(1979).

The features of this type of gold deposits:

1. The gold bearing zone is specially associated with the ductile shear zone, but the orebodies are formed a little later.

2. From outer to inner parts of this gold deposits belt, there occurred the chlorite schistose mylonite, sericite schistose mylonite, albite-felspar-quartz differentiates and other transitional tectonites distributed in symmetric zoning. Ore bodies, usually distributed along the central part of this belt.

3. This belt extends in 6 Km long and 360-900 m in width. There are 6 N-S trending mineralizing zones, several zones in NE 20 and NE 60 trending thus formed a inter connected net-work in plan. Vertically, this belt appeared as fan or inverted fan-like, and varied to "W", "N" or "L" like figures, which depended upon the different intensity of stress acting upon in various portions. The ore bodies distributed mainly in the swelling parts or turning sites of the belt and extended very deeply. But for each group of ore bodies, it usually thinned out every 200m along its dip, and re-appeared another group of orebodies after an interval of non-mineralizing gap about 100-200m. This distribution rule of ore-bodies is useful in the prediction of blind ore-bodies in the depth. At present, exploration drilling has controlled to a depth to 550 m underground, equivalent to 2-3 steps of ore body group.

4. There existed a lithologic change between plagio-amphibolite (original tholeiite) and leuco-granulite (original rhyolite) inside each of the ductile shear zones. We found, the average gold contents that adjacent to those changing area in amphibolite sides were much higher (may up to 255 PPb) than the places that were 300 m farther away from it (down to 15 PPb). During the eruption of tholeiite, there were already a preliminary enrichment of gold and formed the primary gold source bed itself. Whenever the heat-dynamics were superimposed during the forming of ductile shear zones, the mafic rocks were transferred to dynamic metamorphic rocks such as chlorite schistose mylonite, sericite schistose mylonite and albite-quartz differentiates of greenschist phase(t = 200° - 400° C, P = 3 - 9 kb). Metamorphic hydrothermal solution that rich in Si, Na, Ca, Cl, CO_2, Fe, S and Au, migrated to and concentrated in the structural dilatant zone, then precipitated and formed the gold deposits of dynamic metamorphic hydrothermal type.

5. The ore minerals are mainly pyrite, minor molybdenite, galena, chalcopyrite, native gold and gangue minerals albite, quartz, ankerite sericite and chlorite. The ore is characterized by banded structures.

The average $\delta S34‰$ of the ore is -3.7‰, varied between -6.0 to +0.2‰, standard derivation equals to 0.13, they are slightly richer in light sulphur than that of the host rocks (+2.4‰). The average of δO^{18} ‰ and $\delta D‰$ of quartz are +6.11 and -84.11 ‰ respectively, suggesting that the ore bearing hydrothermal solution was mixed in meteoric water and connate metamorphic hydrothermal solution. The REE patterns of the ore and host rocks are similar i.e. rich in LREE and no Eu anomaly.

6. The greenstone belts of China were occurred in an unstable craton and had undergone several later intensified reformations, especially, reformed and superimposed mineralization during Mesozoic structural-magmatic thermal events. Thus resulted the features of multiple episodes and origins in gold mineralization, and complicated the metallogenic history of the gold deposits in this region. Some of the ore-bodies formed during the Archaean were dispered or diminished, and on the other hand, it might superimpose the Mesozoic hydrothermal gold mineralization or regenerate new gold deposits.

The araean albite quartz veins might be penetrated by Mesozoic quartz veins, and the Araean gold mineralization became younger in isotopic age dating are the evidence of above demonstration.

These are the common phenomena existed in Archaean greenstone belt gold deposits in China, also, are the necessary points in considering to construct the metallogenic model of Archaean gold deposits in China.

7. The regional prospecting criteria of this type of gold deposits are the border of Archaean craton and the ductile shear zones or retrogressive metamorphic zones. These tectonic - metamorphic zones, usually distributed spacially in accordance with the marginal places between oval-like granitic batholith and the greenstone belt.

The section parts where ductile shear zone passing through the lithologic changing places between tholeiite and rhyolite are favorable to be mineralized. Whenever there existed chloritization, sericitization, pyritization and carbonatization in such section parts, the gold bearing albite veins or quartz veins are possoble to be found.

The gold bearing veins usually distributed in groups or zones, and extended a long distance both along strikes and dips. Thus, we propose, this type of gold deposits are pretty hopeful and of great potential reserves in prospecting. In China, these hopeful prospects are mainly distributed along the north and south edges of North China Platform. At present, dozens gold mines in different sizes have already discovered and operated there.

Besides, the regions of Archaean granite-greenstone belt that distributed inside North China Platform usually underwent several tectonic - magmatic activities. The places that superimposed tectonic-magmatism are important gold producing areas of different genetic types, especially, along the west Circum-Pacific tectonic - magmatic belt in East China coast. The genetic types are more complicated, they are closely related with migmatization and granitization.

8. Jinchangyu type gold deposits maybe correlated to Archaean greenstone belt gold deposits on their metallogeny and the basic feature of geologic background. For example, it is similar to Mt. Charlotte gold deposit in Kalgoorie greenstone belt of West Australia. But, the regions of Archaean granite-greenstone belts in China craton were unstable, they were strongly affected by later geologic events, i.e. the regional metamorphic rocks were usually in higher grade and often participated migmatitic or partly anatectic magmatic hydrothermal gold mineralization, and the "typical" regional metamorphic hydrothermal gold mineralization were usually concentrated in the dynamic retrogressive metamorphic zones. In such sense, Jinchangyu type may represent the Archaean greenstone belt gold deposits in "China Style", and is different from the similar genetic types occurred in stable craton of Western Australia and Canada.

9. Gold and other metallogenetic substances were originated directly from the hostrock (greenstone belt) in this region. During regional metamorphism, especially in the period of dynamic metamorphism, various forms of gold complexes were formed in metamorphic hydrothermal solution, migrated with the circulated solution, and precipitated in the structural dilant zones inside the ductile shear zones.

Gold mineralization was happened under certain environment of semi-close system, the association of ore minerals mainly depended upon the constituent and content of those elements in the host rock. The major gangue minerals, such as chlorite, sericite, albite, quartz and ankerite were the altered products of plagioclase, amphibole and quartz; the major ore mineral was pyrite only, it was originated from the original pyrite in the host rock and re-precipitated accompanied with hydrothermal alteration, so, other ore minerals were rarely seen. In the same case, gold was remobiled from the host rock by hydrothermal solution and re-precipitated from the solution as well, thus raised the finess of the new born native gold. The silver content was low and the mercury abundance was high.

Topic 1B

PROTEROZOIC REGIONAL STUDIES

Gold mineralization in the Nigerian Schist belts

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INTRODUCTION

The Nigeria schist belts are Proterozoic domains of metasedimentary, metavolcanic and intrusive igneous rocks within the Pan African mobile belt which separates the West African and Congo cratons(fig 1). The belts consist of several occurrences of primary and alluvial gold workings located around Ilesha area in the South, Bini Yauri area in the middle and Maraba area in the northern part of the belts (fig. 2). Mining records put production figures at a total of approximately 12,000 kg gold produced from the early to middle part of this century when production ceased in all the districts. Despite the importance

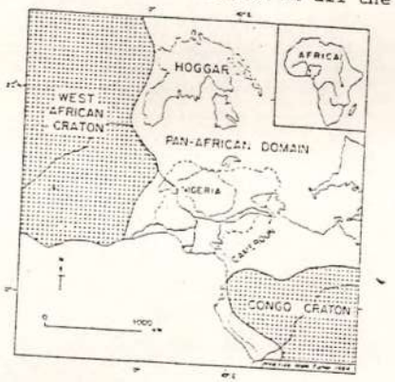


Fig. 1: Location of Nigeria.

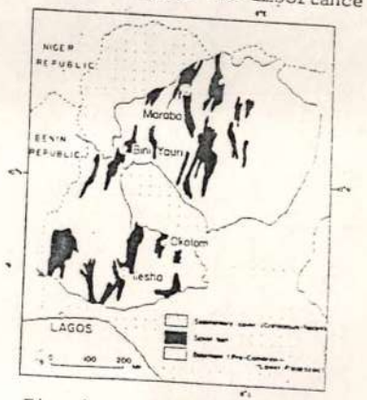


Fig. 2: Nigerian schist belts

of the Nigerian gold-bearing schist belts, information about the geological details of the primary gold-bearing veins is generally lacking. This paper reports on the preliminary geological investigation in the Ilesha, Okolom and Bini Yauri districts in the light of the gold genesis.

GEOLOGICAL SETTING

Metasedimentary rocks (Schists, phyllites, quartzite, marble), metavolcanics (amphibolite) and intrusives (granite, granodiorite) in the schist belts are distributed within Pre-Cambrian to Lower Palaeozic gneisses and migmatites of the Nigerian basement complex. The Pre-Cambrian to Lower Palaeozoic gneisses and migmatite bear imprints of the Liberian (c.a 2,500Ma) and Eburnian (c.a 2,000Ma) tectonic events (1) although the enclosed metasediments and metavolcanic rocks

are assigned to Upper Proterozoic (2). Imprints of the Kibaran tectonic event (c.a 1200M.a) and widespread Pan African ages (600+100 M.a) have been reported in the schist belts (3). The regional foliation trend and principal lineaments in the belts are generally north-northeast and metamorphic grade in the metasediments are dominantly that of greenschist facies. Lower to upper amphibolite facies are common in the older gneissmigmatite complex. These schist belts have been compared with the classic greenstone settings and the gold bearing Birrimian schist belts of Ghana (4). Although the Nigerian schist belts do have many features in common with Archean greenstone belts (e.g. Abitibi greenstone belt in the Superior Superstructural province of the Canadian schield and those of the Yilgarn and Pilbara blocks in W. Australia) especially with respect to their sizes, synclinal structures low metamorphic grade and the presence of volcanic and clastic rocks and their associated gold mineralization, they are characterised by the predominance of metasediments and lesser volumes of volcanic rocks compared with Archean greenstone belts. Recent geological and structural studies (5,2) have considered the belts as parts of a Proterozoic sucession that was developed within an ensialic mobile belt as a result of extensional tectonics involving crustal thinning, doming and rifting.

MINERALIZATION

Primary gold mineralization commonly occur in quartz veins within several lithologies. Host rock to veins include fine grained mica schists, amphibolite schists,,talc tremolite schists-and several varieties of gneisses. The gold bearing quartz veins are generally bedding concordant veins and veinlets or discordant vein systems as in the Ilesha, Okolom and Bini Yauri gold districts.

In the Ilesha district, lodes occur in fractures, folds and foliation planes at the contacts of amphibolite, schist and gneisses. The quartz veins are foliated and commonly contain interleaved mica and feldspar together with minor amount of pyrite, pyrrhotite, chalcopyrite, magnetite and ilmenite. At Okolom, veins and lenses are confined to a north trending antiform occupied by amphibolite and talc tremolite schists within biotite gneiss. Vein contacts are strongly sheared and the contact zones are typically altered and occupied by sericite, chlorite, tourmaline, zircon, rutile, magnetite and hematite. Veins commonly contain pyrrhotite, pyrite, marcasite, chalcopyrite and argentite in the order of decreasing abundance. The Bini Yauri veins are steeply dipping lenticular bodies localized in the contact zone between a mica schist and porphyritic granite. Vein stockworks are common along the shear contact of the granitic body. Schist wall rock is highly altered and the alteration zone is marked by the presence of altered feldspar, sericite, chlorite, calcite, epidote and rutile. Bedding concordant and discordant quartz sericite veins are common. The veins consist of pyrite, pyrrhotite, arsenopyrite, chalcopyrite, marcasite, sphalerite, galena and hematite representing up to 3% of vein constituents.

Free gold is rarely seem in the quartz veins of the districts under study, however, inclusions of small (4 μm) gold grains are contained in chalcopyrite at Bini Yauri. Gold values in the study area

range from 4 to 65g/ton in drill core assays. Supergene concentration in laterite overburden and alluvial deposits in recent streams represented about 90% of total production in these districts early in the century. It is thought that several alluvial and elluvial gold deposits in the districts are probably related to lateritization (6).

FLUID INCLUSION STUDIES

Preliminary fluid inclusion studies carried out on samples of quartz from the three districts gave homogenization temperatures between 90°C and 320°C. A bimodal distribution of temperatures with a low temperature mode between 160 and 180°C and a higher temperature mode between 220 and 240°C were identified in the three districts. The homogenization temperature populations are interpreted as representing at least two episodes of shearing, mineral deposition and recrystallization in the veins. Freezing temperatures suggest a salinity of approximately 1.5 equivalent weight percent NaCl for the ore solution. Clathration was observed between 2.9°C and 4.0°C in some of the inclusions due to the presence of unquantified CO_2 content.

CONCLUSIONS

The lack of lithologic preference for the gold bearing veins and the occurrence of the veins within shear zones crosscutting several lithologies in the study areas suggest that vein formation in the Nigerian schist belts accompanied the deformation of the Nigerian basement complex. Available field and petrographic evidence suggest several stages of quartz veining and recrystallization. The homogenization and freezing data suggest that ore forming fluids are of relatively low salinity and may have been derived from the metamorphic dewatering of the primary sedimentary rocks and their associated volcanics and volcaniclastics to produce the initial bedding concordant veins. Subsequent tectonic events in these settings would have remobilized and redistributed the vein constituents into the present structurally controlled sites.

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CONTROLS ON GOLD MINERALIZATION IN THE REINDEER ZONE: AN EARLY PROTEROZOIC GOLD PROVINCE, NORTHERN SASKATCHEWAN, CANADA

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Between 1946 and 1984 gold exploration expenditures in Early Proterozoic greenstone belts in the Reindeer Zone of northern Saskatchewan amounted to approximately $29 million. An additional $28 million was spent from 1984 to 1986, and in excess of $35 million was slated for gold exploration in 1987. Up to 1984, exploration had yielded about 1.5 million ounces of gold in possible economic discoveries at an exploration cost of $19 per ounce. Comparable exploration costs in Archean greenstone belts of Quebec and Ontario are $23 per ounce and $15 per ounce ($43 per ounce prior to the Hemlo discovery) respectively. Since 1984 known gold reserves in northern Saskatchewan have continued to increase and many new exciting discoveries have been made.

The Reindeer Zone is a collage of Early Proterozoic accreted terranes, forming part of the Trans-Hudson Orogen (Fig. 1). The zone comprises: magmatic - migmatitic belts (Wathaman Batholith and Rottenstone Domain); greenstone belts (La Ronge (LRD), Flin Flon (FFD) and Glennie Lake (GLD) Domains and Hanson Lake Block); an inter-arc basin (Kisseynew Domain (KD)) and minor Archean crustal components (Hanson Lake Block and GLD in part). Gold occurs primarily in the greenstone belts of the LRD, GLD and FFD and less commonly in the KD.

The La Ronge Domain comprises a Central Metavolcanic Belt, flanked by metasedimentary gneisses of the Crew Lake and McLean Lake Belts to the northwest and southeast respectively. Gold occurrences are almost entirely restricted to the metavolcanic belt and are concentrated in four main areas; around Waddy, Tower, Star and Sulphide Lakes (Fig. 1). The gold occurrences are predominantly structurally-controlled quartz vein-type, with subordinate stratabound-type and several postulated epithermal-type. Geological and structural controls of the vein type include:

1. ductile to ductile-brittle shears developed in composite plutons (eg. Star Lake 21 Zone) and surrounding supracrustals (eg. Jolu);
2. fracture systems developed in and around quartz-rich granitic stocks (eg. Komis); and
3. brittle fracture systems developed along regional structures such as the Byers Fault (eg. Tower East).

Stratabound gold mineralization, commonly associated with felsic metavolcanics, is found in:

1. mixed oxide-silicate-sulphide facies iron formation (eg. Twin Zone);
2. barren to base metal-enriched massive sulphides (eg. Anglo Rouyn, Churchill Minerals);

3. carbonaceous, sulphidic metasediments (eg. Sulphide Lake).

Base metal-silver-gold mineralization, which occurs in fracture controlled quartz-carbonate stringer zones in felsic metavolcanics (eg. Earl Lake) or related metasediments (eg. Jojay), is considered to represent modified (metamorphosed and tectonized) epithermal-type mineralization.

The Glennie Lake Domain is underlain by narrow, sinuous, generally southeast-trending greenstone belts separated by broader granitoid and migmatitic regions. In GLD structurally-controlled gold quartz veins occur in mafic to intermediate intrusions (eg. Seabee) as well as supracrustals (eg. Pigeon Lake). Rare stratiform mineralization is also present in volcaniclastics.

The few known gold occurrences in the Kisseynew Domain, an inter-arc sedimentary basin, are typically stratabound-type, being associated with sulphide-bearing amphibolite and calc-silicate rocks (eg. Mari Lake).

Most of the historic gold production in the Reindeer Zone has come from the Flin Flon Domain, primarily as a by-product from the mining of base metal massive sulphide deposits (eg. Flin Flon mine). The Flin Flon Domain possesses two distinctive volcanic assemblages; a predominantly oceanic tholeiitic basaltic assemblage in the eastern half (Flin Flon area) and an intermediate to felsic calc-alkaline island arc assemblage dominates the western half (Amisk Lake area). Gold occurrences in the two areas also differ. In the West Channel area of Amisk Lake, pre- to early syntectonic gold occurrences are characterized by quartz vein systems surrounded by broad carbonate, sericite and silica alteration envelopes developed in interlayered metavolcanics and metasediments (eg. Monarch Mine) and subvolcanic felsic intrusives (eg. Laurel Lake). Formation in a near surface, possibly epithermal environment is suggested in some of these deposits.

East of Amisk Lake gold occurrences are clearly structurally controlled quartz vein-types. A syntectonic group of quartz-sulphide-gold veins were emplaced in mafic metavolcanics along intermittently active fractures systems (eg. Newcor Mine). Late- to post-tectonic fracture-controlled vein systems occur in and around late porphyritic intrusions and possess porphyry-style mineralization and alteration characteristics (eg. Rio Mine). Syngenetic gold is present in the barren and base metal-rich massive sulphide deposits of the FFD.

Many of the features characterizing gold occurrences in the more publicized Archean greenstone belts can be shown to exist in the Reindeer Zone in northern Saskatchewan. Because the geological controls of mineralization are similar in both Early Proterozoic and Archean greenstone belts, the potential for further exploration successes in the Reindeer Zone is extremely high.

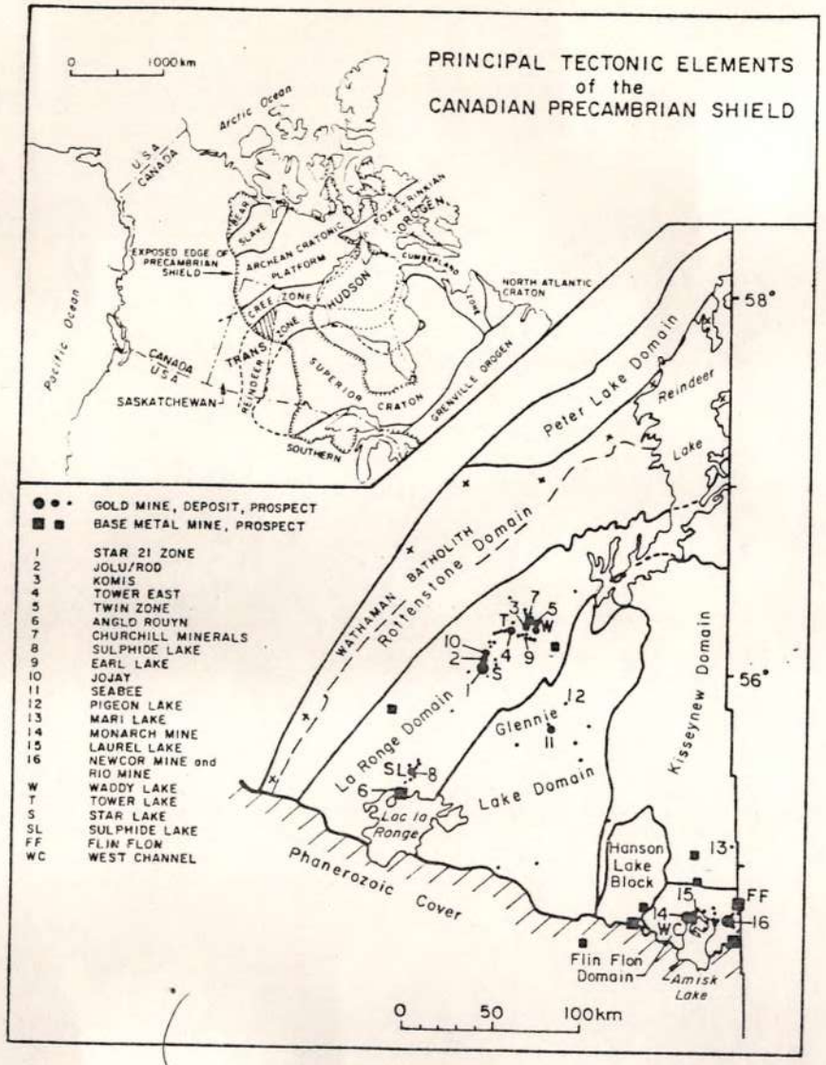


Fig. 1. Location of major gold deposits and prospects in the Reindeer Zone of northern Saskatchewan. Only those occurrences mentioned in the text are named. Inset map shows the Saskatchewan portion of the Reindeer Zone (ruled area) with respect to other major tectonic elements of the Canadian Precambrian Shield.

NEW STRUCTURAL, RADIOMETRIC, AND MINERALOGICAL ASPECTS OF THE AU-BEARING TARKWAIAN GROUP OF GHANA

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The early Proterozoic Tarkwaian Group of Ghana contains one of the three known early Precambrian quartz-pebble conglomerates which are being mined for gold, the others being the Serra de Jacobina goldfields and the Witwatersrand goldfields. As opposed to the latter, the provenance area of Tarkwaian sediments is still preserved, including auriferous chemical sediments and Au-quartz lodes of greenstone affiliation.

Tarkwaian depositories had a high length/width ratio, they developed within intramontane grabens or depressions which formed due to rifting preferentially in central portions of all five major volcanic belts of Ghana (Fig. 1). There is no evidence that the individual depositories were ever linked. Partly due to regional differences in erosion level, the degree of preservation of sediment-infill of the various Tarkwaian depositories is highly variabel; it is best in the Ashanti belt, where Tarkwa Au mine is in operation, and in the Bui belt (Fig. 1). In particular the folding style of the latter suggests that Tarkwaian sediments were deformed by gravity tectonics in connection with rifting, and not by a post-Tarkwaian compressional tectonic event.

Rb/Sr-whole-rock dating of an Eburnean granitoid which underlies Tarkwaian rocks as well as a post-Tarkwaian granitoid confines the formation of Tarkwaian depositories and concomitant sedimentation to the time span between 2081±25 and 1968±49 M.a.

Tarkwaian sedimentation in the Ashanti belt begins with the 250-700m thick Kawere Series in which polymictic, poorly sorted, frequently matrix-supported large-pebble conglomerates play a major role. Pebble components include basic to felsic lava, chert, and some granitoid, tuffaceous argillite, pyroclastics, and quartz. The Kawere Series is is overlain by the Banket Series which contains an Au-bearing conglomerate zone in its lower part. These conglomerates are oligomictic, well-sorted, pebble-supported quartz-conglomerates; macroscopically they show a striking similarity with many Witwatersrand reefs. The differences of Kawere and Banket conglomerates in pebble lithology as well as gold- and heavy mineral content are likely to be due to a better degree of sediment reworking in stratigraphically higher levels of the Tarkwaian. Repeated reworking resulted in destruction of the least durable pebble components, and an enrichment of quartz and heavy minerals.

The main and genetically important difference between Tarkwaian conglomerates and other mineralized Precambrian quartz-pebble conglomerates is the absence of pyrite and uraninite in Tarkwaian ores (uranium concentrations in sediments of all Tarkwaian depositories consistently below 10 ppm). Instead hematite and other "black sand" minerals are the most abundant opaque phases. As in other weakly metamorphosed mineralized conglomerates, the ore minerals may be classed into three groups: (i) allogenic minerals, (ii) authigenic minerals, and (iii) minerals which are present both as authigenic and allogenic constituents.

Abraded allogenic hematite generally reveals diameters less than o.5mm. It frequently carries exsolution discs of ilmenite and/or rutile. A major part of it was possibly derived from Birimian tholeiites. A second hematite variety displays "hatched" twinning and carries no exsolution discs of Ti-minerals. Its little degree of rounding might suggest that it formed supergenly within the depository and was transported only a short distance down the paleoslope. - Recrystallized in situ formed hematite is predominant; it frequently replaces allogenic or authigenic magnetite. This latest hematite variety seems to be related to metamorphic overprint and/or the emplacement of dikes cutting the conglomerates.

Magnetite is present as detrital mineral and as authigenic in situ formed euhedral magnetite. The detrital variety does not contain exsolution lamellae of Ti-minerals. However, occasionally it carries chromite cores. All investigated chromite cores (N=6) display anomaleously high zinc concentrations which lie between 7.8% and 2o.2% ZnO. In general, chromite is a very rare constituent in the Tarkwaian paragenesis, this probably being a function of the near-absence of ultramafic rock in the source area. - Authigenic in situ formed magnetite frequently forms heavy mineral foresets, thus demonstrating that it is in fact metamorphogenically reconstituted detrital magnetite.

Further minerals of the Tarkwaian paragenesis include complex detrital rutile/ilmenite intergrowths, zircons, and sporadically diamonds, as well as rare to very rare authigenic sulfides which formed only locally in the vicinity of crosscutting dykes and quartz veins. Replacement of iron oxides by sulfides (mainly pyrite) postdates the formation of the above authigenic minerals. Pyrrhotite, chalcopyrite and bornite were noted in the investigated sample suite, too. Arsenopyrite - a prominent mineral in primary Birimian Au deposits - is absent.

Gold is present as free particles, but also as intergrowths, overgrowths or inclusions with ilmenite/rutile aggregates, magnetite, hematite and pyrite. Au particles reach diameters of up to 12o micron. Silver contents in the 4 measured Au grains vary between 1.44% Ag and 4.8% Ag, and thus resemble closely the ones panned from present-day Ghanaian rivers. This contrasts with true fineness data of primary Birimian Au deposits which are in the range between 81o and 85o.

A mineralogy comparable to the one of Phanerozoic placers, the proximity of primary Birimian Au deposits which are eligible as source, a good correlation between "black sands" contents and mineable Au contents, as well as the fact that Tarkwaian pebble lithology may in some parts directly related to host rocks of primary Au deposits, leave little doubt that the Au-bearing Tarkwaian quartz conglomerates are of a placer origin. They must have formed at atmospheric oxygen levels comparable to present-day ones, as opposed to the ca. 8oo-5oo Ma older Witwatersrand conglomerates. Then detrital uraninite and pyrite grains as well as silver contents in detrital Au particles were chemically stable during fluvial transport - due to a highly oxygen deficient atmosphere during Witwatersrand times.

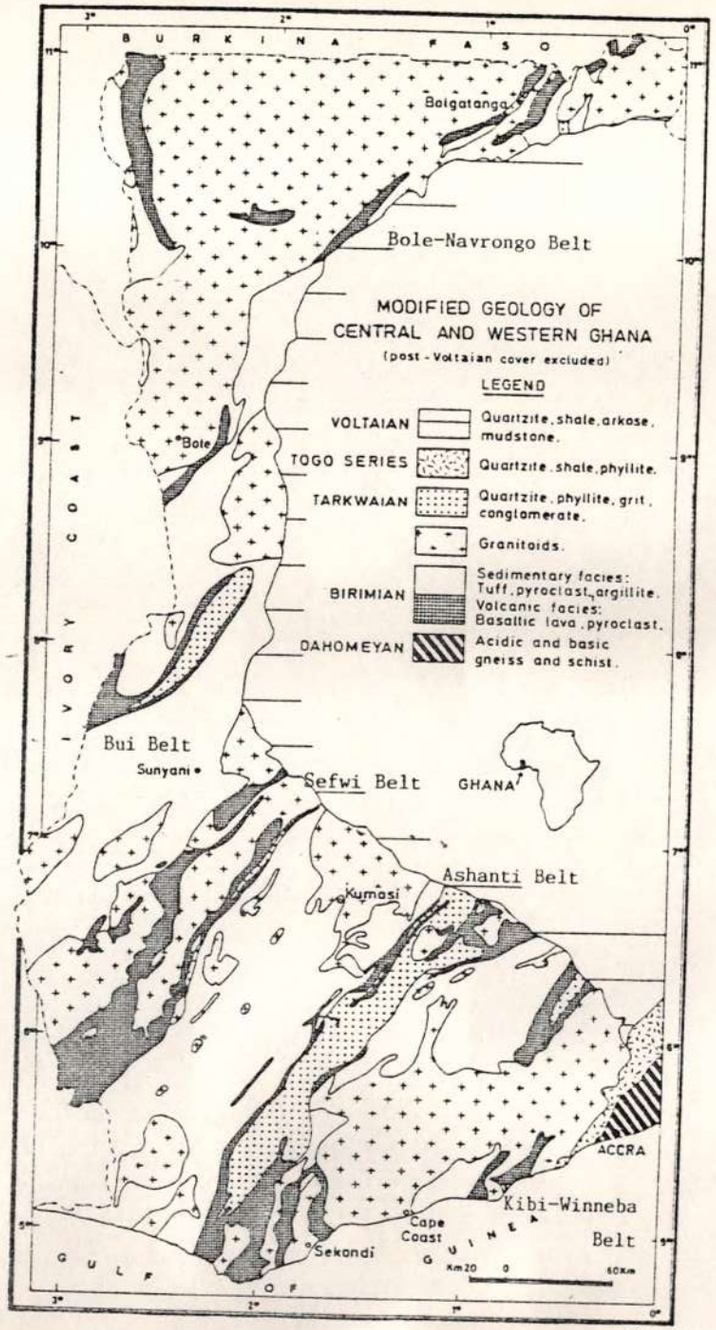


Fig. 1

NEW ASPECTS ON DISSEMINATED AND VEIN TYPE GOLD MINERALIZATION IN GHANA / WEST AFRICA

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More than 90% of the Ghanaian gold production is from rocks of the Birimian Supergroup (2.2 to 2.1 Ga). The Birimian comprises five parallel volcanic belts of several hundred km in length. They are separated by sedimentary basins filled with volcaniclastics derived from the volcanic activity of the belts. Belts and basins show the same age, but belong to different facies units.

The vast majority of the Birimian gold deposits occurs aligned along the flanks of the volcanic belts (Fig. 1), especially the NW flank of the Ashanti and the SE flank of the Sefwi belt.

There is a spatial relationship between manganese and gold occurrences on a regional scale. Manganese is predominantly bound to the flanks of volcanic belts, i.e. a transitional chemical facies between belt volcanics and basin sediments formed by individual gold deposits. There is ample field evidence that manganese which occurs as oxide or carbonate is of syngenetic-sedimentary origin. Seen on a local scale, Mn and Au do not coincide with each other, i.e. no gold mine occurs directly within Mn-rich strata.

In addition to manganese and gold, the transitional zones along the flanks of the volcanic belts are characterized by the presence of other chemical sediments, namely sulphides, cherts, Fe-Ca-Mg-carbonates, and rocks rich in elemental C. The length of the "corridors" characterized by chemical sediments (and thus prospective for gold) may attain several hundred km and reach a width up to 25 km. The chemical sediments occur intermittently and are superimposed on and intercalated with metavolcanics, as well as metavolcaniclastics and minor phyllites.

Sulphides consist of pyrite and arsenopyrite, which generally occur in the disseminated form; sulphide layers or bands are rare. A close spatial relationship between sulphides and gold occurrences is particularly evident along the NW flank of the lava inlier at the NW flank of the Ashanti volcanic belt, where disseminated sulphides are ubiquitous for several tens of kilometers along strike. Previous work claimed that <u>all</u> the Birimian gold was related to deep reaching structural elements which developed due to competency differences in the transition zones between belt volcanics and basin sediments. Therefore one would expect this gold to continue along a well developed fault- and shear zone at the NW flank of the Ashanti belt, where those competency differences are most pronounced. Instead the gold follows strata rich in chemical sediments, i.e. structural elements do only carry gold mineralization if they are developed within the zone of the auriferous chemical sediments; those outside are generally barren.

It seems that in the Birimian of Ghana structure is of

importance as a <u>local</u> ore control (i.e. on the mine scale), whereas lithofacies (chemical sediments) controls Au both regionally and locally.

Gold in the Birimian of Ghana occurs as two major types: the <u>disseminated sulphide type</u> (DST) and the <u>quartz-vein type</u> (QVT). The quartz-vein type is solely structure-controlled whereas the sulphide type is predominantly bound to chemical sediments - i.e. lithofacies controlled - and to a much lesser degree structure-controlled (occurs as sulphidic selvages of quartz veins). In general, quartz-vein gold ores carry better grades than those of the disseminated sulphide type. At present the quartz-vein type is almost exclusively exploited and the sulphide type is hardly known as a potential resource.

The formation of quartz-veins and associated mineralization and alteration post-dates peak-regional-metamorphism. Smoky blackish vein quartz - containing graphite - generally reveals higher Au contents than white or clear quartz varieties.

Most arsenopyrite and pyrite (i.e. the lithofacies-controlled sulphides) formed before regional metamorphism and the major shearing and faulting event both of which pre-date the formation of gold quartz-veins and the associated wallrock alteration. Besides arsenopyrite and pyrite, the "ore minerals" recorded in sulphide-type ores are pyrrotite, chalcopyrite, sphalerite, galena, bornite, alabandite, ulmannite, gerdorffite, covellite, native gold, marcasite, rutile/titanite/leucoxene, and unspecified Mn-oxides and -hydroxides.

Major differences between DST and QVT ores with respect to their ore mineralogy are: QVT contains visible "free gold", whereas DST carries gold predominantly as submicroscopic inclusions in sulphide. QVT sulphides occur in orders of magnitude less than in DST: if sulphides are present in QVT, the base metals - particularly galena - play a more important role than in DST.

With respect to <u>structure-controlled</u> gold deposits, the following different types of processes or factors contributed to the conditions presently encountered at the investigated sites:

- quartz-vein emplacement and their continued subsequent shearing and fracturing;
- sericitization (k^+- and H^+- addition) and concomitant Na loss from wallrocks at the selvages by means of plagioclase hydrolysis;
- dolomitization;
- sulphidation (including As-tradition);
- graphite formation through reduction of CO, CO_2 and/or CH_4;
- local formation of paragonit and gangue albite.

Sericite- and pyrite/arsenopyrite- rich selvages frequently carry higher gold values than the quartz-vein itself, this being corroborated by generally very good correlations between Au and K and Au and As. Consequently alteration and the accompanying sulphidation + As addition are the major governing factors in Au precipitation.

Carbonate gangue is ubiquitous, but generally the negative dolomitic alteration even in unmineralized quartz veins precludes any importance of CO_2 alteration as Au- mineralizing factor.

Graphite in quartz-vein selvages or in the realm of shear zones - probably formed by CO-, CO_2- or CH_4- reduction - shows a sympathetic relationship with gold, suggesting that it acted as Au precipitant.

The fracturing of the tectonized quartz veins appears to be of primary importance for Au transport as well as precipitation of native Au facilitating fluid ascent and rapid hydrothermal fluid degassing (boiling), resulting in Au-complex destabilization on a micro-scale.

The presence of "graphite" in association with siderite in and around some of the quartz fissures limits the temperature range of the ore-forming fluids as follows: The temperature must have been more than 300°C (presence of graphite) and less than 430°C - 440°C (absence of magnetite). Since marcasite is rapidly transformed into pyrite above 350°C, the marcasite-bearing parageneses cannot have been exposed to temperatures exceeding this value. The highest recorded fluid inclusion homogenization temperature amounts to 390°C.

The <u>lithofacies-controlled</u> disseminated sulphide-type ores show good correlation of Au with K and As similar to the vein type and could suggest that part of the Au precipitation mechanisms were not fundamentally different from those of vein deposits, i.e. destabilization of Au sulphur complexes through sericitization and resulting pH increase after fluid discharge an the seafloor.

A negative correlation between gold and LOI, CaO, and Na_2O in lithofacies-controlled disseminated sulphide-type ores suggests that neither CO_2- nor sodium alteration played a role in gold precipitation on auriferous chemical sediments.

The following genetic model is favoured at present:

Formation of relatively low grade gold-bearing chemical sediments (disseminated sulphide type) by dehydration-generated (i.e. burial-metamorphogenic) seafloor fluid discharge. At a subsequent stage (further burial metamorphism, regional metamorphism, granitoid emplacement), mobilization of Au, SiO_2 and CO_2 in the pre-enriched sediments at depth where upper greenshists or amphibolite facies conditions were attained. Ascent and emplacement of these constituents in zones of structural weakness as quartz-vein type.

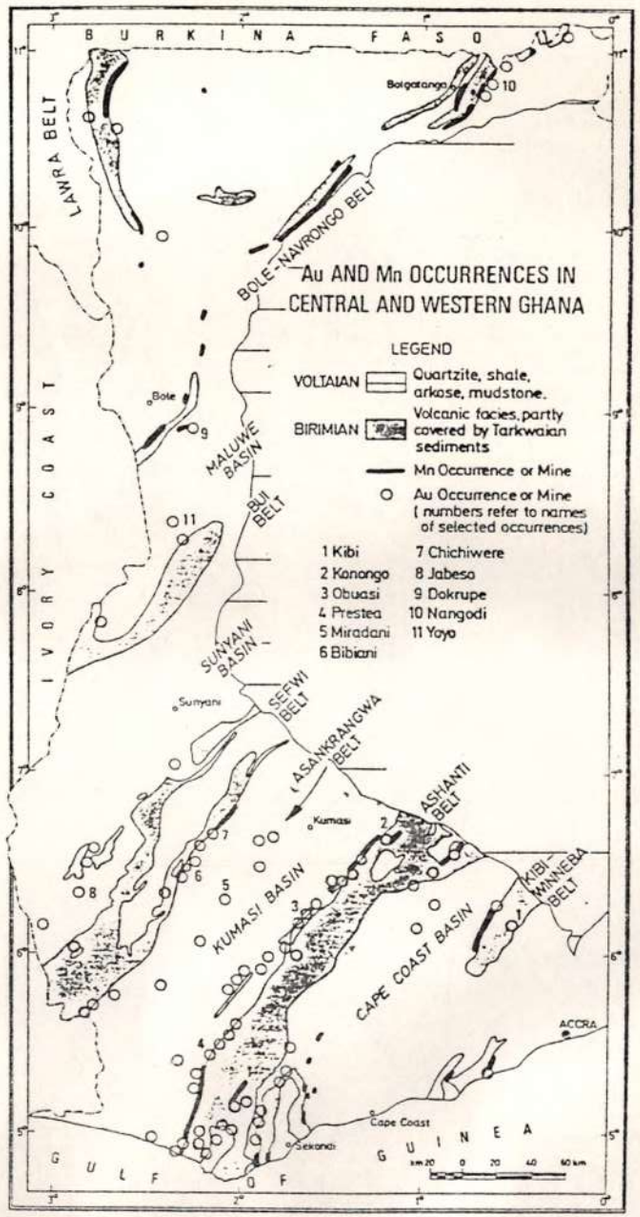


Fig. 1

PROTEROZOIC, GOLD-BEARING VEIN OCCURRENCES ASSOCIATED WITH THE GRANITOIDS IN WESTERN FINLAND

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INTRODUCTION

Several minor vein-type gold occurrences have been found in association with granitoid plutons in the border zone of the Early Proterozoic schist belts and the large granitoid complex of central Finland. In Middle Bothnia, the gold occurrences are associated with 1.93-1.86 Ga old synkinematic Svecokarelian granitoid plutons (Nurmi and Haapala 1986), which consist of quartz diorites, tonalites, trondhjemites and granodiorites. The granitoids are calc-alkaline, and their chemical and mineralogical characteristics indicate I-type affinities. The plutons are mostly surrounded by intermediate to basic volcanic or subvolcanic rocks, rarely sedimentary mica schists and gneisses. The metamorphism is mainly of medium-grade, and the rocks are multiply deformed. The Early Proterozoic plutons and supracrustal rocks belong to the Svecofennides, and have built up ancient island arc environments.

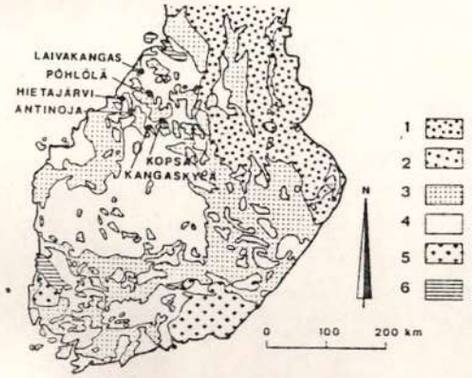


Figure: Occurrences of gold-bea ing veins in Middle Bothnia. Main Precambrian units (Simonen 1980): 1. Archaean gneisses, 2. Presvecokarelian schists, 3. Svecokarelian supracrustal rocks, 4. Svecokarelian plutonic rocks, 5. Rapakivi granites, 6. Jotnian sedimentary rocks.

GOLD-BEARING VEINS

The gold-bearing veins of Middle Bothnia are situated at the contacts of the plutons and near the contacts in the surrounding supracrustal rocks. The occurrences at Kopsa, Pöhlölä and Kangaskylä have been encountered in the granitoids. At Laivakangas, the mineralized veins cut the contact of the tonalite and the metabasalt. At Hietajärvi and Antinoja, they are located in the supracrustal rocks.

Gold-bearing veins consist mostly of quartz, seldom or arsenopyrite. Veins are narrow: usually from a few centimetres to half a metre in width. They form parallel en echelon swarms, some of which have been sheared and/or folded. The veins have crystallized into joints, faults and shear zones.

Major ore minerals are arsenopyrite, chalcopyrite and pyrrhotite, and minor pyrite, sphalerite, galena, loellingite and scheelite. The most important accessory ore minerals are molybdenite, sulphosalts and metallic bismuth. Gold is metallic, and contains very little silver. It occurs as small and angular inclusions, usually in quartz, arsenopyrite and loellingite.

Hydrothermal wall-rock alteration is usually weak, and occurs mainly as narrow zones around the veins. Silicification, propylitization and potassic alteration (K-feldspathization and/or biotitization) are common. Minor sericitization and tourmalinization have been observed. Propylitization is characterized by epidote, carbonate and chlorite, sometimes approaching epidotization.

METALLOGENIC ZONING AND SOME ASPECTS OF ORE GENESIS

Metallogenic zoning is encountered in the occurrences studied in Middle Bothnia. In mineralized areas, the zoning is (Mo,Cu) - (W,Au,As) - (Ag,Pb,Zn) from the centre of the pluton towards the supracrustal rocks. At the Laivakangas gold deposit, Cu/As and Au/Ag ratios of the tonalite decrease towards the contact of the supracrustal rocks. The metallogenic zoning suggests that intrusions have been thermal centres driving the convection of the hydrothermal ore-forming fluids (Boyle 1979, pp. 417-422). The intrusions have deformed the surrounding bedrock and produced joints and faults. These joints, faults and shear zones have been suitable traps for hydrothermal fluids.

In addition to the vein-type occurrences, there are stratiform gold occurrences located in the schist belts around the granitoid complex of central Finland. They occur farther out from the vein-zone in supracrustal rocks but near the plutons. They might have been trapped into places, where there has been a great difference between consistencies of neighbouring formations or beds, or into the pressure minima such as anticlines. More investigations, like isotope and fluid inclusion studies, are needed to resolve the origin of hydrothermal fluids and

the genetic connection of the synkinematic plutons and the mineralizations.

ORE POTENTIAL

Both vein and stratiform occurrences seem to be small in tonnage (0.01-1 million ton), even though they often have high gold contents. Pilot plant tests were carried out at Laivakangas in 1985. The total tonnage of the Laivakangas deposit is about 400 000 tons with the ore grade of 3.5 g/t gold. The amount of the bulk sampling was 5 600 tons, and the milled grade was 2.6 g/t gold. The concentration was done by gravimetric and flotation methods with the recovery of 70 %. The Laivakangas gold deposit is at the moment calculated to be uneconomic, due mainly to expensive selective stoping.

CONCLUSIONS

Hydrothermal gold occurrences associated with the granitoids are encountered around the border zone of the granitoid complex of central Finland. They seem to be most common type of gold occurrences in southern Finland. The studies of gold-bearing veins in Middle Bothnia could be applicable also in other places in the border zone of the Early Proterozoic schist belts and the granitoid complex of central Finland. Especially in the Tampere schist belt, south of the granitoid complex, there are gold occurrences of similar features.

The genetic model needs more research, but even now it could be applied to exploration of gold. The example of Laivakangas shows that many problems in evaluation, extraction and concentration of this type of gold deposits have to be solved before they can be exploited.

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ENVIRONMENT OF ORE FORMATION IN THE SABIE-PILGRIM'S REST GOLDFIELD, SOUTH AFRICA

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Paper withdrawn at the last minute

GOLD DISTRIBUTION IN VOLCANOGENIC MASSIVE SULFIDE ORES, SKELLEFTE DISTRICT, N. SWEDEN

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The early Proterozoic Skellefte District in northern Sweden is one of the few gold-enriched volcanogenic massive sulfide provinces in the world. The Boliden deposit, with an average Au grade of 15.5 $g.t^{-1}$ in 8.3Mt ore, was one of the largest gold ores in Europe. Gold grades vary across the district from less than 1 $g.t^{-1}$ to more than 300 $g.t^{-1}$ in bonanza-type local concentrations. The controls on the gold distribution in these ores is unknown and this communication relates preliminary results of an investigation into the origin of massive sulphide-hosted gold in this district.

Geology

The Skellefte district (Fig. 1) comprises more than 100 massive sulfide deposits in a 200 x 50 km zone along the Skellefte river at 65°N latitude. The mineralization is hosted by 1.89Ga volcanics and sediments, which have suffered up to epidote-amphibolite facies metamorphism. The volcano-sedimentary pile has been intruded by a synvolcanic, I-type granitoid complex and a series of younger 1.78Ga, S-type granitoids.

The district represents an early Proterozoic island arc sequence which collided with a northern Archean continent at around 1.89Ga, as part of the 1.9-1.7Ga Arizona-Finland geotectonic event. Mineralization was mainly located along a lateral EW rift and closely related to a period of bimodal volcanic activity. Deformation associated with collision resulted in intensive isoclinal folding on SE-NW axes with associated faulting.

Mineralization

The massive sulfide mineralization is typically Kuroko-type. It commonly consists of massive pyrite lenses and stockworks closely associated with high level felsic intrusives or extrusives and coarse fragmental felsic volcanics. It is usually situated at or near the contact with overlying fine-grained clastics (phyllites) and often includes local chemical sediments in the present form of carbonate or calc-silicate lenses. Many of the common Kuroko-type ore textures have been identified including proximal mounds, slumped mounds, sedimented sulfides and sulfate-rich deposits. The alteration is typically silicic close to and beneath deposits with well-identified sericite and chlorite alteration halos.

The main ore mineral is pyrite, and chalcopyrite and sphalerite occur in varying amounts. Galena is rare to absent. The Boliden company is one of the world's major arsenic producers and arsenopyrite is common in some deposits. Gold and silver are common accessories. The silver is mainly associated with sphalerite and gold occurs mainly as electrum, often within the pyrite and arsenopyrite. The district has produced over 65Mt of ore with an average tenor of 0.8% Cu, 2.3% Zn, 0.29% Pb, 0.8% As, 30% S, 39 $g.t^{-1}$ Ag and 1.5 $g.t^{-1}$ Au from 25 mines. Ten mines are operating at present.

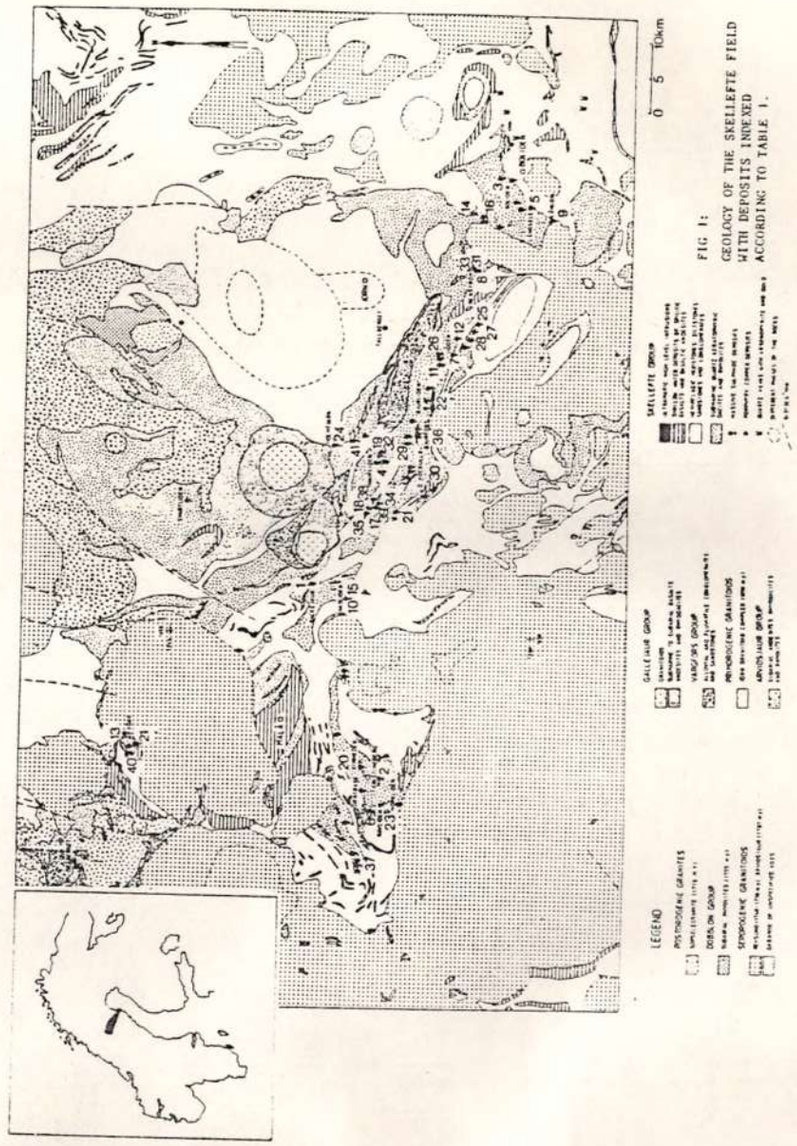
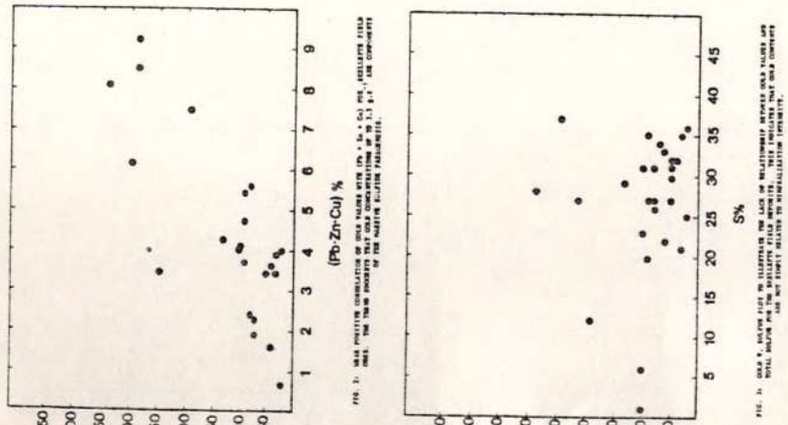


FIG 1: GEOLOGY OF THE SKELLEFTE FIELD WITH DEPOSITS INDEXED ACCORDING TO TABLE 1.

ORE DEPOSIT	Zn%	Pb%	Cu%	Au g/t	Ag g/t	As%	S%
1 Rakkejaur	2.25	-	0.28	1.00	45.00	1.85	27.00
2 Kristineberg	2.36	0.30	1.03	0.90	23.00	-	27.00
3 Boliden	0.92	0.27	1.43	15.50	50.00	6.80	25.00
4 Maurliden	2.45	-	0.18	0.60	42.00	-	33.00
5 Långsele	4.00	0.30	0.44	0.90	26.00	0.36	35.00
6 Rävlidmyran	3.68	0.54	1.20	0.90	55.00	-	20.00
7 Udden	4.83	0.45	0.31	0.80	38.00	0.15	27.00
8 Renström	6.66	1.79	0.80	2.80	155.00	0.10	28.00
9 Långdal	5.84	1.50	0.13	1.90	149.00	-	12.00
10 Näsliden	2.95	0.26	1.06	1.30	35.00	1.33	29.00
11 Svansele	0.32	0.06	0.28	0.20	4.00	0.05	36.00
12 Kedträsk	2.80	0.20	0.42	0.50	4.00	0.30	27.00
13 Rudtjebäcken	2.90	0.10	0.90	0.30	9.00	-	35.00
14 Kanberg	2.80	0.40	0.25	2.40	45.00	0.76	37.00
15 Näsliden N	1.65	0.16	0.59	0.80	25.00	0.43	26.00
16 Åkulla W	-	-	1.00	0.70	12.00	0.24	34.00
17 Inre Sjömalmen	2.17	-	0.45	0.50	35.00	0.44	31.00
18 Maurliden Ö	0.15	-	0.84	0.80	16.00	-	31.00
19 Adak	0.10	-	1.90	0.30	8.00	-	-
20 Klinbeden	0.07	-	1.17	0.03	6.00	-	21.00
21 Elvaberget	1.86	-	0.59	0.50	26.00	-	32.00
22 Bjurliden	3.70	0.20	0.10	0.20	40.00	-	25.00
23 Rävliden	3.14	-	1.90	0.60	67.00	-	22.00
24 Holmtjärn	4.80	0.60	0.40	8.00	120.00	-	32.10
25 Åsen WM	1.84	0.46	1.74	1.00	64.00	0.12	23.00
26 Svansele Väg	3.14	0.04	0.25	0.30	7.00	-	-
27 Åsen ÖM	0.84	0.20	1.22	0.70	34.00	-	-
28 Åkulla Ö	0.07	-	1.70	2.10	14.00	0.11	27.00
29 Bastuheden N	3.20	0.80	0.10	1.00	85.00	1.80	6.00
30 Ö Högkulla	12.60	0.65	0.18	0.60	110.00	-	28.20
31 Renström Ö	6.08	1.69	0.30	3.30	68.00	0.01	-
32 Norriliden	2.50	0.30	0.80	0.40	43.00	-	-
33 Kyrkvägen	6.00	1.70	0.80	2.80	155.00	-	-
34 Långvagen	0.68	0.11	1.50	0.50	19.00	1.69	-
35 Yttre Sjömalmen	3.65	0.39	2.10	2.90	50.00	2.34	-
36 Bjurfors M	3.50	0.20	-	1.00	45.00	-	31.00
37 Vindelgransele	8.90	2.50	-	1.00	150.00	-	-
38 Lomviker	0.70	0.10	0.80	0.40	12.00	1.40	-
39 Rågbogen	0.40	0.10	1.40	0.70	18.00	0.40	-
40 Elvaberget W	0.50	-	2.40	0.40	23.00	-	32.00
41 Allden	-	-	0.10	1.00	24.00	0.30	1.00
42 Gädderäsk	-	-	0.80	0.10	7.00	-	-

Table 1: COMPOSITIONS OF SKELLEFTE FIELD MINERALISATION.



Gold Distribution

The concentration of gold and other base metals are listed in Table 1 for deposits located on Fig. 1. These data represent best estimates for deposit grades computed from production statistics and present ore reserve calculations. Although millfeed grades alone reflect temporal economic conditions, the listing in Table 1 reflects closely the actual mineralization grades to very low cut-off limits. As such we believe that the grades shown are good approximations to the absolute concentrations of the listed elements in the ore paragenesis.

X-Y plots of element association reveal no correlation between the concentration of any of the listed elements and gold. Thus although arsenic may be locally closely associated with gold, there is no general trend and gold occurs as frequently in the absence of arsenic as in its present. The erratic gold-arsenic relationship probably arises from the association of both elements with very reducing conditions.

A weak trend has been identified between (Zn + Cu + Pb) versus Au (Fig. 2) for gold grades up to 3.5 $g.t^{-1}$. This relationship has low statistical significance as might be expected, but indicates that gold is part of the normal base metal paragenesis of these ores, in low concentrations. There is no relationship between gold concentration and total metal including iron, or total sulfur (Fig. 3) in these mainly pyritic ores. Two deposits (Boliden and Holmtjarn), which have >3.5 $g.t^{-1}$ Au, do not follow this trend.

Gold appears not to have any particular regional distribution in the District even taking into account the deformation. Although there is a concentration of gold-rich deposits in the Boliden area in the eastern part of the district (Fig. 1, Table 1, No. 3), the high grade exhibited by the Holmtjarn deposit (Fig. 1, Table 1, No. 24) in the northern central area negates geography as a major parameter. This in turn implies no original geotectonic control on gold distribution.

Controls on Gold Distribution

The general relationship between gold values and total non-ferrous base metals suggests that gold is a normal component of the massive sulfide paragenesis in low concentrations. The lack of relationship of gold (and non-ferrous base metals) with intensity of mineralization (as indicated by the sulfur contents of these pyritites) reflects the differing transport and precipitation chemistries of gold and the non-ferrous base metals and pyrites.

It appears that gold in the gold-rich ores of Holmtjarn and Boliden is not part of the normal massive sulfide paragenesis. Interestingly Boliden exhibited bonanza-type gold in quartz veins, often associated with tourmaline and arsenopyrite. Furthermore, in the eastern area where Boliden is situated, gold-quartz veins not associated with massive sulfides are widely distributed, as indicated on Fig. 1. Holmtjarn does not exhibit gold quartz veins but it is situated at the margin of a later granitoid intrusion and is transected by a major shear zone.

Conclusions

Gold in the volcanogenic massive sulfide deposits of the Skellefte district appears to have been mainly formed during the processes that produced the original sulfide mineralization. However, metamorphism/metasomatism has enhanced gold values in some deposits leading to distinct gold overprints of as much as 15 $g.t^{-1}$.

GOLD-BEARING SULPHIDE DEPOSITS IN THE KUUSAMO EARLY PROTEROZOIC VOLCANO-SEDIMENTARY BELT, NORTHEASTERN FINLAND

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INTRODUCTION

The Kuusamo Early Proterozoic volcano-sedimentary belt is situated in northeastern Finland, just south of the Arctic Circle. It is part of a greenstone belt association extending from the Norwegian Sea to Lake Onega in the U.S.S.R. It is triangular in shape and covers about 7000 km^2.

Seventy per cent of the Kuusamo greenstone belt is composed of sedimentary rocks. The rest is mainly mafic with minor felsic volcanic rocks, all unconformably overlying the Archaean basement. The western contact is transitional into a younger granitized area. Along the southern contact layered gabbro complexes were intruded 2.45 Ga ago between the basement and supracrustal rocks.

GEOLOGY OF THE ORE POTENTIAL UNITS

The lowermost stratigraphic unit consists of mafic continental volcanic rocks (Greenstone Formation I). It is composed of volcanic breccias, amygdaloidal rocks, homogeneous lavas, and tuffite schists underlain by a thin, discontinuous basal conglomerate.

The Sericite Quartzite Formation overlies the volcanic rocks and consists of sericitic quartzites, sericite schists with dolomitic interlayers, quartz-pebble conglomerates, and felsic albitic tuffs and tuffites.

Greenstone Formation II, a relatively thin, subaqueous basaltic flow, interrupts the sedimentary sequence. It is overlain by fine-grained arkosic, argillaceous, or dolomitic schists as well as felsic volcanic rocks (Siltstone Formation). These are frequently hematite-bearing and reddish in colour. Breccias are common in the lower part of the Siltstone Formation where quartz-carbonate-albite matrix envelops variably albitized dolomitic siltstone fragments.

The ore potential units are covered by a wide basalt flow. Conformable differentiated albite diabase sills and dikes have intruded into unfolded and partly unconsolidated sediments. Also syenitic sills and dikes have intruded in the sedimentary units.

The regional metamorphic grade in Kuusamo varies between the lower and upper greenschist facies. Near the granitized area in the west, the amphibolite facies becomes dominant. A striking, duplicating anticline-syncline pattern developed during the folding.

The whole volcano-sedimentary belt has been broken into multisized tectonic blocks by NW-SE and NE-SW striking normal faults.

HYDROTHERMAL ALTERATION

A distinct hydrothermal alteration is always associated with a mineralizing process both in the hanging wall and the footwall. The same type of altered rocks have also been found without sulphides. This alteration appears to be more or less zonal.

The outer albitization zone occurs in all the deposits and is usually overlapped by carbonatization and silicification. Quartz-carbonate-albite veins are often associated with the carbonate alteration, but only a few contain gold.

The later alteration is chloritization which is typically composed of quartz, chlorite, amphibole, and occasionally disseminated magnetite. In higher metamorphic conditions, garnet, chloritoid, staurolite, and cordierite may occur.

The most intensively altered and mineralized is a sericitic alteration zone which typically consists of quartz, sericite, and sulphides with or without chlorite and biotite. Silicification is common in this zone. Sericitization is associated with high-grade deposits and is mainly lacking in low-grade ones.

Tourmaline, rutile, leucoxene, and sometimes allanite are typical accessory minerals in the altered rocks. In some deposits, epidotization is distinctive.

SULPHIDE DEPOSITS

There are twenty-five known sulphide deposits in the region, of which fourteen are gold-bearing. Most of the gold-bearing deposits are located within a 4 km wide, and at least 40 km long, SW-NE trending linear zone. The sulphide deposits are mainly strata-bound and are situated in the two lowermost sedimentary formations. These formations are separated by the Greenstone Formation II. The unaltered host rocks are sericitic quartzites, sericite-carbonate schists, intermediate and felsic tuffs, and siltstones. The origin of the host rock is not always clear because of the pervasive hydrothermal alteration.

The premetamorphic hydrothermal alteration is syngenetic with the ore-forming process. The deposits consist of disseminated sulphides with some thin massive sulphide layers. The disseminated sulphides are remobilized along schistosity and enriched during the metamorphism. The later faulting may have dislocated and enriched some deposits.

The typical metal paragenesis is Fe, Au, Co, U, Cu, W, Mo, Pb, Te, Bi, As, and S. The main sulphides are pyrite and pyrrhotite with minor cobaltite, Co-pentlandite, linnaeite, and chalcopyrite. Accessory minerals are native gold, uraninite, brannerite, scheelite, molybdenite, galena, and tellurides.

The average grade is 0.1 - 0.3 % Co and 0.5 - 10 ppm Au in individual ore deposits. The total proven gold reserves are about 12,000 kg in Kuusamo. The copper content varies greatly in separate deposits (0.01 - 0.4 %), but the total enrichment is low. Nickel, zinc, and silver are almost completely absent. Uranium, tungsten, molybdenum, lead, and tellurium are typical minor elements in the gold-bearing parts of the deposits. The Co/Ni-ratio varies from 4 to 45, usually 10-20.

The Juomasuo deposit is situated in the sericitic and silicic alteration zone. The thickness of the zone varies between 20 and 80 meters, and it is variably mineralized. Host rocks in the hanging wall are almost pure albite rocks, originally felsic volcanic rocks. In the footwall, there are albite-amphibole rocks which are partly sericite-

and chlorite-bearing. Copper is enriched in a hydrothermally altered mafic sill, 50 meters above the ore zone. The Juomasuo deposit is a strata-bound, flattened pipe with maximum dimensions of 40 m x 100 m x 500 m and dipping 45° to the southwest. It appears to be fault-controlled. The deposit contains one million tons of ore with 6 ppm Au and about two million tons of ore with 0.2 % Co. Cobalt is distributed uniformly, but gold is concentrated with uranium and tungsten in several different horizons within the sulphide ore. Two smaller deposits of the same type are known.

The Konttiaho deposit differs from all the other known deposits. The ore is located in a cluster of hydrothermal breccia pipes, 1 - 30 meters in diameter. Fragments, up to 2 m in diameter, are hydrothermally altered, mainly albitized and carbonatized, but also sericitized and chloritized. The matrix is composed of albite, carbonate, and quartz with minor sericite, chlorite, biotite, and amphibole. Gold is enriched in the matrix with uranium and sulphides. All pipes are not mineralized. The mineralization is epigenetic but precedes the peak metamorphism.

The sericitic alteration is lacking in four low-gold deposits where gold and cobalt occur in the chloritic alteration zone. In these deposits, cobalt is also enriched in albitized and carbonatized zones.

CONCLUSIONS

The evolution of the Kuusamo volcano-sedimentary belt started about 2.5 Ga ago or earlier with a hot-spot activity followed by continental rifting. As a result of sedimentation and magmatism, the rift evolved to an aulacogen. The volcano-sedimentary belt possibly represents the failed arm of the triple junction in the NW-SE trending Norwegian Sea - Lake Onega rift.

The Kuusamo sulphide deposits are quite unique. No deposit of the exact same type has been described in the literature. Some similarities can be found with ore deposits in the Zambian Copperbelt and Idaho Cobaltbelt and also with the Bidjovagge deposit in Norway. The source of the most cobalt-bearing deposits is suggested to be differentiated mafic magmas or ophiolite complexes.

The source of metals appears to be the magma of layered gabbro intrusions and/or ancient sulphide occurrences. Sulphide-bearing glacial boulders from the layered gabbro complexes have been verified as gold-bearing. Typical grades are 30 - 600 ppb with a maximum of 12,000 ppb Au. Metal-transporting fluids may be either magmatic or metamorphic. These fluids have been transported along rift-tectonic fractures, and some ore elements from the country rocks, especially uranium, may have been added to these fluids. There are known to be some uranium-bearing stratiform horizons in the sericitic quartzite.

The mineralization is Early Proterozoic (< 2.45 Ga) and it precedes the peak metamorphism. The gold-bearing sulphide deposits appear to be epigenetic, although a syngenetic origin can't be overruled. Facts supporting the epigenetic origin: 1) exceptional metal paragenesis of Au, Co, U, Cu, W, Mo, Te, As, 2) hydrothermal breccia pipes in the Konttiaho deposit, 3) occasionally sulphide- and gold-bearing quartz-carbonate-albite veins associated with ore deposits, 4) flattened pipe shape of deposits, 5) fault-controlled, and 6) hydrothermal alteration enveloping the deposit.

The significance of alkalic rocks and large granitized units (1.8 Ga), no more than 30 km west of the gold deposits, is not fully known.

GOLD MINERALISATION IN THE INTRACONTINENTAL BRANCH OF THE DAMARA OROGEN, NAMIBIA

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INTRODUCTION

The Damara Orogen is one of the late Proterozoic Pan African orogenic belts. The Orogen lies between the Congo and Kalahari cratons and consists of a northern coastal arm, a southern coastal arm, and a NE-trending, 400 km-wide, intracontinental branch. The meeting point of the three arms was a triple junction from which South America and southern Africa separated, leading to the breakup of late Proterozoic supercontinent. The evolution of the Damara Orogen appears to have involved the opening and closing of a narrow ocean, and therefore the tectonic history of the Orogen can be broadly summarised into an extensional-rifting phase and a compressional-collision phase. On the basis of structural, tectonic and metamorphic patterns, and on stratigraphic and geophysical characteristics, the Damara Orogen is subdivided into a number of zones (Fig. 1). From north to south they are: Northern Platform (NP), Northern Zone (NZ), Central Zone (CZ), Okahandja Lineament Zone (OLZ), Southern Zone (SZ), Southern Marginal Zone (SMZ), (Miller, 1983a).

GOLD METALLOGENY

Gold mineralisation in the intracontinental branch was studied by examining the spatial and temporal association of the known deposits, by field examination and geological evaluation. The known Au mineralisation in the intracontinental branch mostly occurs within the CZ and the NZ (Fig. 1). The Au mineral occurrences appear to have a clear relationship to NE-trending lineaments and to postulated graben faults. Many Au occurrences, as well as other metallic mineral occurrences, are distributed around a major gravity anomaly in the CZ (Fig. 2). This, and two other similar anomalies in the NZ, are spatially associated with ring-type igneous complexes of Karoo age. Another noteworthy feature is that most Au deposits are located within reaction isograds defining areas of upper amphibolite and upper greenschist facies (Fig. 2).

During the extensional-rifting phase base metal + Au mineralisation was formed in rocks of oceanic affinity (Matchless Amphibolite Belt). Some Au mineralisation also may have accompanied exhalative metallic deposits along incipient graben faults. The compressional-collision phase probably involved large scale movements of fluids during regional metamorphism and during the emplacement of granitoids (Miller 1983 b, Haack et al. 1984, Schmidt et al. 1987). During these phases structurally controlled Au mineral-

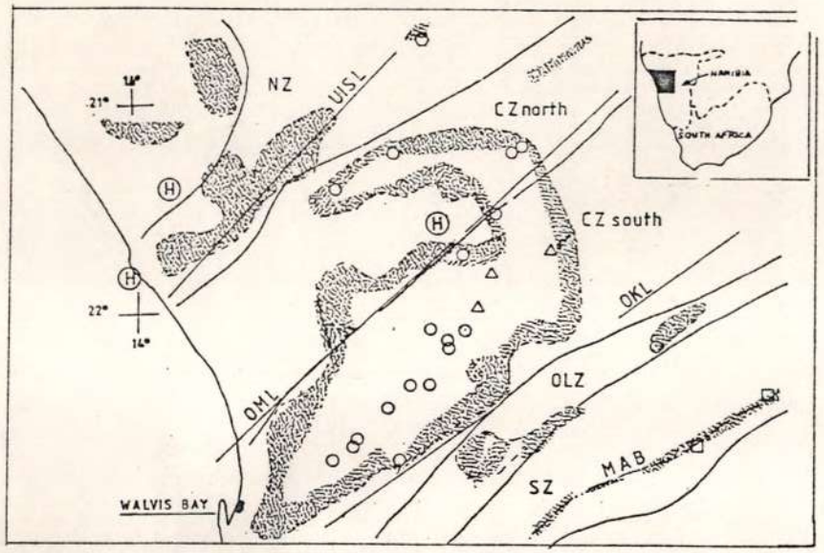


Figure 1. Part of the intracontinental branch of the Damara Orogen showing tectonostratigraphic zones (see text for explanation of acronyms); major tectonic lineaments UISL = Uis Lineament; OKL = Okahandja Lineament; OML = Omaruru Lineament; MAB = Matchless Amphibolite Belt. H = Gravity highs (see Fig. 2). The majority of mineral deposits (Au and other metals) of hydrothermal or magmatic-hydrothermal affiliation occur within shaded areas.

Au Mineralisation

- ○ Shear zone-related or, unknown relationship
- △ Marble-hosted
- ⬡ Metaturbidite-hosted
- □ Metabasite-associated (Matchless Amphibolite)

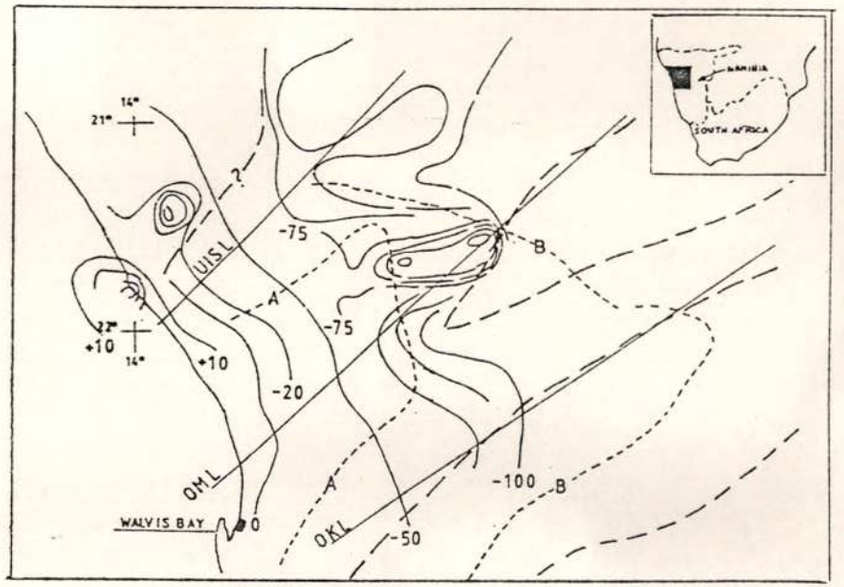


Figure 2. Part of the intracontinental branch of the Damara Orogen showing: Bouguer anomaly contours (after 1:1000000 scale geological map of Namibia, and Aldrich, 1986). Thick dash lines represent postulated graben faults, taken from Porada (1983); small dash lines represent reaction isograds (A = upper amphibolite; B = upper greenschist, see Miller 1983a, p. 470).

sation was formed in a variety of lithologies. Thus Au is found within meta-turbidite rocks, marbles and along shear zones and/or thrust faults in both pre-Damara basement and in the clastic sediments deposited in the developing graben basins. A special type and style of Au mineralisation, as yet undocumented as far as the authors are aware, is that found in the marble rocks of the Karibib Formation in the CZ. This marble-hosted Au mineralisation was only recently discovered and is assuming economic importance. The Karibib Formation consists of metapelites, marble and calc-silicate units, locally intercalated with metabasaltic lavas. The latter have a geochemical signature indicative of continental rift setting (Miller 1983a). Field evidence indicates that the marble-hosted Au mineralisation of the CZ may have formed through multistage processes, beginning in the extensional rifting phase, with Au being introduced during exhalative activity connected with the outpouring of mafic lavas along graben faults. Regional metamorphism of dominantly high T/low P, and later compression, resulted in large scale movements of fluids (mainly CO_2 and H_2O), perhaps derived at least in part from devolitisation reactions. These fluids produced extensive regional-scale alteration (Ca and Mg metasomatism mainly) and, introduced Au into areas where the fluids encountered protore lithologies. Syn to post-tectonic granitic intrusions may have locally redistributed the Au within associated vein systems.

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PROTEROZOIC GOLD MINERALIZATIONS IN THE SKELLEFTE DISTRICT, NORTHERN SWEDEN.

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Several, mostly minor gold mineralizations occur in the Proterozoic Skellefte volcanic massive sulphide ore district. They are related to intrusive rocks and tectonic lineaments in local settings.

The Skellefte district (fig 1) is believed to be an early Proterozoic analogue of a Phanerozoic island arc. It consists of a lower succession of metamorphosed mainly marine acid volcanics and pelitic sediments with intercalations of basic volcanics, overlain by the younger Vargfors shallow water and subaerial sediments and volcanics. The supracrustal formations have been intruded by granitoids of two generations: the synkinematic Jorn granitoids (1.9-1.87 Ga) and the late- to postkinematic Revsund granitoids (1.8-1.77 Ga). The district constitutes a border zone between an inferred Proterozoic partly Archaean continent to the north and a coeval marine sedimentary basin to the south. This setting continues across the Gulf of Bothnia into the Vihanti-Pyhäsalmi area in Finland, where similar massive sulphide and gold deposits occur.

The marin metavolcanics can be divided into two units. The lower unit consists of acid pyroclastics with minor basic and sedimentary intercalations , deposited on an unknown basement. The unit terminates with a stage of minor massive sulphide deposition. The upper unit is bimodal with a large component of reworked volcanic material and small massifs of quartz porphyries. This unit contains the majority of the massive sulphide deposits, deposited in small fault-bounded basins.

The synkinematic Jorn granitoids are calcic to calcalkaline, volcanic arc type intrusives believed to be comagmatic with the volcanics. The main massif (Fig 1) occurs in the northern part of the district as a concentrically zoned batholith with small high-level quartz-feldspar porphyry stocks and related porphyry copper mineralizations in the tonalite-granodiorite margin surrounding an inner granodiorite-granite . The Jorn granitoid domes acted as rigid bodies during later folding and show evidence of brittle to brittle/ductile deformation whereas the supracrustal rocks deformed plastically.

The Gallejaur intrusive complex (Fig 1) consists of a weakly layered mafic intrusion differentiated into a monzonite. The Gallejaur intrusion is comagmatic with the Vargfors subaerial andesites and tentatively correlated to the basic dike swarms in the Jorn massif. The Gallejaur igneous activity occurred in a stabilized crust along structurally controlled zones.

Epigenetic gold mineralizations occur both in the intrusive rocks and in the volcanic-sedimentary pile. They are spatially controlled by repeatedly active growth faults and shear zones, formed early in the history of the Skellefte district.

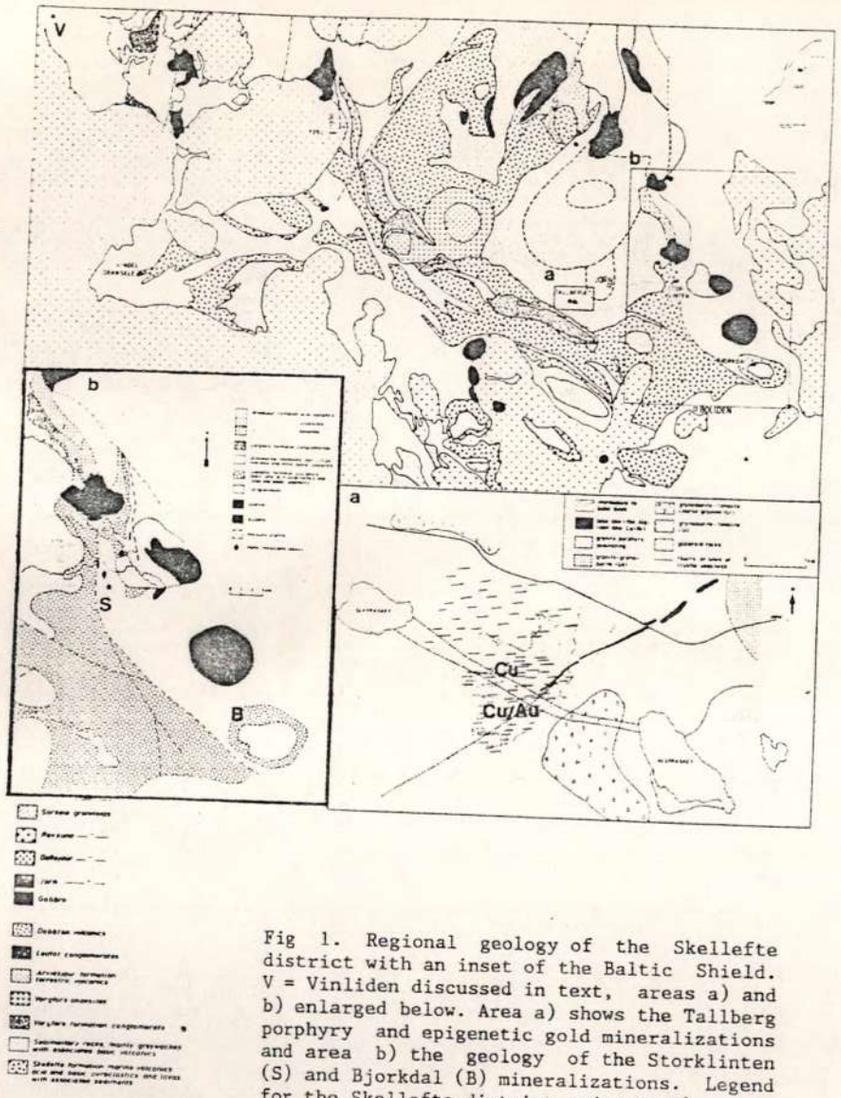


Fig 1. Regional geology of the Skellefte district with an inset of the Baltic Shield. V = Vinliden discussed in text, areas a) and b) enlarged below. Area a) shows the Tallberg porphyry and epigenetic gold mineralizations and area b) the geology of the Storklinten (S) and Bjorkdal (B) mineralizations. Legend for the Skellefte district and area b).

These tectonic features also controlled the margins of the sedimentary basins and influenced the emplacement of intrusive rocks.

The Tallberg deposit (fig 2) consists of a porphyry copper mineralization, characterized by tonalites with a mixed phyllic-propylitic alteration, high contents of magnetite and low grade Cu mineralization. This mineralization is cut by shear zones with

phyllic alteration, higher grades of pyrite, sphalerite and gold and lower grade of magnetite. Basic dikes have intruded the porphyry copper mineralization subparalell the shear zone direction. In the extension of the main gold zone the ultramafic-mafic Algliden dike with low-grade Cu-Ni-Au mineralization is situated.

The Bjorkdal deposit (fig 1) consists of steeply dipping, parallel quartz veins with pyrite and gold emplaced into a large shear zone at the contact of a tonalitic Jorn pluton and the enclosing supracrustals.

The Storklinten, Vinliden and Vindelegransele mineralizations (fig 1,2) are different from the Tallberg and Bjorkdal deposits, as they are related to small granitoid stocks and dikes intruding a mainly sedimentary environment along structurally controlled zones. These deposits are characterized by abundant sodium enrichment, evidence of small scale brittle deformation and arsenopyrite as the dominant ore mineral. Ultramafic-mafic dikes and sills also occur in this environment.

Quartz veins with arsenopyrite and gold also occur in the Gallejaur complex close to the contact zone between the monzonite and enclosing gabbro. Similar mineralizations have recently been discovered in other parts of the district.

Other types of gold mineralizations include the Boliden and the Akulla E deposits, which are quartz vein and shear zone lodes emplaced close to or inside massive sulphide deposits. The Boliden deposit was the largest gold producer in Europe during four decades of mining. Related to this type of mineralization are sulphide disseminations with occasional gold grades which occur at the massive sulphide stratigraphic level. However, the genesis of these mineralizations are debated as they might belong to the massive sulphide systems.

A common type of gold mineralizations are quartz veins with arsenopyrite. They are normally very small. They can be linked to large tectonic lineaments and local lithologic competence differences, for example basic intercalations in sediments.

As evidenced from isotope age work, the evolution of Skellefte district took place in a short time span, approx. 30 Ma (1900-1870 Ma). The explosive acid volcanic activity followed by basic volcanism, structurally controlled quartz porphyry magmatism and basin-related volcanoclastic sedimentation indicates an early control of volcanics and mineralization by tectonic lineaments. These were still active during later tectono-magmatic processes (granitoid intrusions and folding) and became critical for deposition of gold during brittle and ductile deformation stages of the newly formed crust. Different sources for the ore forming solutions may explain the affinity of arsenopyrite to sedimentary environments and pyrite-chalcopyrite of the deposits hosted by volcanics and Jorn granitoids. The close relationship between the porphyry copper and gold mineralization at the Tallberg deposit indicate that the synkinematic intrusives form the hydrothermal centres and the heat source for the ore forming solutions, also evidenced by zoning patterns noticed for similar gold mineralizations in Finland. Gold was deposited during the brittle to semibrittle tectonic stage of the Gallejaur magmatism, evident in coeval faults, shear zones and basic dike intrusions.

Topic 2B

PROTEROZOIC CASE HISTORIES

PAHTOHAVARE, A NEW COPPER GOLD DEPOSIT IN THE KIRUNA GREENSTONE BELT, NORTHERN SWEDEN

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A new copper gold deposit has been discovered in the Kiruna greenstone belt only 9 km from the Kiruna iron mine. The discovery is the result of intensive gold exploration in Norrbotten by the Swedish Government since 1982.

The geology in the area is divided into the Kiruna greenstone group, Kurravaara conglomerate and the Kiruna porphyry group. These units are of Proterozoic age and are resting on a base of probably Archean age.

The present deposit is located in the Kiruna greenstone group consisting of gabbro intrusions and sills (massive flows) covered by basic agglomerates, lappilli tuffs, basic banded tuffs and metasediments.

Five different ore types and mineralizations have been distinguished.

1. In the inferred Archean basement, quarts diorite with skarn zones with dissminations of chalcopyrite and bornite occur.

2. Intrusive gabbro stocks and sills with disseminations of pyrrhotite and chalcopyrite.

3. Hydrothermal alteration zones in intrusive gabbro stocks, comprising carbonatization, scapolitization, silicification and biotite alterations accompanied by disseminated pyrite, chalcopyrite and native gold.

4. Exhalative chert with massive chalcopyrite ore with native gold. The chert is deposited together with graphitic schist on differentiated basic magmatic rocks. Scapolite alteration is common.

5. Layered and disseminated chalcopyrite and minor sphalerite in banded tuffs and metasediments similar to the Viscaria ore deposit 9 km north of Pahtohavare.

So far approximately two (2) million tons ore has been outlined in different positions. The grade is estimated to 3,7 g/t Au and 4,3 % Cu. Exploration is still in progress.

The Pahtohavare area is tectonically complex with domes, major shearzones, boundary faults and isoclinal folding.

TARCOOLA GOLDFIELD

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Tarcoola Goldfield occurs in the central Gawler Craton, 600 km north-west of Adelaide, within a sequence of folded Middle Proterozoic sediments, c. 1600 Ma in age overlying Archaean basement. Tarcoola Formation consists of a basal pink arkosic grit, likely fluvial, with locally abundant banded iron formation fragments, overlain by laminated carbonates and thin to very thick-bedded, well-sorted quartzites, deposited on a shallow marine shelf. The quartzites are interlayered with and overlain by thin-bedded, carbonaceous and pyritic quartzites and siltstones deposited in a more restricted marine basin.

Tarcoola Formation is folded along east-west trending axes reflecting movement along Archaean basement structures. The goldfield is situated on the moderately-dipping southern limb of an easterly trending anticline. Hiltaba Suite granite c.1580 Ma has intruded the folded sediments along a strike length of 11 kms, with a contact which crudely parallels strike of the sediments. Large subvertical to vertical gold-bearing quartz reefs cross-cut the sediments and were emplaced following development of tension fractures, generally perpendicular to strike, by the upwardly stoping granite. The granite is locally very chloritic, may contain abundant sulphides and has been mined for gold.

Hiltaba Suite granite, Tarcoola Formation and quartz reefs are intruded by dacitic and andesitic dykes which contain detectable gold. Gold-bearing quartz reefs are up to 2 m wide, 250-300m long, with a vertical extent of at least 100 m and contain abundant crushed xenoliths of quartzite and carbonaceous siltstone. Reefs have been historically described as narrower within thick-bedded quartzites and broader within thinbedded carbonaceous siltstone and quartzites. A great deal of stoping has been done within the carbonaceous siltstones. Records suggest rich gold values have been obtained where quartz veins initially cross-cut carbonaceous siltstones. Sampling by Emperor Mines and recent drilling by Tarcoola Gold Ltd indicate gold haloes with associated sericite, chlorite and pyrite alteration also occur around quartz veins cutting quartzite. Present-day workings indicate anastomosing quartz veins of up to 20 cms width, enclosing crushed wall rock suggesting reefs were probably quartz-vein sets. Many small quartz veins which contain gold occur between the major reefs.

The ore contains not only gold but Ag, and locally abundant sulphides of Cu, Pb, Zn and As. Reefs characteristically produce erratic gold values both laterally and vertically and contain both very fine-grained and coarse gold.

Outcropping in the Pahtohavare area is very poor which has necessiated extensive use of ground geophysics, geochemistry and drilling methods.

Gossanous ore zones have been developed by preglacial weathering and are here for the first time encountered in northern Sweden.

Between 1901 and 1986, 2.387 tonnes of gold was produced from 63 703 tonnes of ore (37.47 g/t bullion). The bulk of production occurred prior to 1918. Potential for open cut mining of the Tarcoola Blocks Mine and nearby granite is currently being investigated by Tarcoola Gold Ltd and by BHP Gold Ltd in joint venture with Aberfoyle and Afmeco.

BHP Gold Ltd has drilled and excavated costeans across the granite-quartzite and carbonaceous siltstone contact to the northwest of Tarcoola Blocks Mine. Significant results near surface have been obtained and further drilling is planned. Tarcoola Gold Ltd similarly has completed reverse-circulation drilling in the vicinity of the Tarcoola Blocks Mine. The Mine (107 m deep) has been dewatered and a new head frame erected. Underground trial mining and drilling of reef zones will begin in 1988 to provide data on ore-grade metallurgy and reserves. A 100 000 tpa high grade gold extraction gravity/CIL plant is in the design stage with construction of the first 50 000 tpa stage expected in April.

THE FLAMBEAU AND RITCHIE CREEK DEPOSITS: GOLD ENRICHED MASSIVE SULFIDE MINERALIZATION IN THE WISCONSIN PENOKEAN VOLCANIC BELT

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Extensive exploration work completed since the mid-1960s has defined at least three massive-sulfide districts in the Northern Wisconsin Penokean Volcanic Belt (Early Proterozoic) of the Southern Structural Province of the Canadian Shield. Thick glacial cover has prevented detailed geologic mapping but information from numerous diamond drillholes coupled with airborne geophysical surveys suggest that the districts are located along the flanks of the core of a major volcanic complex (Ladysmith-Rhinelander Volcanic Complex) and within felsic centers.

Significant gold mineralization exists in at least two of the three districts, the Ladysmith and Somo districts, each of which hosts several gold-bearing massive-sulfide occurrences. Examples include the Flambeau deposit and Ritchie Creek prospect.

Flambeau, to date the largest and best known deposit in the Ladysmith district, has drill-indicated reserves of 4 to 6 million short tons at 4 percent copper, 1.6 percent zinc, and 0.05 ounces of gold per ton. Stratiform copper- and zinc-bearing recrystallized (porphyroblastic) massive (more than 50 percent) and semi-massive (more than 30 percent) sulfide mineralization is hosted by a steeply dipping quartz-sericite schist (rhyolitic lapilli tuff) and is enveloped by a wide halo of disseminated pyrite. Primary vertical zoning is observed for copper-zinc with increasing zinc content toward the stratigraphic top of the deposit. Several small zinc-rich lens are present in the stratigraphic hanging wall. Microprobe analyses indicate that micron-sized hypogene gold mineralization occurs in its native state or as electrum, disseminated uniformly throughout the massive- to semimassive-sulfide mineralization. No gold zoning has been described.

Development of a classic gossan-oxide-supergene zone has resulted in secondary enrichment in both copper and gold near the deposit's subcrop; a thin oxide layer (1 to 3 feet thick) is believed to contain several thousand ounces of secondary gold, and the gold enrichment also extends vertically into the supergene zone.

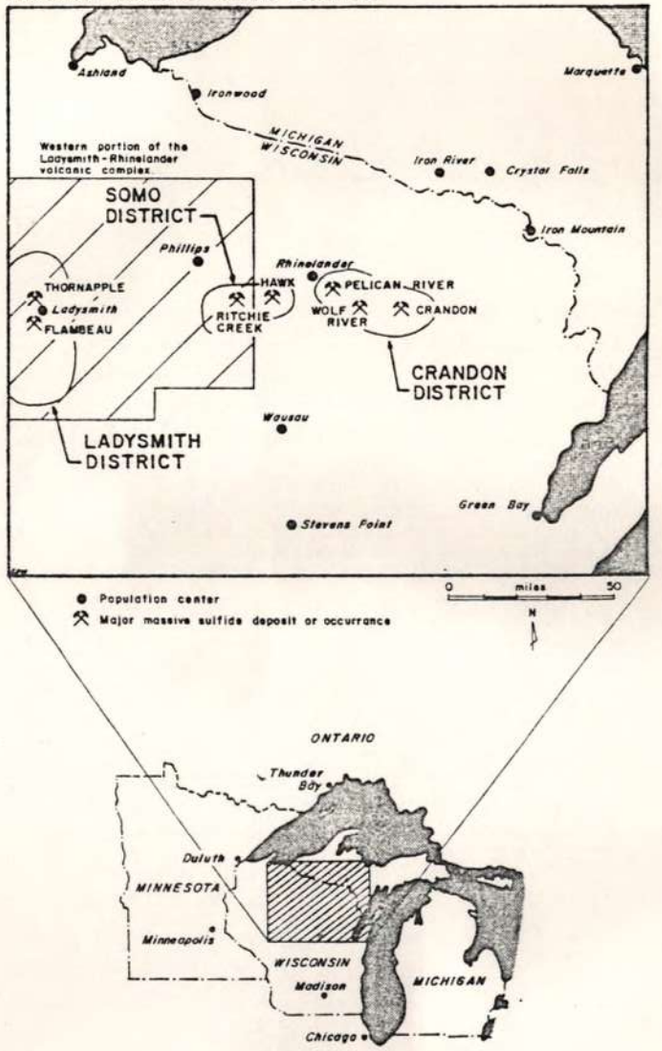
Approximately 1.5 million short tons of secondary, enriched direct-shipping ore (10 percent copper and more than 0.1 oz/ton gold) amenable to open-pit mining has been delineated by Kennecott. The supergene enrichment zone is currently being prepared for development; initial production should begin by 1990.

The Ritchie Creek prospect is approximately fifty miles east of Flambeau, in the Somo district. Its Main Zone, containing drill-indicated reserves of approximately one million tons with a grade of 1.5 to 2 percent copper, consists of stratiform recrystallized copper-bearing massive and semi-massive sulfide mineralization hosted by a steeply dipping quartz-sericite schist (rhyodacitic tuff lapilli tuff) unit and additional ore-grade zinc-copper-gold mineralization has been identified to the west along strike but stratigraphically above the Main Zone. Hypogene gold concentrations are generally low (0.007 oz/ton) in the sulfide zone, a stratigraphically uniform assay horizon averaging 0.03 oz/ton gold is present within the surrounding sulfide halo, and at least two high-grade (0.10 to 0.31 oz/ton) gold shoots are developed along cross faults where they transect the assay horizon. The fault structures are expressed as zones of intense carbonate-chlorite-sericite alteration, silicification, mafic igneous intrusion, and shearing. Microprobe analysis indicates that most of the gold occurs in solid solution within the mineral altaite (PbTe). These structurally controlled shoots may contain significant tonnage and grades approaching economic importance and are the target of active exploration.

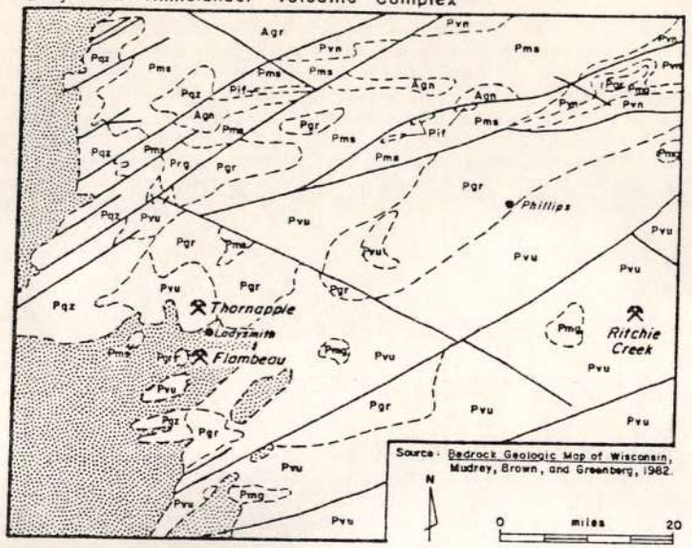
The Flambeau and Ritchie Creek deposits effectively illustrate that important gold values occur in a number of different environments, both primary and secondary, within a given massive-sulfide system, in these two districts.

The presence of significant precious-metal values in many of the massive-sulfide deposits and occurrences makes these districts attractive exploration targets under current economic conditions. However, this exploration camp has not enjoyed the level of activity that might be expected. This is primarily due to past political and environmental problems faced by the exploration companies operating in Wisconsin. Recent improvements in these conditions, particularly the political situation, as they are perceived by the companies, coupled with stronger metal prices and the development of the Flambeau Mine, should renew interest in this Wisconsin camp.

Regional Maps showing locations of the Wisconsin Massive Sulfide Districts

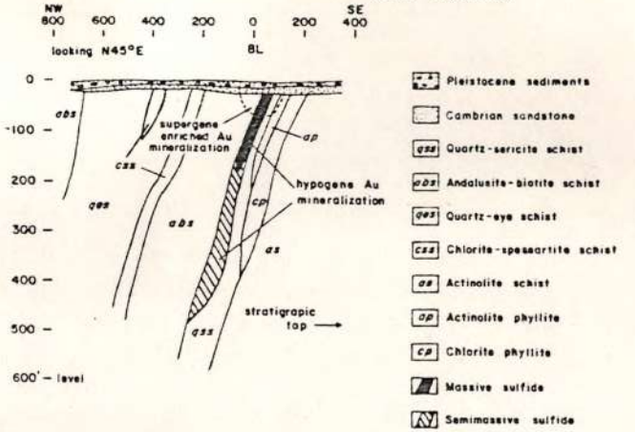


General Geologic Map of the Western Portion of the Ladysmith - Rhinelander Volcanic Complex

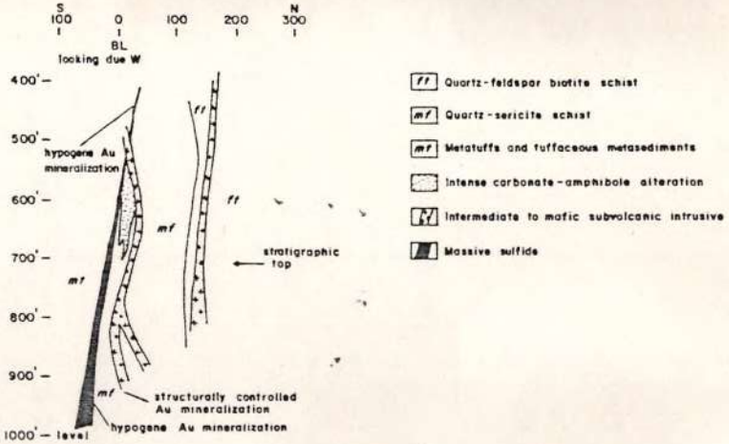


Cambrian		Mount Simon Sandstone
Early Proterozoic	Pqz	Barron Quartzite
	Prg	Biotite granite plutons
	Pgr	Intermediate to granitic intrusive rocks
	Pmg	Metamorphosed ultramafic to mafic intrusive rocks
	Pms	Metasedimentary rocks
	Pif	Magnetic iron formation
	Pvu	Mafic to felsic metavolcanic rock and subordinate metasedimentary rock
Late Archean	Agr	Granite and associated rocks
	Agn	Quartz to feldspathic gneiss, migmatite and amphibolite

Geologic Cross-section through the center of the Flambeau Deposit, Rusk County, Wisconsin
(after May, 1976)



Geologic Cross-section along Grid Line 200E of the Ritchie Creek Main Zone, Price County, Wisconsin



MINERAL PARAGENESIS IN THE Au-Ag-Cu-Zn-Pb-Te DEPOSIT OF LEGA DEMBI (ETHIOPIA)

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The primary gold mineralization of Lega Dembi was recently discovered in the "Adola Gold Fields" (Sidamo, South Ethiopia) where since long time gold placers were known and exploited. It occurs in an area covered by tropical forest, buried under variably thick residual soil.

The country rocks belong to the Upper Proterozoic volcano-sedimentary sequence, accompanied by intrusive rock units. Biotite gneisses, biotite quartz-feldspatic schists, carbonaceous mica-quartz schists and amphibolite schists are the main rock types belonging to the volcano-sedimentary complexes. Talc-tremolite schists and amphibolized gabbro are the metamorphosed products of the ultramafic intrusives.

The orebodies are confined to a narrow zone of biotite quartz--feldspatic schists and carbonaceous quartz-mica schists. They occur as quartz lenses, veins and stock-works grouped according to an elongated N-S trending swarm, following an important shear zone, concordantly with the host rock structures (foliation, limits of the different volcano-sedimentary units).

The quartz gangue, in surface, is sugary, white, fine to medium grained, evolving to a more compact milky type in depth. Its change is accompanied by a parallel evolution of the ore minerals, probably mostly due to leaching bound to the severe weathering processes: gold is generally alone near the surface, whereas it is accompanied by a complex mineral association in depth. The overall paragenesis, determined by microscopy studies and electron microprobe analyses, is given by (in order of abundance): pyrrhotite, chalcopyrite, galena, pyrite, gold, electrum, tellurides (altaite, hessite, petzite), sfalerite, cubanite, arsenopyrite, pentlandite, ullmannite, Ag-tetrahedrite, breithauptite, boulangerite, bournonite, meneghinite, Ag-pentlandite, nisbite, gersdorffite, mackinawite.

Native gold and electrum occur either as free isolated particles of various size, from finely dispersed up to visible nuggets and dendritic bodies (pure gold), or as grains and droplets associated with different sulfides, mainly galena. Gold and electrum form two well defined populations, so that it is possible to distinguish two different sets of conditions in the gold behaviour during crystallization, according to the Ag content (fig. 1). It can generally be said that an

initial phase is characterized by pure gold to low Ag content gold deposition, as free and isolated particles in quartz or in association with chalcopyrite and pyrrhotite. It is followed by gold which has an increasing Ag content, until true electrum, often associated with galena.

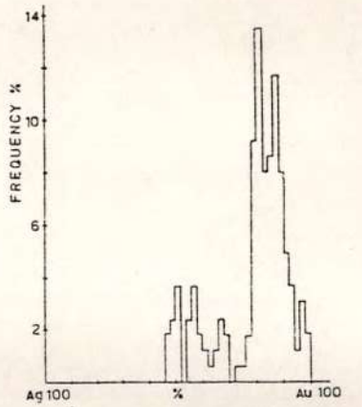


Fig. 1. Gold and electrum populations, determined by electron microprobe analyses.

A common feature of the gold-electrum deposition is given by a typical "bleb structure" (fig. 2), due to the contemporaneous open spaces filling by both gold and galena, where gold-electrum is always a bleb attached to the cavity wall ("wall effect" as catalytic influence on gold crystallization), with mutual boundaries to galena. An important character of this phase of the mineralizing process is shown by the Te type of occurrence. Te is present in galena either as droplets, blebs and lamellae-shaped exsolutions or as high Te content (up to 15,900 ppm). This different behaviour, together with other charac



Fig. 2. "Bleb structure" of gold (white) with galena (grey) in quartz (dark). Reflected light, 240 x.

ters: distribution of gold, electrum and sulphosalts allows to schematize the geometry of the Lega Dembi deposit dividing the ore zone into two major parallel mineralized belts, simply called "orebody n.1" and "orebody n.2".

On the basis of the available informations it is possible to propose the following evolution of the mineralizing process:

1 - The origin of the protore related to mafic volcanic events is strongly suggested by the presence of Ni-bearing minerals, sometimes directly associated with gold (the very rare nisbite is to be emphasized), together with amphibolite members in the host metamorphic sequence.

2 - Repeated tectonometamorphic actions were responsible of mobilization of substances, leading to the concentration of the ore minerals in the present ore zone, where their undisturbed attitude is an indication of the continuous submission to the developing new conditions and renewed equilibria, through phases of even high temperature (250°--300°, geologic thermometers: cubanite exsolutions in chalcopyrite; sfalerite star-shaped exsolutions in chalcopyrite; chalcopyrite exsolutions in sfalerite).

3 - Gold deposition started at the end of the Fe and Cu sulfides crystallization: its association with pyrrhotite is rare, with chalcopyrite unfrequent and it does not appear when there are high temperature characters (cubanite exsolutions, sfalerite star-shaped exsolutions). The last phases of the mineralizing process were the most favourable for the gold deposition, at physico-chemical-conditions consistent with the galena and tellurides genetic environment. Te seems to have played an important role in gold concentration.

THE GOLD BEARING CANASTRA PHYLLITES OF LUZIANIA: A MODEL OF THIN SKINNED THRUST MINERALIZATION OF THE BRASILIA BELT

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INTRODUCTION

The southern part of Goias, Brazil, has traditionally been a region of gold exploration due to the presence of near surface gold enriched phyllites and deposits of alluvial (lateritic) origin. Recent exploration in the Luziânia area (approximately 70 km south of Brasilia) has led to renewed interest in the geologic and structural setting of the three ancient gold deposits in the area, as well as their genetic relationship.

STRUCTURAL SETTING

The old Luziânia gold deposits in southern Goias lie within the N-S Late Proterozoic Brasilia fold belt. This belt is marked by a series of SE trending thrusts which control brittle-ductile horizontal laying shear zones, which are exposed at the surface in the Luziânia area. The shear zones are characterized by mylonite bands (ultra-, orthomylonites) and high stress related sheath folds (average b-axes N30E) which have resulted from an eastward thrust displacement.

In the Luziânia area the metasediments of the Canastra group have been carried by internal piggy back thrust propagation, south-eastwards towards the São Francisco craton. Lateral ramps consist of mylonite bands, whereas flats are displayed by unsheared and only slightly deformed metasedimentary strata. Both are nearly completely eroded and the flats now represent the footwalls of the former thrusts (nappes).

Throughout the mapped area there exists a characteristic S1 foliation (N40E striking and 30NW dipping); locally, in more ductile mica rich rocks, an S2 foliation can also be observed.

LITHOLOGY

Lithologically, this part of the Brasilia fold belt consists of a monotonous series of phyllites which vary in quartz content. Locally, in the working area, and characteristically on top of the phyllites, and garnet-sericite-schist has been mapped. The metapelitic strata in this part of the Brasilia belt are confined by low to medium grade metamorphism.

The rocks that host the gold mineralization are hydrothermally altered phyllites with quartz veins, and boudins, which are

mineralized and interbedded parallel to the S1 and, where present, S2 foliation. The lithology in the three ancient gold deposits exhibits the regional trend following a well developed N45E striking and 20° to 30° NW dipping S1 foliation. Table 1 shows x-ray fluorescence and atomic absorption analyses of phyllite samples (6, 16, 19/2) collected from each of the three ancient gold deposits west of Luziânia, in the Brasilia belt.

TABLE 1

Sample No.	6	16	19/2	
SiO_2	53.26	60.26	64.19	in weight %
Al_2O_2	21.19	16.34	14.99	
CaO	0.06	0.05	0.06	
MgO	0.69	0.95	0.74	
Fe_2O_3	7.10	5.88	2.91	
TiO_2	1.29	1.03	1.04	
K_2O	5.07	4.97	4.13	
Na_2O	0.29	0.21	0.23	
TOTAL	88.95	89.69	88.29	
Wt. loss	11.05	10.31	11.71	
Au	0.20	3.35	1.50	in ppm
Ag	1.00	0.70	0.80	
Pb	217.00	180.00	56.30	
As	463.00	1113.00	807.00	
Ni	10.50	7.20	15.00	
Cu	47.30	41.70	21.30	
Zn	44.30	26.00	7.20	
Fe wt. %	4.09	3.06	1.53	
% wt. loss	4.63	2.83	4.03	

GOLD MINERALIZATION

Gold is found around the thin alteration wall zone of the sheared quartz veins and boudins, and within the boudins themselves. The veins and boudins show a pitch of approximately 20° to the east which coincides with the axis of the sheath folds. The mineralization is marked by pervasive hydrothermal alteration syngenetic to the ultra- and orthomylonites that were developed along the thrust planes. It is clearly epigenetic in respect to the protoliths, whose primary nature has not been clearly determined.

Pyritization, sericitization, and chloritization accompany the pyrite-arsenopyrite-chalcopyrite-tetrahydrite assemblage which is associated with gold. Typical gold values range from 0.1 to 3.35 ppm (see Table 1). Gold occurs within the sulfide minerals and as free gold in minute flakes, 1 to 10 um long. Close to the surface, dentritic and tabular root shaped gold grains have been observed in typical alluvial (lateritic) deposits.

GENETIC MODEL

The genetic model (Fig. 1) illustrates the generation of two types of gold mineralization through two different processes:
(1) an initial enrichment at the time of overthrusting through the upward migration of gold enriched hydrothermal fluids along thrust planes, and

(2) secondary supergene enrichment through meteoric water cycling at the present surface.

Together these meteoric and hydrothermal water systems seem to be responsible for the higher gold values in the ancient Luziânia gold deposits.

The Luziânia deposits lie within the same metalotect and have structural controls similar to those of the recently developed Paracatú mine (about 100 km south of Luziânia) which has been erroneously tied to syngenetic sedimentary processes.

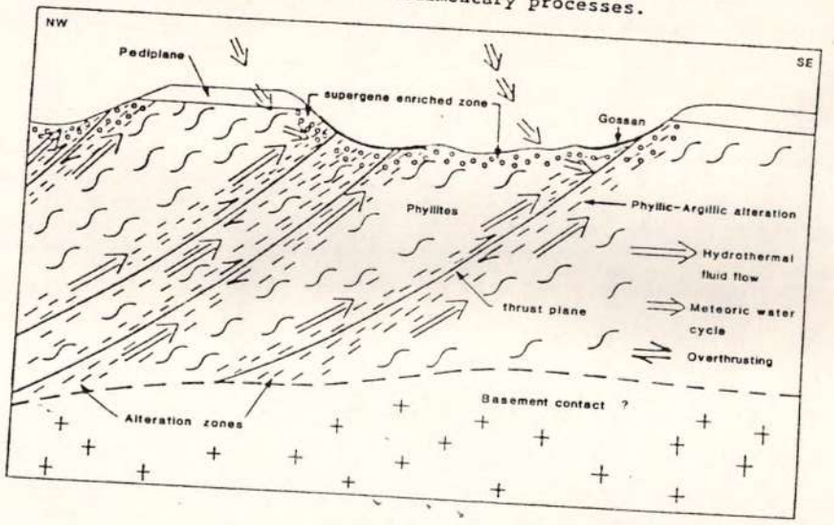


Figure 1. Structurally controlled genetic model for gold mineralization in the Luziânia area, southern Goias, Brazil.

GEOCHEMICAL ALTERATION, REGIONAL SETTING AND STRUCTURAL CONTROL OF THE LOWER PROTEROZOIC PAHTAVAARA Au-PROSPECT, FINNISH LAPLAND

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The past few years have seen a marked increase in gold exploration in Finland, reflecting to a large extent the general world wide interest in the metal. An important additional factor however has been the development of more rapid and accurate analytical techniques by the Finnish Geological Survey in connection with regional studies of till and regolith geochemistry. This has led to the discovery of a number of potential Au mineralizations of which the komatiite- hosted Pahtavaara prospect, located within the early Proterozoic Central Lapland Greenstone Belt, (CLGB, Fig. 1), is one of the better investigated examples, although its economic potential has yet to be evaluated.

Attention was drawn to the area surrounding Pahtavaara after systematic geochemical mapping of till and drainage systems (initially with a sampling density of 10/km^2) revealed a close correlation between the distribution of komatiitic lithologies and regionally anomalous concentrations of Mg, Ca, Cr, Ni and Co, closely reflecting the regional distribution of komatiitic bedrock. More specific Ni-Cu-Co-Pb anomalies were identified as potential targets for sulfide mineralization and selected for follow-up studies, involving sampling of till at a grid spacing of 100 m x 50 m. These results, revealed elevated gold contents as well, particularly in the vicinity of Pahtavaara itself, and led to detailed analysis of weathered bedrock, with sampling at 5 m intervals along profiles spaced 50 m apart, combined with detailed lithogeochemical mapping of almost 600 m of exploration trenches. As a result, a hydrothermally altered zone approximately 100 m x 500 m in extent was outlined, differing geochemically from surrounding terrain by its high K, Ba and Sr contents and relative depletion in Mg, Co and Zn. Detailed lithogeochemical study and evaluation of drill core material subsequently obtained at a 50 m x 50 m grid spacing is still in progress but initial results show intersections averaging 10 ppm Au over intervals of 10 m.

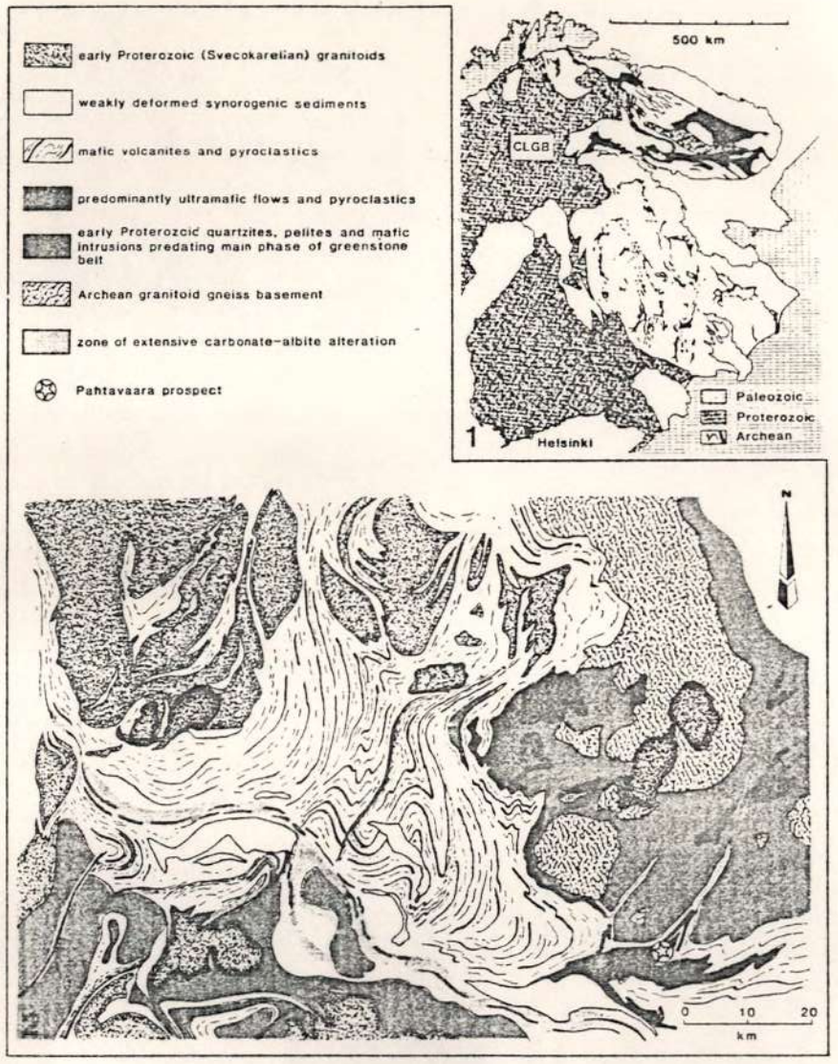
Mineralization at Pahtavaara is hosted by greenschist facies, originally komatiitic tuffs retaining relict pyroclastic textures but now present as three distinct lithologies representing varying degrees of alteration. Chlorite - actinolite - talc - carbonate schists are the least altered whereas biotite schists show extensive gains in K, Ba, Na, Si and Fe and depletion in Mg and Ca; homogeneous Cr/Al and Al/Ti ratios indicate both the stability of these elements during the biotite alteration process and the primary komatiitic nature of the protoliths. Biotite alteration is attributed to high permeability within the original tuffs during

early hydrothermal metamorphism, supplemented by the high heat flow associated with the komatiitic volcanism. The earliest phase of gold precipitation was associated with these processes and/or the widespread formation of talc-carbonate-pyrite veins during the initial stages of deformation. This preceded formation of the third lithological type, namely irregular coarse-grained tremolitic pods and associated quartz-barite lenses and veins, characterized by Si and Na enrichment, with corresponding MgO loss and containing visible gold.

The Pahtavaara komatiites lie towards the eastern end of the Central Lapland Greenstone Belt (CLGB) which extends in a N-NW direction across the northern Fennoscandian Shield from Finnish Lapland into northernmost Norway (Fig. 1). The CLGB differs from the more typical late Archean greenstone terranes of the Shield in both its younger age and distinct tectonic setting, having developed at around 2.5 Ga by rifting of an older, 3.1 - 2.9 Ga cratonic substrate, but remaining substantially undeformed until the Svecofennian orogeny between 2.0 - 1.8 Ga. During the earlier, more protracted rift phase of evolution, minor bimodal komatiitic - tholeiitic - felsic volcanism alternated with a widespread and mature shallow-marine quartzite-pelite association and were accompanied by various suites of mafic layered intrusions between 2.4 - 2.2 Ga. The main phase of volcanic activity is believed to have culminated around 2.1 - 2.0 Ga and consisted dominantly of submarine tholeiitic volcanites, with komatiitic flows and pyroclastics intercalated in the inferred lowermost parts of the sequence, particularly towards the eastern end of the belt (Fig. 2).

Deformation of the CLGB resembles that in thin-skinned foreland thrust-belts and commenced during overthrusting of the Lapland granulite belt from the NE followed by imbrication of opposite vergence associated with the earliest stages of the Svecofennian orogeny. Progressive deformation resulted in further shortening and accommodation to granitoid intrusion around 1.9 - 1.85 Ga with the formation of major WNW-NW trending dextral shear systems. Persistent ductile and brittle reactivation of these structures subsequently influenced late orogenic terrestial sedimentation and granitoid emplacement, but was not significant in vein formation or remobilization of mineralization at Pahtavaara.

However, a distinctive structural feature throughout Finnish Lapland which may be of significance to mineralization at Pahtavaara is the occurrence of NE-trending ductile subparallel shear zones to the inferred thrusting direction. These zones are regarded as analogous to lateral ramps or tear faults caused by differential displacements within thrusts sheets and the underlying Archean craton; as such they may have faciliated large scale fluid circulation through the crust. The Pahtavaara prospect is located where one such shear system intersected already extensively altered komatiites and irrespective of whether an exotic fluid source was involved, it is clear from their geometry that the tremolite - quartz - barite veins having the highest Au contents are genetically, as well as spatially connected with dilatation and progressive deformation within the shear zone.



THE MIDDAGSBERGET Au-As-DEPOSIT --- A NEW TYPE OF GOLD OCCURRENCE IN NORTHERN SWEDEN

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The Middagsberget gold deposit is a vein-type deposit with gold as native metal associated with arsenopyrite-pyrrhotite-quartz in a dioritic rock of middle-Proterozoic age. It is situated in the westernmost part of the Skellefte sulphide ore district, northern Sweden.

Quartz-fracture fillings in dilatant zones within the ore-hosting diorite as well as in surrounding, strongly folded metasedimentary and metavolcanic rocks, occurrence of acidic porphyritic dykes and exotic xenoliths within the ore zone, and frequent minor faults and schistosity developed by shearing within the intrusion, surmise an epigenetic character of emplacement. Alteration assemblages and gold-sulphide-paragensis favour a multi-stage, hydrothermal gold deposition. The dioritic intrusion is weakly differentiated -- diorite/quartzdiorite and clearly of a I-type of granitoid. A hypidiomorphic texture of sericiticed andesine in a fine-grrained, biotite-chlorite matrix is well developed. Accessories are K-spar, carbonate, apatite, titanite, rutile, zircone and tourmaline.

The diorite has been emplaced after a regional phase of folding-metamorphism. A limited alteration --- silicification, sericitisation and skarn development --- occurs around the gold- and sulphide-bearing horizons.

The auriferous, mainly quartz-arsenopyrite ore zones, 0,2 - 5,0 metre in thickness and 25 - 100 metre of strike length, form a subvertical stockwork in the diorite.

The surrounding supracrustal sequence includes several mafic flows, a few containing anomalous gold (> 25 ppb). Limited lithological studies do not prefer any occuring rock-type as a gold source. Mineralogically the relationship between arsenopyrite and gold is very pronounced. Most gold occurs as native gold in minor droplets and interfillings within arsenopyrite crystals. In minor amounts electrum and native gold are found in quartz. Besides iron-sulphides minor amounts of sphalerite, chalcopyrite and galena are present.

Isotope analyses of ore samples are in progress, aiming at determining the model age of the mineralization and its source in relation to other ore-types within the Skellefte ore district.

At present delineation of the deposit is in progress. Surface-near ore reserve is estimated to about 1 Mt grading 3-6 g/ton Au. In the

vicinity of the deposit smaller auriferous quartz-vein occurrences of subeconomic value has been located.

The Middagsberget gold deposit is a "new" type regarding northern Sweden. Very similar gold deposits have recently been found in the central and the northern part of Finland.

EARLY PROTEROZOIC GOLD PLACERS OF THE MOEDA FORMATION WITHIN THE GANDARELA SYNCLINE, MINAS GERAIS, BRAZIL.

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Alluvial gold was first reported from Minas Gerais in the late 17th Century. During a gold boom in the 18th Century, almost all of Brazil's gold, totalling about 800 tons, and representing 60 percent of world production, was produced from eluvial and alluvial deposits in the Iron Quadrangle, much of it weathered from gold-bearing massive sulphide deposits in the Archean. It is likely that this Arcnean basement was a potentially rich provenance area for the production of Proterozoic placers during early cratonic sedimentation of the Moeda Formation.



Figure 1. Location map of Iron Quadrangle in Minas Gerais.

The Moeda Formation, which is a clastic sequence of early Proterozoic rocks, unconformably overlies deformed Archean strata. It is buried beneath Superior-type iron formation in an area known as the Iron Quadrangle in the state of Minas Gerais, Brazil (Fig. 1). These gold-bearing placer conglomerates have been dated between 2.2 and 2.8 Ga.

Prospectors were mining Moeda gold ore before 1846 and had noted that the grades were better where the ore was associated with 'reniform quartz and rounded pyrite'. However, the possibility of these components being waterworn and of the deposits being fossil placers had been

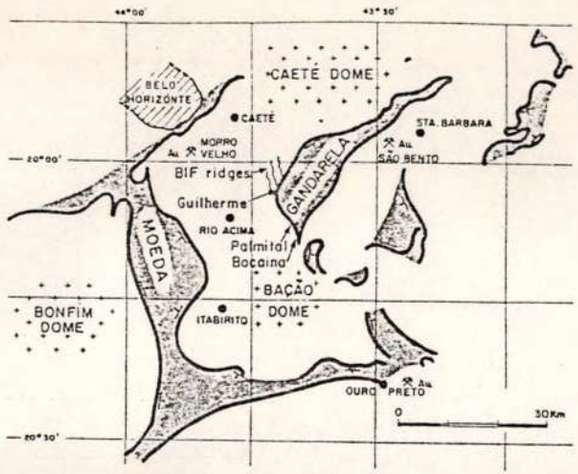


Figure 2. Location map of Gandarela Syncline.

discounted. The Moeda deposits discussed in this paper concern only those that occur in the Gandarela Syncline, and in particular along the northwestern and western outcropping margin of the syncline.

In the Gandarela Syncline the Moeda Formation has been subdivided into three informal units, which at this stage are simply numbered stratigraphically from the base upwards. These units are separated by unconformities which onlap each other towards the north and west. In this paper each unit is considered to represent a synthem. Unit 1 fines upwards from conglomerate to coarse- and medium-grained sericitic quartzite. Unit 2 is an equigranular, very fine-grained, white siliceous quartzite that blankets the Unit 1 strata and provides an excellent datum from which to measure the geometry of the Unit 1 package and thus the paleotopography of the underlying Nova Lima surface. Isopach contours of Unit 1 indicate that it wedges out to a basal remnant along a line striking northeast from Bocaina. This represents a paleostrike and is consistent with a south to southeast palaeocurrent direction measured in the sediments. The thickening of the Unit 1 succession to the southeast of this paleostrike margin indicates the site of a sediment depository, whereas in the area north of this margin the Unit 1 sediments were in transit. In other words, the Moeda palaeosurface from Guilherme to Palmital is interpreted as an upland drainage area, and Bocaina and the area to the south and east is interpreted as a fan and braidplain environment.

The first Moeda sediments, lowest in the stratigraphy, are sheetlike pebbly diamictites, which are exposed at Bocaina in adits. They are composed of angular quartz,

chert, phyllite and yellow felsic lava clasts supported in a sheared argillaceous matrix. The diamictites carry low gold contents of 1 or 2 ppm, are generally less than 1m thick, and are distributed patchily. These diamictites are evidently mass-flow conglomerates. Because of their lack of stratification;, ungraded bedding and clay-rich matrix-supported nature, they are considered to represent cohesive debris-flows. Their depositional environment is considered to have been subaerial because they are overlain by sharply scour-based clast-supported fluvial conglomerates.

The oligomictic cobbly large-pebble conglomerates overlying the debris-flows fine upwards into coarse-grained trough cross-bedded quartz-arenites. These channelised conglomerate arenite couplets are the result of waning flow after flood stage deposition of gravel, and comprise increments of deposition that have accumulated into sheets up to 12 m thick, although 2 m is a more general average.

South and east of Bocaina the basal conglomerates are laterally extensive, but up the paleoslope from Bocaina they are confined to discrete channelwaays or to wide shallow valleys in which individual conglomerate sheets up to 200 m wide and 600 m long have been identified. At Guilherme, in the northern area, transverse sections of channels 250 m wide and 6 m deep outcrop. They contain boulder-sized clasts of vein quartz, and cross-bedding and channel orientations indicate transport to the south and southeast. It seems that vertically disposed folded iron formation units in the Nova Lima may have weathered positively during the Proterozoic and therefore locally controlled the Moeda drainage system.

The placer conglomerates at the base of the Moeda are mineralized predominantly with sulphides. Approximately 95 percent is pyrite, occurring as large, slightly rounded cubes of up to 8 mm across, well-rounded spheroids of amorphous, layered, concentric and porous types, up to 3 cm in diameter, and also euhedral authigenic pyrite. In outcrop these large pyrite particles oxidize to limonite or weather out to leave large pock marks. In addition, arsenopyrite (sometimes rounded grains), chalcopyrite, pyrrhotite, pentlandite, gersdorffite and covellite, usually included in the pyrite, have been identified in polished sections. Thin traces of kerogen seams and granulated kerogen have been observed in places at the base of Unit 1. Gold grains, generally less than 20 microns in size, are included in pyrite. High grade porous pyrite contains covellite remnants after supergene alteration of chalcopyrite, and the silver content of associated gold particles is approximately 5 to 10 percent. Electron microprobe analyses of freed gold particles, have indicated an average silver content of 12 percent and a mercury content of 2 percent, accounting with the gold for 99.8 percent of the sample. These results lie within the range of most Witwatersrand gold particles. Gold concentratios in well mineralized layers are typically between 10 and 20ppm.

THE WHITE DEVIL GOLD DEPOSIT, TENNANT CREEK NORTHERN TERRITORY.

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The White Devil gold mine located about 40 km northwest of Tennant Creek, Northern Territory, is currently being developed by Australian Development Ltd. following a successful exploration programme in an area of former mining. Surface quartz-hematite lodes were discovered on the White Devil-Black Angel-Crusader leases in 1935 and several small open cut mines were developed. Underground mining at the Black Angel to 1951 produced 3000 oz. A shallow open cut at White Devil produced approximately 300 oz. In 1985 Australian Development Ltd. acquired the White Devil-Black Angel leases from Peko Mines Ltd. and developed a small open cut operation based on the Black Angel mine. This produced 20,000 tonnes of ore at 4 g/t Au. Exploration on the White Devil lease resulted in the discovery of a significant gold resource. Published ore reserves are 280,000 tonnes at 22 g/t.

The well-bedded siliciclastic sedimentary rocks of the Lower Proterozoic Warramunga Group, which host the mineralization, have undergone two main deformations. The early ductile deformation (D_1) was a moderate deformation, which produced upright east-west trending open-close folds, with a regular plunge 40-50° toward 245° (fig.1). The late semi-ductile to brittle deformation (D_2) was a progressive deformation which was associated with at least three closely spaced events. These were the the intrusion of a set of semi-concordant porphyries, an early east-west upright shearing associated with the emplacement of hydrothermal quartz-magnetite bodies (ironstones) and a progressive shearing associated with the mineralization. The shearing produce a slickenside/ growth fibre lineation (L_2), that suggests a vertical-oblique displacement with the south block eastwardly uplifted and the north block westwardly downthrown.

The magnetite veins usually have a brecciated texture and en-echelon arrays of sygmoidal tension microfractures are extensively developed. The geometric forms of these microfractures and the internally crystallizing vein fibres indicate that they were formed during a progressive and incremental deformation. The gold-bismuth-copper mineralization in the White Devil deposit was formed during the late stage of this progressive deformation. Detailed study of the ore minerals shows that apparently unstrained gold, bismuth and copper minerals are mainly concentrated in the tension fractures and have replaced quartz and chlorite fibres. The continued progressive shearing was the latest event in the second deformation since it both displaced the porphyries and brecciated the ironstones. However, the relationship between the ironstones and the porphyries is equivocal; a displacement by shearing and a concordant contact with the ironstones can be seen in the western porphyry whereas the ironstone seems to be cut and offset by the

central porphyry.

The deposit displays an intense geophysical signature which is characterised by a pair of "bulls-eye" magnetic anomalies. In cross section, the gross geometry of the ironstone complex at White Devil-Black Angel is sigmoidal and subvertical to steeply north dipping.

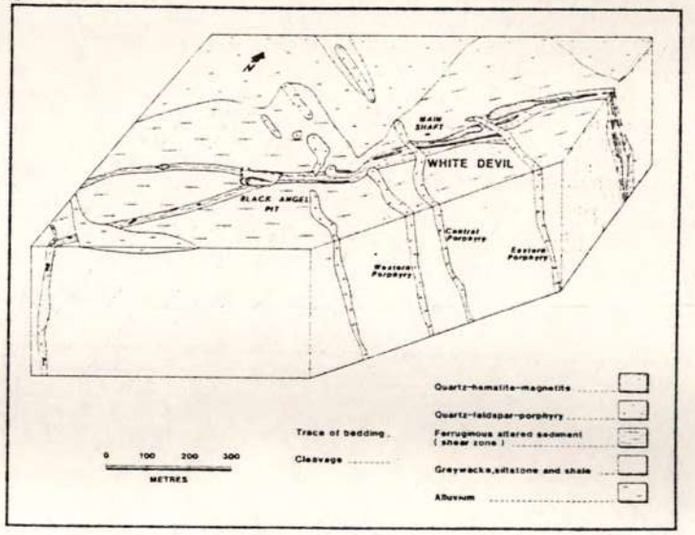


Fig. 1 Schematic block diagram of the Black Angel and White Devil areas.

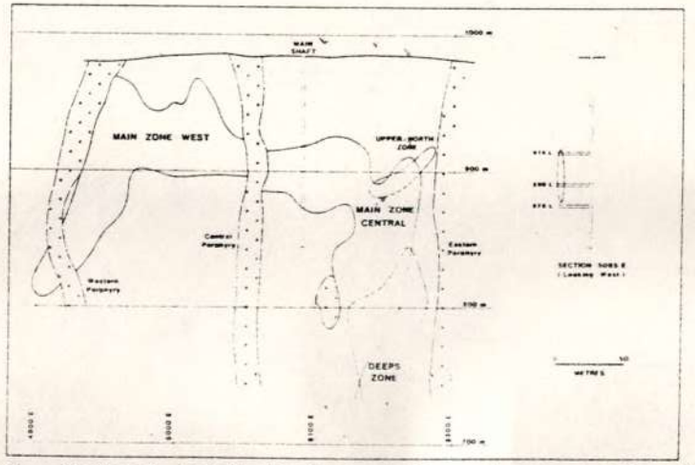


Fig. 2 Vertical longitudinal projection and cross section, White Devil mine.

The gold-bismuth-copper mineralization in the White Devil deposit is mainly confined to four distinct zones and concentrated between the eastern and western porphyries (fig.2). These zones are mainly associated with the concentration of magnetite-hematite-quartz lodes in the hinge region of an anticlinal F_1 fold. In detail, the deposit comprises two different styles of mineralization:

i) Thin, shear related mineralization (Main Zone West, Main Zone Central and Upper North Zone) having a thin, vertical, sheet-like form and concentrated in long, thin magnetite-rich bodies and extending, to varying degrees into the adjacent chloritized sediments, especially within the shear zone. Average thickness of this style of mineralization is 2 to 3m.

ii) Mineralization (the "Deeps") which is restricted to the magnetite-chlorite-quartz ironstone proper and which is more akin to the classical Tennant Creek gold pod. Average dimensions of the "Deeps" pod is 50mx40mx12m.

Mineralogical composition of the ore is relatively simple and consists of native gold, chalcopyrite, bismuthinite, native bismuth, pyrite, pyrrhotite and molybdenite associated with magnetite, chlorite, quartz and hematite with minor carbonate and talc. Variation in mineralogical abundances are characteristic of the mineralization styles. Shear related mineralization has greater concentrations of pyrite and chalcopyrite while the "Deeps" zone contains, on average, higher levels of Bi and, to a lesser extent, Au.

Ore grades are quite variable with Bi up to 15% and Cu up to 8%. Gold is generally fine grained and not visible in hand specimen, except in local sections of the orebody exceeding 500g/t Au.

The deposit has a well developed weathering profile which is best displayed by copper. The leached zone extends to approximately 50m below the surface. Average Cu values in this zone are less than 50ppm. A well developed supergene enrichment zone extends from 50m to approximately 90m below the surface and is characterised by abundant sooty chalcocite and minor chalcopyrite and has an average Cu grade of >1% . The primary sulphide zone consists of chalcopyrite and 0.5 to 0.8% Cu.

Textural relationships of the ore minerals and heating and freezing studies on fluid inclusions in quartz demonstrate that there were two distinct phases of the hydrothermal fluid involved in formation of the deposit. The magnetite was formed from a fluid of relatively high temperature (approx.400^{o}C) and high salinity (probably $CaCl_2$-NaCl). The later gold-bismuth-copper mineralization was formed from a fluid of lower temperature (approx. 300 to 350^{o}C) and moderate salinity (probably NaCl-rich). Analyses of chlorite associated with the ore confirm the fluid inclusion temperatures. The origin of the solutions reponsible for the emplacement of the White Devil orebody is not yet conclusively demonstrated; however, the results of a preliminary sulphur isotope study suggest a magmatic origin for the sulphur. The close association of the ore and the magnetite suggests that the magnetite was an important factor in controlling ore deposition.

GOLD MINERALISATION AT THE REDWING MINE, MHANGURA, ZIMBABWE: MINERALISED ULTRAMAFIC DYKES OR GOLD-BEARING MAGNETITE SKARNS?

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INTRODUCTION

A number of dyke-like gold orebodies, comprising amphibole, talc and often magnetite-rich rocks have been identified in the Redwing Mine and its immediate surrounds (Fig 1A). Approximately 2 km north of the Redwing mine workings two small magnetite-rich zones had been pegged originally for iron ore (Fig. 1A) minor gold was disclosed by early prospectors. Most of these ores are supergene, but the Redwing mine has been developed to a depth of 60 metres, allowing examination of un-weathered ore. Gold production from the Redwing Mine, and its immediate environs had by mid-1987 amounted to 70.54 kgs from an ore production of 19820 tonnes at an average grade of 3.6 g/t (Nutt 1987).

The host rocks comprise a sequence of phyllites, weakly metamorphosed argillites and impure sandstones of the Piriwiri Group of the early Proterozoic Lomagundian sequence of sediments. These rocks have undergone thrusting and synchronous upright folding of the c 1800 Ma Magondi orogeny.

REDWING MINE

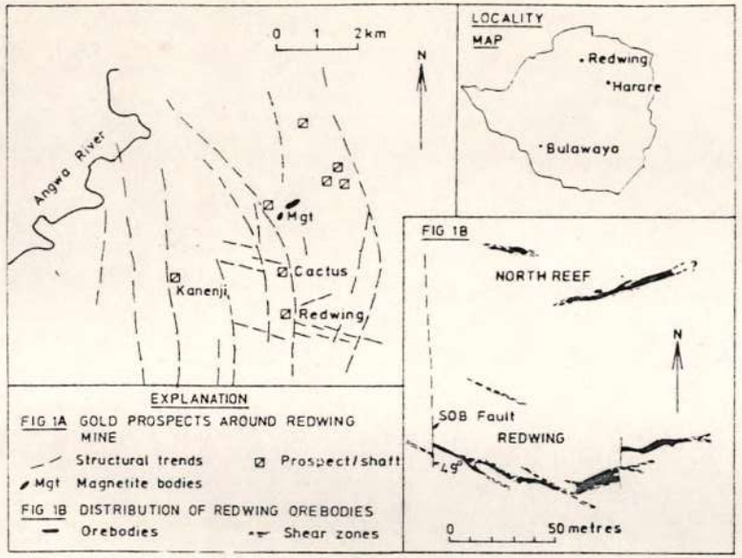
The mineralisation comprises a number of discontinuous lenticular pods, surrounded by thin (< 1m thick) chloritic alteration zones. They are situated within vertically dipping brittle- ductile shear zones that form a conjugate set trending east-north-east and east-south-east (Fig 1B), and cut across the northerly Magondian trends. The shear zones contain irregular poorly developed quartz veins associated with minor chloritic alteration of the surrounding sedimentary rocks. Minor pyrite and sporadic sub-economic gold concentrations are also present in these shear zones.

Gangue minerals are a mixture of sheaf-like aggregates of cummingtonite, interstitial talc and serpentine, siderite, and chlorite. Portions of the North Reef are composed of coarse granular magnetite (up to 15 %) within coarsely crystalline siderite (>50 %) and minor talc. The ore mineralogy in the pods is dominated by pyrite, and lesser chalcopyrite with minor amounts of arsenopyrite, galena, cobaltite. The sulphides replace both siderite and magnetite in the pods but their relationship with the talc is uncertain but talc-rich veinlets cut subhedral magnetite grains, tentatively suggesting synchronous talc and sulphide formation. The chloritic alteration zones are dominated dark green chlorite with numerous, discontinuous quartz and quartz-carbonate stringers. The alteration rapidly fades into the buff and grey sedimentary hosts. The sulphide mineralogy is dominated by pyrite and minor chalcopyrite, which locally attains 10 percent of the rock, especially within more highly sheared areas.

The gold content of the cummingtonite-pods is higher (4.8 ppm) than the surrounding chloritic alteration (3.1 ppm). However in both lithologies higher gold contents occur in small ductile shear zones containing more locally abundant talc, siderite, quartz and sulphides, and thin carbonate-quartz-pyrite stringers.

OTHER GOLD OCCURRENCES

The only other gold deposit with a declared production is the



Cactus Mine, situated about 500 metres north of the Redwing Mine. The gold was obtained from a 50 m long amphibole-rich pod surrounded by a chloritic alteration zone.

The most significant exposure on surface is two closely-spaced magnetite-rich bodies, situated 1.5 km north of Redwing Mine. Preliminary mapping by one of us (DMC) of these bodies has revealed massive coarse magnetite zones with intermingled weathered talcose units. These are surrounded by quartz-magnetite breccias with numerous cubic voids indicating either weathered pyrite or carbonate. Initial sampling shows these two areas to have low (0.2 to 2.8 ppm) gold contents.

The Kanenji prospect (Fig 1A) has produced minor gold, with small quantities of copper and wolframite concentrates from a quartz vein, hosted by phyllites.

DISCUSSION

The known pods have been tentatively suggested as being intrusive ultramafic dykes. This hypothesis was based on their discordant relationship with the surrounding sediments and the presence of angular, partially chloritised, blocks of country rock. An attempt was made to relate the pods to the Chimbadzi Dyke, a troctolite and cumberlandite intrusion, 30km east of the mine (Nutt 1987). The high Fe, Mg and low Al, alkali contents of this intrusion and Redwing pods compared favourably (Table 1). However, the low Ti of the Redwing lithologies compared with the extremely high Ti levels of the cumberlandite and Ti's immobility mitigate's against the alteration of a cumberlandite dyke.

The enrichment of Co, Cu, As and Ni in the pods and the abundant magnetite and hydrous magnesium silicates suggests the presence of magnetite skarns. With the exception of As, magnetite skarns from the Larap deposit (Phillipines), Cornwall and Grace (Pennsylvania) have abundant Fe and comparable Ni, Cu and Co contents (Table 2). The Redwing silicate assemblage of talc-cummingtonite and chlorite is similar in some aspects to the retrograde assemblages of the Cornwall skarn (actinolite-pyrite-magnetite-serpentine-zeolite) and the Grace skarn (serpentine-talc-chlorite). The anhydrous ore phase would be the

formation of cummingtonite, and possibly magnetite, followed by the hydrous phase would have introduced the gold and converted some of the amphibole to talc and serpentine. There is no known unequivocal intrusive igneous rocks in the vicinity of these pods and the magnetite bodies further north, indicating that metamorphically derived fluids were necessary for ore formation.

Table 1. Average major element ananlyses of Redwing ore types and Chimbadzi cumberlandite.

	Amphibole ore Mean	S.D.#	Chlorite halo Mean	S.D.	Chimbadzi Dyke
No. of analyses	24		9		2
SiO2	27.96	14.70	41.60	17.04	17.73
TiO2	0.01	0.01	0.58	0.17	7.78
Al2O3	0.64	0.88	14.85	3.16	0.00
Fe2O3*	34.82	11.94	25.52	11.94	54.67
MgO	12.59	5.51	7.85	4.00	15.73
CaO	6.68	8.51	1.21	2.04	0.02
Na2O	0.02	0.04	1.58	2.29	-
K2O	0.05	0.09	0.05	0.05	-
MnO	0.41	0.41	0.39	0.46	0.89
P2O5	0.02	0.02	0.37	0.65	-
LOI	19.16	9.33	8.98	1.09	0.01
TOTAL	102.38		102.98		96.81

* Total Fe expressed as Fe2O3.
\# Standard deviation.

Table 2. Trace element abundances of Redwing and some magnetite skarns.

	Amphibole ore	Chlorite ore	Larap (#)	Cornwall (#)	Grace (#)
Au (ppm)	4.7	3.1	1.2	-	-
Cu (%)	0.19	0.09	0.12	0.30	0.06
Co (%)	0.04	<0.01	0.03	0.04	0.02
Fe (%)	24 (*)	18	43	41	44
Ni (%)	0.06	0.01	0.02	-	0.01

(*) Does not include magnetite zones north of Redwing Mine.
(#) Einaudi et al 1981.

The possiblity of a gold-bearing magnetite skarn ore in the Proterozoic rocks introduces a new dimension to gold and metal exploration in Zimbabwe. Skarn ores have been hithertoe ignored by Zimbabwean explorationists, but now need to be closely examined in both Archaean and Proterozoic terranes. Gold deposition, whether in skarn environment or with Fe-rich ultramafic dykes, is enhanced by the presence of abundant magnetite and Fe-rich silicates. Sulphide-bearing fluids migrating through the shear zones on reaching the pods converted these minerals to iron sulphides with synchronous gold precipitation.

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GOLD-QUARTZ VEIN MINERALIZATION IN EARLY PROTEROZOIC ROCKS AT BRIDGE CREEK, HOWLEY AREA, NORTHERN TERRITORY, AUSTRALIA

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INTRODUCTION

The Howley Area, part of the Pine Creek Geosyncline, is known for gold occurences in different environments (Nicholson et al.,1984):
- synsedimentary and probably metamorphically upgraded Au-deposits in anticlinal structures
- epigenetic in gold-quartz veins within anticlinal hinge zones
- placer deposits

New mineralogical and geochemical data are presented, and a model for the formation of gold-quartz mineralization within the anticlinal hinge zone at Bridge Creek will be discussed.

GEOLOGY

Gold-quartz veins at Bridge Creek occur within the hinge zone of the Howley Anticline. The wallrocks belong to the South Alligator Group and mainly consist of black shales (Koolpin Formation), a sequence of felsic tuffs, cherts, mudstones (Gerowie Tuff) and semiconcordant sills of metadolerite (Zamu Dolerite) which have been tightly folded with regional greenschist metamorphism at the end of the Early Proterozoic (1800 mio a; Stuart-Smith et al., 1980). The concentric shape of the Howley Anticline was caused by the late orogenic intrusion of the adjacent Burnside Granite (1780 mio a; Riley, 1980).

GOLD MINERALIZATION

Gold bearing quartz veins are preferentially developed within the hanging wall of the steeply dipping fold axis plane.
Preferred locations of mineralization are: the transition zone between the Gerowie Tuff and the underlying Koolpin Formation as well as the contact zone between the lower part of the Gerowie Tuff and the superjacent Zamu Dolerite. The more intensive gold mineralization on the up dip side of the axis plane points to a pre-existing fold structure. The tightly banded rocks of the Gerowie Tuff served as channelways for ore-bearing fluids, while the flanking metadolerite and black shales sealed the system perpendicular to the layering. After formation of barren quartz in veins, gold deposition occured during two stages:

Stage 1: Arsenopyrite, pyrite, pyrrhotite, sphalerite, chalcopyrite, bismuthinite, galena
Native gold occurs as inclusions in arsenopyrite, pyrite, bismuthinite and quartz. Most of the gold deposition seems to be related to this stage.

Stage 2: Chalcopyrite, sphalerite, pyrrhotite, galena, bismuthinite
Native gold is intergrown with chalcopyrite.

After stage 2 mineralization CO_2 was introduced into the system. Barren quartz-carbonate and calcite veins have been formed followed by latest quartz veinlets.

WALLROCK ALTERATION

The wallrock next to quartz veins is generally chloritized, locally silicified and carbonatized. The primary mineral paragenesis of the metadolerite, Mg-rich amphibole (hastingsite), alkali feldspar, quartz, biotite and ilmenite, has been altered to Mg-rich chlorite, sericite/muscovite and Ti-minerals like rutile, anatase, leucoxene and titanite. Quartz was depleted, while biotite was newly formed adjacent to veins. Mass balance calculations of the alteration envelope within the metadolerite show that Au, As, K, Rb, Mg, Ba, Ga and Zr have been enriched, while Si, Na, Ca, Sr, Mn, Fe, Ni, Cu and Zn have been depleted. Al, Ti and P acted as immobile elements (Fig. 1).

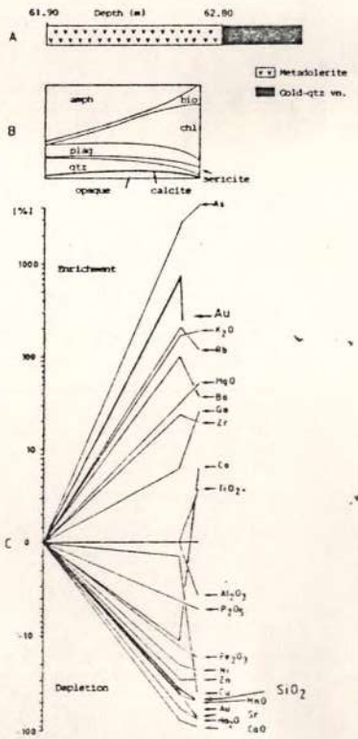


Fig.1:
A: Schematic section of drill core interval from metadolerite at Bridge Creek
B: Mineral distribution within the alteration envelope adjacent to gold-quartz veins
C: Relative enrichment/depletion of elements within the alteration envelope

PHYSICO-CHEMICAL CONDITIONS DURING GOLD-SULFIDE MINERALIZATION

Besides gold As, Mg, K, Rb, Ba, Ga and Zr have been transported in hydrothermal solution. Boron and sulfur have not been analyzed, but the occurence of tourmaline in veins and ubiquitous sulfidization related to quartz veining show that B and S must have been further components of the fluid phase. Sericitization of the wallrock during ore mineralization points to pH values between 4.5 and 6.5. Strong sulfide mineralization related to quartz veining puts constraints on the transport of gold as $Au(HS)_2^{1-}$, AuS^{1-} or as mixed sulfido-bisulfido complexes. Both Fe^{2+} -rich metadolerite and black shales offered reducing conditions for the precipitation of gold. In addition the high Fe^{2+} -content of the metadolerite led to the formation of sulfides and therefore to the destruction of the gold-thio complexes. The variable trace element content in ore minerals like arsenopyrite, sphalerite and gold reflects the interaction between a slowly ascending fluid and the wallrock. Arsenopyrite thermometry revealed a formation temperature of about 330° C for stage 1 with $f_{S2} = 10^{-9} - 10^{-10}$ and $f_{O2} = 10^{-33}$.
Sphalerite and pyrrhotite geothermometry indicates a maximum mineralization temperature of about 250°C for stage 2 with a lower sulfur fugacity.

GENESIS

As the temperature range during gold mineralization at Bridge Creek was considerably lower than that assumed for regional metamorphism (about 450° C), the late orogenic and high-level intrusion of the Burnside Granite is likely to have played an important role. Gold has been released from underlying synsedimentary gold occurences in the Middle Koolpin Formation or from metamorphic gold-quartz veins. The hydrothermal fluid was focussed into a pre-existing fold structure, where gold deposition took place controlled by structural and lithological parameters.

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THE FEDERATION GOLD-QUARTZ VEIN SYSTEM, CROYDON NORTH QUEENSLAND - A MESOTHERMAL GRANITE-RELATED GOLD DEPOSIT

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INTRODUCTION

Within the Croydon goldfield North Queensland, gold-quartz veins are hosted by undeformed and unmetamorphosed Middle Proterozoic calc-alkaline ignimbrites and lavas, together with cogenetic granites. The Federation gold-quartz vein system is a volcanic- hosted deposit that has recently been subject to open-cut mining. This has permitted the first adequate three-dimensional view of a quartz vein system in the Croydon Goldfield. The study of the vein system, particularly with regard to vein and ore shoot distribution and controls, mineralization styles and deposit genesis was the basis of an MSc. thesis by the writer at JCUNQ (Shelton, 1987) and a succeeding paper (Shelton, in press). This paper is published with valuable assistance from and permission of Barrack Mines Ltd/Central Coast Exploration and Pancontinental Mining Limited.

FEDERATION VEIN SYSTEM

The Federation vein system is one of several within the Tabletop area of the Croydon Goldfield. This area is located approximately 14 km. NNE. from the Croydon township, and is completely within units of the Croydon Volcanic Group. Many of the vein occurrences in the area are characterized by substantial vein thicknesses (up to 17m., but generally 0.2-5.0m.) and sub-horizontal to shallow dipping attitudes which may display numerous dip reversals.

The Federation is a multiple vein system hosted by two units of the Carron Rhyolite - a dominant graphitic ignimbrite and the overlying, partly conformable Federation Rhyolite. The vein system consists of three intersecting mineralized veins referred to as Q1,Q2 and Q3 (Fig. 1). Q1 is a shallow dipping, planar fissure vein hosted by the Federation Rhyolite. This is cojoined to the dominant Q2 vein - a shallow plunging antiformal fissure vein hosted by the ignimbrite. Q3 is a steeply dipping quartz-filled shear that cuts Q1 and the hinge zone of Q2, but terminates just below the intersection. Only the Q1 and Q3 veins outcropped at surface.

The Q1 and Q2 veins represent the same fissure filling event hosted in two different volcanic lithologies wheras the Q3 vein is a later sheared and strongly oxidized fissure vein localised at a normal fault. Each of the vein types has a characteristic gold distribution but in all cases there is a strong association between basemetal sulphide content (primary or oxidized) of the gangue and gold content uniess the sulph-

ides are dominantly those earlier in the paragenetic sequence eg. pyrite. For the Q1 and Q2 veins gold is associated with concentrations of basemetal sulphides located near vein margins and particularly the hangingwall. Gold in the Q3 vein is typically associated with zones of shearing and brecciation close to the vein margins. Gold mineralization occurs throughout the Q1 and Q3 veins and in the hinge zone of the

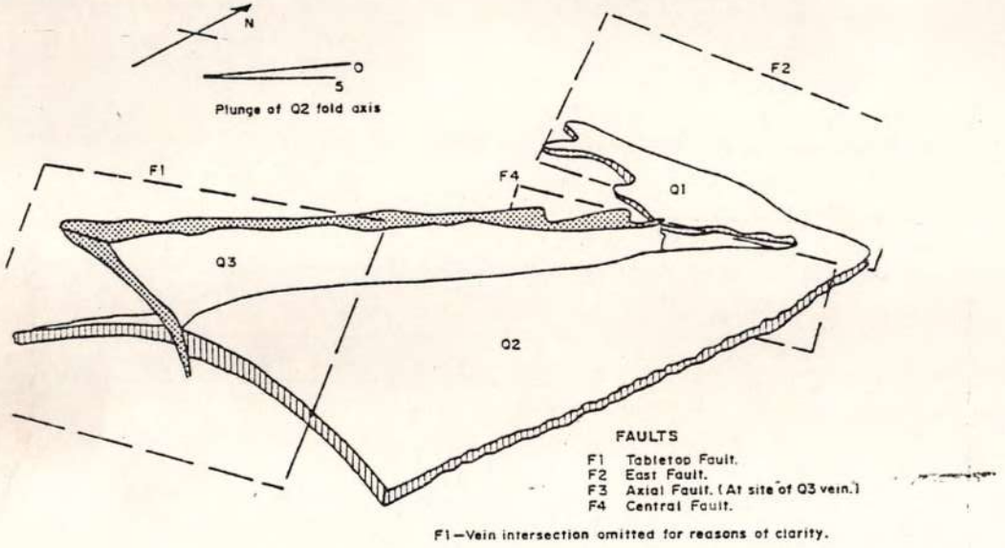


FIGURE 1 BLOCK DIAGRAM OF THE FEDERATION VEIN SYSTEM.

Q2 vein. Small high-grade shoots in Q1 and Q3 appear to be localised by bulges in the hinge zones of late stage minor folds.

ALTERATION AND MINERALIZATION

The veins are single or composite structures with local zones of shearing and brecciation, wallrock inclusions and marginal stockwork veins and veinlets. The host rocks have undergone strong pervasive sericitisation within the whole Tabletop area. Alteration about the vein system consists of a weakly superposed quartz-sericite-pyrite(arsenopyrite) alteration, and silicification. The individual veins consist dominantly of a white buck quartz consisting of tightly packed coarse euhedra, and a later finer clear quartz phase. This phase is particularly associated with later stage basemetal sulphides and gold. The gold occurs as electrum in rounded grains or in interstices, associated with galena, pyrite, arsenopyrite, chalcopyrite and sphalerite. An average gold fineness of 722, as determined by electron microprobe, is comparable with production bullion fineness for volcanic-hosted

veins in the goldfield. These values may be contrasted with the average value of 580 for granite-hosted veins in the goldfield. It has recently been suggested that this difference may reflect the relative openess of these granite-hosted vein systems to waters from shallow crustal levels (Rose, in press).

ORIGIN OF THE VEIN SYSTEM

A mesothermal environment of mineralization is indicated by the mineralization and alteration styles, and vein textures and compositions. This is supported by preliminary fluid inclusion and isotopic data. The close spatial relationship of veins to the contact of the Esmeralda Granite and the volcanic units, the undeformed and unmetamorphosed nature of host lithologies, the similarity of ore assemblage in volcanic and granite hosted reefs and the zonation of decreasing gold fineness values at depth and towards the granite contact suggest that there is one major mineralizing episode related to the granite. Such mineralization may not be an inherent feature of the original S-type magma but related to the assimilation of graphitic metasedimentary wallrocks. The ore-bearing hydrothermal fluids were conducted from the granite along joint systems propagated through the cooled shell of the pluton, and by both the joint systems and deep-seated faults through the overlying volcanic succession. The final deposition site in the Federation area was shallow dipping, extensional curvilinear fractures. These fractures are interpreted as resulting from contraction of the pluton shallowly underlying the Tabletop area.

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GEOLOGY, EXPLORATION AND EXPLOITATION OF HIGH GRADE GOLD ZONES, BIDJOVAGGE MINE, NORTHERN NORWAY

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The Bidjovagge gold-copper mine is located 40 km northwest of Kautokeino in Finnmark, Northern Norway. Exploration from 1956-66 led to the discovery of several mineralizations with total ore reserves of approximately 3 mill. tons averaging 1.8% Cu and 0.5 g/t Au. The deposit was leased and mined from 1970-75, closure being due to low copper prices and technical problems. New and detailed data on gold distribution made it possible for Outokumpu Oy to re-open the mine in 1985 and it is now operated as a gold (copper) mine with an annual production of 360,000 t from open pits. In 1987 1.220 kg Au and 3 435 t Cu were produced. Present reserves indicate a further 1-2 years production.

The Precambrian of Finnmark is dominated by Archaen gneisses and amphibolites separated by three north-south trending proterozoic greenstone belts, of which the westernmost Kautokeino greenstone belt hosts the Bidjovagge area.

The Bidjovagge mineralizations are situated in the lower part of the Cas'kejas Formation on the eastern limb of a N-S trending antiform. Diabase sills and dykes occur in a sequence of primary shallow marine sediments with dolomites, black shales, grey-green shales, limestones, tuffites and thin greenstones. In the mine area both the sediments and diabases are albitized. This sodic alteration is thought to have been caused by seawater circulation or by sodium rich brine of sea-water origin and is pre mineralization. Gold-copper mineralizations are dominantly hosted by albite felsite and to a lesser extent by altered diabase. Non economic copper mineralization with low gold is also found in graphite felsite.

Mineralization distribution is controlled by complex shear zone tectonics and the ore-bodies always occur in close proximity to and often as extensions of graphite felsite. Continuous transitions from graphite to albite felsite are interpreted as oxidation fronts.

The ores are relatively small tabular bodies (50-100 x 5-35m) with tonnages of 50-400,000 t grading 2-6 g/t Au (Cut) and 0,5-1.5% Cu. Several ore-types can be distinguished but the only economic ore minerals are gold and chalcopyrite.

Recent exploration has resulted in the discovery of several high grade gold zones. The D ore exploited in 1986/87 contained in the hanging wall contact a 50 x 50 x 4 m zone grading 26 g/t Au and 0,1% Cu. The hostrock is a carbonate rich albite felsite

characterized by late, zoned hastingsite porphyroblasts. The EVA ore (in production from 1988) has intersections up to 40-50 m. grading in excess of 10 g/t Au and 1.5-2.0% Cu with richer parts in excess of 30 g/t Au over 10-15 m. Gold occurs mainly as native metal and grain size is usually less than 50 microns.

There is a clear positive correlation between gold and radioactivity and also between the occurrence of gold and tellurides. High radio-activity is caused by the occurence of davidite and other uranium-rare earth minerals. The correlation between gold and copper is often poor.

In the ore bodies the high grade gold zones are located close to oxidation fronts whilst copper contents increase away from the fronts.

In order to achieve optimum results, highly selective mining techniques are used at Bidjovagge. This is difficult both due to arctic conditions and to difficulties in distinguishing between ore and wasterock. Prior to mining the ores are divided into classes according to grade. Zones with subeconomic ore are mined and stock-piled separately for possible later use. Zones of waste rock are also separately removed.

Grade control utilizes effective sampling methods such as diamond drilling, percussion drilling and sampling of production holes. Rapid analyses are carried out in the mine laboratory. Effective radio-metric grade control methods have also been developed and scintillo-meters are rutinely used in diamond, percussion and production holes and also in the open pits for determining ore/waste boundaries.

Experience has shown that the main mineralizations are restricted to oxidized areas in a shear zone system where graphite felsite has been oxidized to albite felsite and where magnetite bearing diabases have been altered and hematite deposition has taken place. These geological features can be defined by detailed electromagnetic and magnetic ground surveys, where breaks in the EM pattern combined with magnetic lows indicate interesting target areas. These features can also in certain cases be discerned by a close evaluation of airborne surveys.

Radiometric survèys form an important part of exploration work, where especially radiometric logging of drillholes has proved to be extremely successful.

New discoveries of similar gold-copper deposits in N. Sweden and N. Finland in greenstone belts of the same age as the Kautokeino greenstone belt indicate that there is a good chance of finding more Bidjovagge type deposits in Northern Scandinavia.

THE PROTEROZOIC STARRA AU+CU IRONSTONE DEPOSIT - SYNTECTONIC MINERALISATION IN A FOLDED EARLY REGIONAL ZONE OF DECOLLEMENT

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The Starra Au+Cu deposit in the Mount Isa Inlier (7 mt of ore at 5 g/t Au) represents one of the few significant world Proterozoic Au deposits, and is of particular interest in being hosted by a stratiform ironstone, analogous to the major class of ironstone Au deposits found in the Archaean. The Starra deposit displays features consistent with a syntectonic replacement deposit. Both the host ironstone and the Au+Cu sulphide mineralisation show strong structural controls, at all scales, on their timing and localisation. The Starra deposit is not a syngenetic banded iron formation Au deposit.

The ironstone is of regional extent and lies within a still more extensive zone of high strain (shear zone) formed during the first deformational phase D1. This one kilometre thick shear zone follows the folded regional contact between the high-grade (upper amphibolite facies) Gin Creek Block to the south and the low-grade (middle greenschist facies) Staveley Formation to the north (Figure 1). The envelope of the major D2 folds defined by the contact indicates that the D1 shear zone prior to D2 folding dipped shallowly in a general northerly direction.

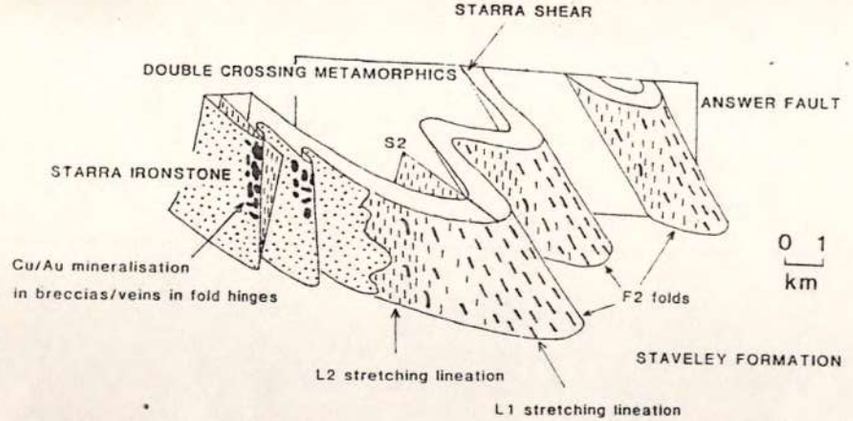


Figure 1. Schematic block diagram looking southwest, showing the structure of the Starra shear zone and its contained ironstone hosting the Starrra Au+Cu mineralisation. The interpreted major D1 displacement on the shear zone is Staveley Formation down to the right.

A strong L1 stretching lineation plunges shallowly north within the shear zone's mylonitic foliation, and well developed s-c planes in outcrop consistently after unfolding show an upper block to the north sense of shear. The upper block (Staveley Formation) is younger than the lower block (Double Crossing Metamorphics); with the upward decrease in metamorphic grade, these features indicate a major normal sense of displacement on the shear zone. Marked compression of peak metamorphic isograds within the shear zone, from D2 biotite+muscovite above, through D2 biotite+ muscovite+andalusite within the shear zone, to D1 sillimanite+Kfeldspar below, and the change of metamorphic peak from D1 to D2 are also consistent with a major normal sense of movement syntectonic during D1 and D2. The lower Staveley Formation units lie within the shear zone parallel to the contact. Granitoid magmas were emplaced into the Gin Creek Block during D1/D2 and post D2. Most of the syntectonic granitoids contain a strong S2 foliation; at least one body with an S1 mylonitic foliation was intruded prior to D1. These various features strongly suggest that the Starra shear zone was a major crustal detachment fault during extensional D1 orogeny with the Gin Creek Block representing a metamorphic core complex.

D2 deformation produced the major regional fold geometry of tight upright folds with a strong axial plane schistosity S2. The generally plunging D2 folds are coaxial with the pre-existing shallow L1 stretching lineation. Within the S2 axial plane schistosity a strong mineral stretching lineation L2 plunges downdip. In the limbs of the major tight D2 folds the S1 and L1 fabrics are rotated toward parallelism with S2 and L2.

The Starra ironstone lies within the upper (eastern) part of the Starra shear zone on the steeply dipping limb of a major D2 antiform which defines the flank of the Gin Creek Block. The ironstone consists of many parallel lenticular quartz+magnetite+haematite bodies within a 100-200m wide envelope which extends a strike length of +15 km along the shear zone. The ironstone lenses are massive to poorly foliated with variable grainsize, from fine to coarse, in irregularly shaped domains in outcrop. Some lenses show isoclinal D2 fold hinges with axes anomalously steeply plunging parallel to the L2 stretching lineation. The folds show sinistral asymmetry, congruent to the adjacent D2 antiform.

The ironstone is developed along the boundary between mylonitised basic volcanics in the footwall and a calcareous metasediment unit in the hangingwall. The envelope around individual ironstone lenses comprises a magnetite-rich chloritic schist, particularly in the footwall. No other lithotype has been found within the ironstone which might represent a precursor lithotype. Microstructural relationships indicate that the magnetite in the ironstone grew as porphyroblasts in the S2 schistosity; haematite, finer, is interpreted as primary material, equivalent to the fine haematite which is found abundantly throughout the regional Staveley Formation. The magnetite formed early in D2, because the ironstone was folded and boudinaged during D2.

The Starra Au+Cu deposit consists of several bodies of sulphide mineralisation within brecciated and veined ironstone in the hinges of D2 folds. There are two textural types, granular and foliated. Pyrite formed synchronously with the magnetite in early D2. Chalcopyrite formed later in D2, in fractures within magnetite and pyrite and as infill or replacement between magnetite and pyrite. Au, as fine free gold associated broadly with magnetite and intimately with pyrite and chalcopyrite, was introduced with the pyrite during sulphidation of magnetite in a reaction similar to that proposed for Au in Western Australian Archaean ironstones.

A subsidiary metallic assemblage of Sn, W, Sb, Bi and rare earths is present. Hangingwall alteration of the calc-silicates: actinolite, chlorite, carbonate, scapolite, K-feldspar and quartz.

The structural control of the Au+Cu mineralisation is clear. Granular ore (dominant) lies in hinges and foliated ore (subsidiary) lies in limbs. Dilation and/or absence of shear strain in the hinges explain the textures and spatial location of the ore. Progressive deformation of the early-formed magnetite+pyrite aggregate later in D2, as the fold hingelines rotated toward the stretching direction, produced boudins, fractures and veins which localised the Cu+Au mineralisation.

Primary fluid inclusions within quartz contain CO_2 and crystals of KCl, Fe and Ca chlorides. Homogenisation temperatures are around 200°C and temperatures of dissolution of KCl are around 400°C. The mineralising fluid was clearly very saline; it was not a CO_2 dominated fluid as found in the Western Australian Archaean ironstone Au deposits.

Evolution of the Starra deposit began in a regionally extensive D1 ductile shear zone, which may have tapped deep fluids and/or fluids from the overlying plate. Its fluid channelling role continued into compressive D2 deformation. In major D2 fold limbs metamorphic fluids reduced pre-existing haematite to magnetite during shear reactivation of the S1 mylonitic foliation. This process was localised within the folded shear zone at the contact between basic volcanics and the overlying calcareous unit. Local sulphidation within the ironstone thus formed, precipitated pyrite+gold and the evolving fluid then formed chalcopyrite+pyrite+gold replacement and infill in dilatant, partly brecciated hinge zones. The presence of both the ironstone and the Au+Cu mineralisation is due to the very clear interplay of both structural and chemical controls.

The fluid is at least partly metamorphic in origin. However its highly saline nature requires a specific source. This might be (i) saline fluids from basinal sequences in the fractured upper plate of an extensional tectonic setting; (ii) metamorphic fluids buffered by saline evaporitic units within the metamorphosing sequence; or (iii) magmatic fluids in a saline porphyry-style system. There are strands of evidence for each of these: (i) the presence in the upper block (Staveley Formation) of ubiquitous haematite and widespread potassium metasomatism is characteristic of the regional metasomatism observed in the upper plate of detachment systems; (ii) evaporitic assemblages appear to have been present in the Staveley Formation; and (iii) the subsidiary metal association is similar to that observed in porphyry systems, and the syntectonic granitoids in the Gin Creek Block may relate to a porphyry-style magmatic system.

The localisation of a major mineralising conduit along an early flatlying regional shear zone, which may have been a detachment fault in an extensional tectonic setting, raises a number of important regional questions. What is the relationship between this system and the early thrusts identified elsewhere in the Mount Isa Inlier; what are the ages of the respective extensional and compressive tectonic regimes? Is there potential for syntectonic Au mineralisation along thrust systems similar to their demonstrated Cu potential? Where else in the Mount Isa Inlier are potentially mineralised extensional tectonic systems (upper plate, detachment(s), lower plate, magmatic intrusives)? What other metallic associations should we expect in these systems? The study indicates that Proterozoic ironstones elsewhere should be re-examined for possible syntectonic origin and associated Au potential.

Topic 1C

PALAEOZOIC REGIONAL STUDIES

GOLD IN THE NEW ENGLAND FOLD BELT IN NEW SOUTH WALES

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The New England Fold Belt is the youngest fold belt in the Tasmanides and comprises mainly Early-Late Palaeozoic volcanic arc-forearc basin-accretionary prism complexes, intruded by syn- and post- orogenic granitoids. Major deformation occurred in the Middle Devonian, Middle-Late Carboniferous, and Middle Permian-Late Triassic. Some Au is related to pre-accretionary terranes but the bulk of the +50 t production from the Fold Belt in N.S.W. is from late- and post-orogenic deposits.

The accretionary prism complexes of the New England Fold Belt host indigenous Au mineralization of both vein and stratabound type. The Devono-Carboniferous Sandon Association (turbidites, chert, minor mafic volcanics) hosts stratabound Cu-pyrite, stratabound Mn, and auriferous chert and quartz veins. Some Mn, chert and vein-type Au deposits are spatially associated (e.g. Limbri). Late Carboniferous Coffs Harbour Block rocks host stratabound quartz-magnetite, Cu-pyrite, and Au-chert and Au-quartz-vein deposits (e.g. Dalmorton, Coramba). The Au-quartz veins in both complexes probably formed by remobilization of chert-hosted stratabound Au.

The andesitic Middle Permian Drake Volcanics host numerous volcanic-epithermal Au, Ag and base metal deposits occurring as veins, stockworks, disseminations and breccia infillings. These deposits commonly have complex mineralogies. Ag/Au ratios vary greatly.

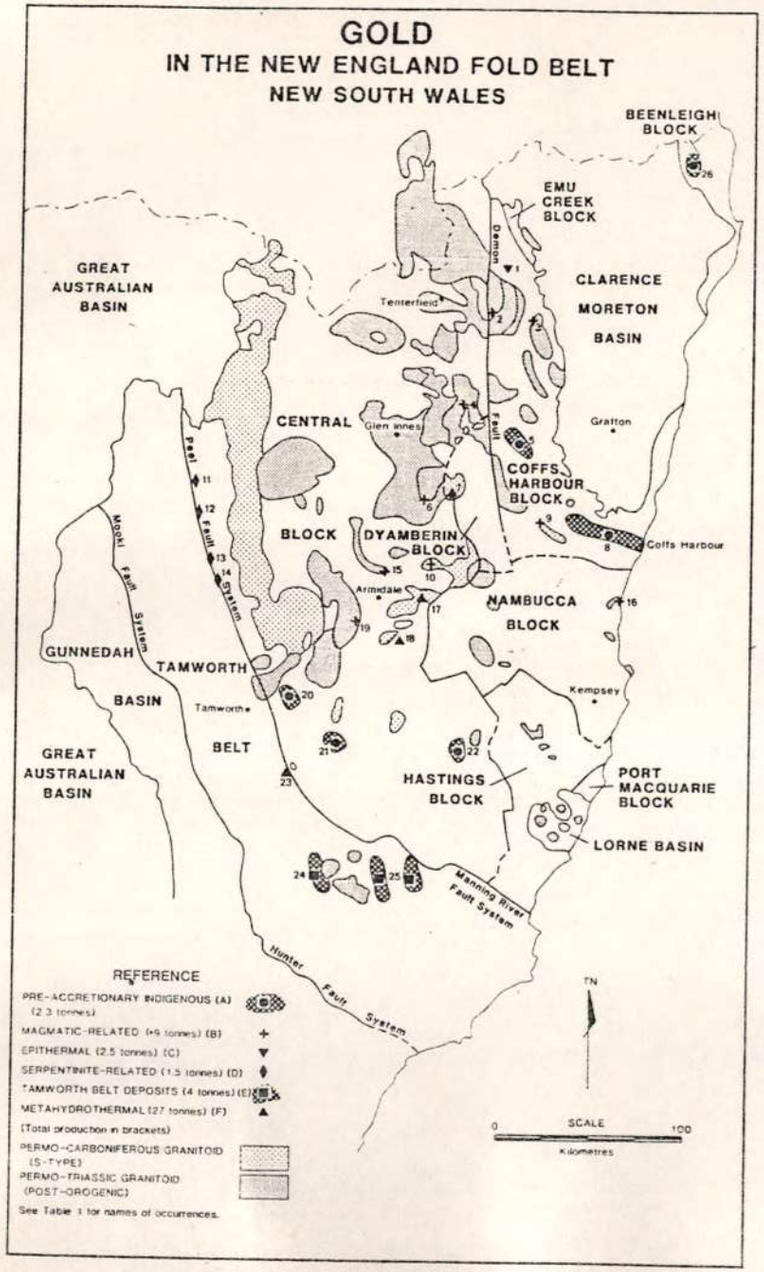
Gold is associated with many New England granitoids. Hillgrove style Au-Sb veins cluster about several foliated syn-orogenic granitoids but a genetic association appears limited to a few laminated veins around the Rockvale Adamellite (Comet mine) and Dundurrabin Granodiorite.

Several Middle Permian hornblende-bearing granitoids have related Au-Sb veins (e.g. Uralla Granodiorite, Tilbuster Granodiorite). These granitoids may have been the source for major deep lead and placer gold. Permo-Triassic leucogranitoids in northern New England sourced numerous Sn/Mo deposits and some carry Au. At Poverty Point, low grade Au disseminations occur in altered? Stanthorpe Adamellite. High Ca, low K, hornblende-rich granitoids (Clarence River Plutonic Suite) appear to be the source for Au-Sb veins in the Lunatic area (Drake), and Au-quartz-calcite veins at Lionsville. Au-quartz-calcite veins in the Upper Hunter and Copeland-Barrington areas appear, at least in part, related to the intrusion of the Barrington Tops Granodiorite.

TABLE 1
MAJOR GOLD DEPOSIT TYPES, NEW ENGLAND FOLD BELT

Age	Association*	Deposit type(s)	Geological Setting	Host rocks	Examples
Triassic	B	Vein Au-As	Post-orogenic I-type coastal granitoids	Valla Adamellite	Valla (16*)
Triassic	B	Vein and disseminated Au in granite	Post-orogenic magmatism (Leucoadamellite suite)	Stanthorpe Adamellite, Oban River Leucoadamellite, Kingsgate Granite	Poverty Point (2) Oban (6) Glen Elgin (4)
Permian-Triassic	F	?Metahydrothermal vein and replacement Au ± Sb (± W)	Major fracture and fault-controlled	Range of host rocks	Hillgrove (17) Nundle (2)) Knockbondra (7) Enmore-Melrose (18)
Middle Permian	B	Vein Ag-Au-As-Sb Thin sourced large Recent placer and Tertiary deep lead deposits	Post-orogenic magmatism, Uralla Plutonic Suite (I/S-type granitoids)	Uralla Granodiorite, Tilbuster Granodiorite	Uralla (19) Tilbuster (15)
Middle Permian	E	Vein Au (± Sb)	Surrounding post-orogenic granitoid (Barrington Granodiorite)	Tamworth and Parry Groups	Upper-Hunter (24) Copeland-Barrington (25)
Middle Permian	C	Epithermal vein, replacement and stockwork Au-Ag	Shallow marine - terrestrial volcanism	Drake Volcanics	Drake (1)
Middle Permian	B, A	Vein Au-Sb ✓	Post-orogenic magmatism (?A-type) Clarence River Plutonic Suite	Dumbudgery Creek Granodiorite	Lionsville-Solferino (3)
Early-Middle Permian	D	Vein Au ✓	Peel Fault system	Serpentinite and adjacent rocks	Upper Bingara (12) Bingara (11) Woodsreef (13) Crow Mountain (14)
Permo-Carboniferous	B	Vein Ag-Au-As-Sb	Hillgrove Plutonic Suite	Rockvale Adamellite, Dundurrabin Granodiorite	Rockvale (10) Dundurrabin (9)
Late Carboniferous	A	Indigenous mineralization auriferous chert, stratabound, copper, remobilized Au-quartz veins	Accretionary prism rocks	Coffs Harbour Block	Coramba-Orara (8) Dalmorton (5) Oki (26)
Devonian-Carboniferous	A	Indigenous mineralization: auriferous chert, (?anhedral) proximally related to stratiform manganese, remobilized Au-quartz veins.	Accretionary prism rocks	Sandon beds, Cookburn Formation	Limbri (20) Wingadla (21) ?Cells Creek (22)

* See figure 1 for explanation * See figure 1 for location



Small gold fields are scattered along the Peel Fault system. The Au-quartz-carbonate veins are hosted by serpentinite and adjacent rocks. Many of these deposits are probably genetically related to the serpentinisation process.

More than half the gold produced from New England has been from Au+/-Sb(+/-W) vein deposits at Hillgrove and Nundle. Similar deposits occur at Kookabookra and Enmore. The Hillgrove, Kookabookra, and Enmore deposits cluster in or near S-type granitoids. Some of these deposits are localized in mylonite zones. These deposits are poorly understood but are thought to be of metahydrothermal origin. In the Tamworth Belt, Au-W-Sb veins are associated with dolerite dykes and sediments at Nundle. The Nundle deposits are restricted to the eastern boundary of the Tamworth Belt adjacent to the Peel Fault.

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PRELIMINARY STUDY ON THE ORIGIN AND MINERALIZATION FEATURE OF MERCURY AND GOLD DEPOSITS IN GUIZHOU PROVINCE EAST PART

Hua Yongfeng

The Cambrian strata of the eastern district in Guizhou province is distributed along the western edge of the "Southwestern Platform". The bestow on a series deposits of sedimentary and strata-bound ore deposits in Cambrian strata, include phosphorus, nickel, molybdenum, vanadium, uranium, potassium, silver, mercury and gold, etc. Mercury and gold deposits are most important. The gold-bodies and mercury-bodies are associated close together, mainly in Middle Cambrian and Lower Cambrian strata. The country rocks are limestone and dolomite. Most alteration types have silicification, dolomitization, calcitization and the major minerals include cinnabar, native gold, stibnite, sphalerite, pyrite, galena, realgar, etc. Sulfur isotope $\delta^{34}S$ 11.9 - 21.1‰, (table 1) the account for sulfur for sulfate of sea water sedimentary. Hg, Au, Sb, Zn, Fe, Pb, As mine-materials from sedimentary mine-source strata - black carbonaceous shale of Lower Cambrian and mineralized strata. These mine materials preliminary concentration in strata on sedimentary stage, the set up background content of high abundance, the for example Hg 0.2 - 0.8 ppm, Pb 4.0 - 100.0 ppm, Zn 6.0 - 192.0 ppm, As 0.8 - 2000 ppm, Sb 0.4 - 20.0 ppm, Au 0.2 - 1200.0 ppb, etc. Low temperature hydrothermal mineralization stage, it is temperature 136 - 167°c. It is concluded that the mercury-gold deposits might be of sedimentary origin at an early incipient stage, studies of the fluid inclusions and some geological conditions of the deposits suggest that the mercury-gold mineralization has undergone a late, low temperature hydrothermal solution stage probably in the nature of heated confined groundwater action. Consequently the mercury-gold deposits concerned should be considered as of a 'sedimentary-nonmagmatic hydrothermal' type.

Table 1. Sulphur isotope composition (‰) in Wanshan District

Locality No.	Mineral			Strata and Country Rocks
1	cinnabar	17.4	21.840	Middle Cambrian dolomite
2		17.1	21.846	
3		17.4	21.840	
4		15.8	21.874	
5		17.6	21.836	
6		15.9	21.872	
7		14.8	21.896	
8		16.4	21.861	
9		15.7	21.876	
10		16.6	21.857	
11		19.6	21.793	
12		19.0	21.806	
13		19.0	21.806	
14		18.2	21.823	
15		17.9	21.829	
16		16.2	21.866	
17		15.4	21.883	
18		20.0	21.780	
19		20.0	21.784	
20		20.8	21.767	
21		10.4	21.818	
22		17.6	21.836	
23		18.2	21.823	
24		16.9	21.851	
25		21.1	21.761	
26		20.9	21.765	
27		19.6	21.793	
28		19.5	21.795	
29		19.7	21.791	
30		17.2	21.844	
31		15.4	21.883	Lower Cambrian limestone
32		16.3	21.864	
33		11.9	21.959	
34		15.2	21.887	
35		14.0	21.913	

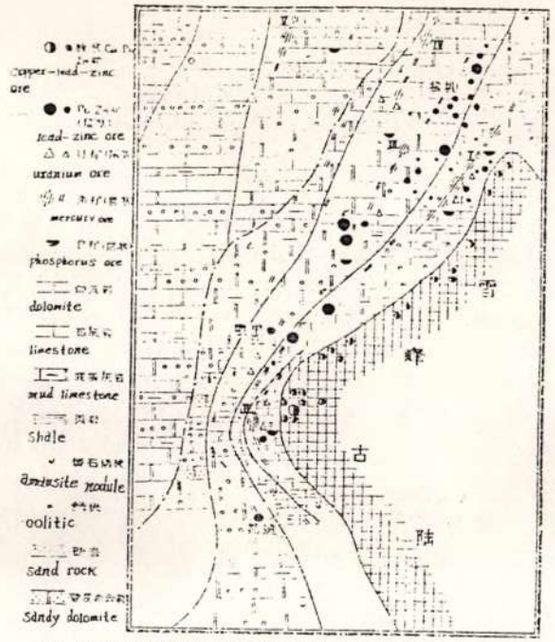


图7 黔东中寒武世岩相及寒武系中Hg Pb Zn P U矿分布关系示意图

FIG. 1. Geologic map of Hg. Pb、Zn、P、U deposits in Cambrian strata and middle-Cambrian lithofacies in Guizhou Province east part.

I: XIANG-GIAN mercury ore zone
II: SHANG-DAN mercury ore zone

图 26

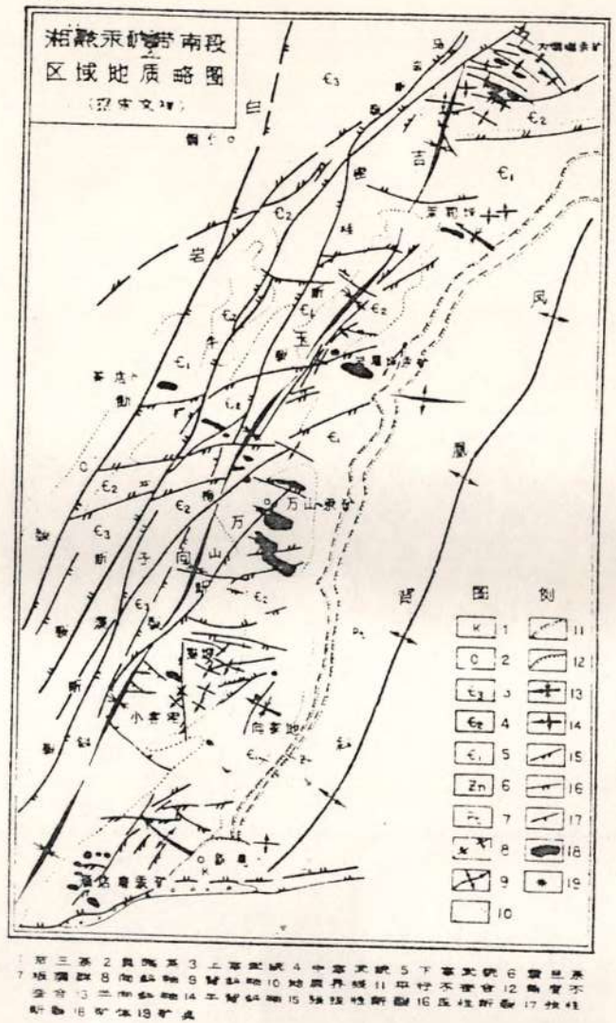


FIG. 2. Geologic map of South part of XIANG-GIAN mercury ore zone

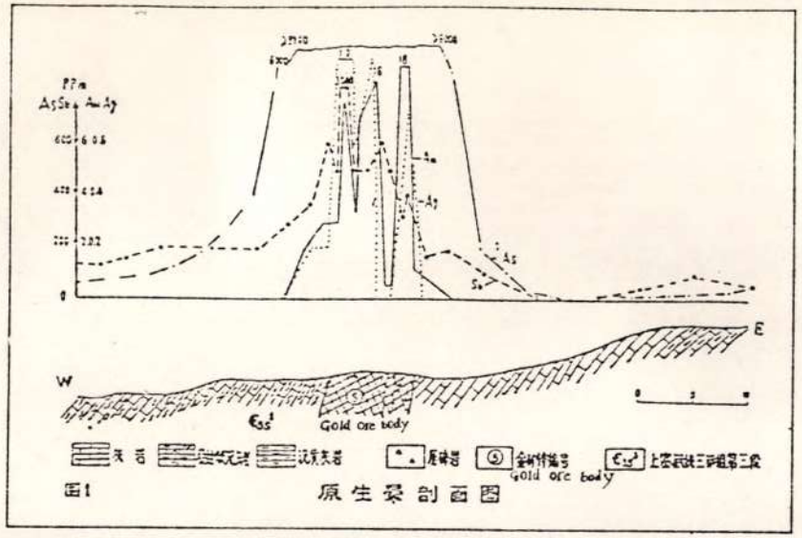


FIG.3. Cross Section of primdry halos of SHANG—DAN mercur ore zone

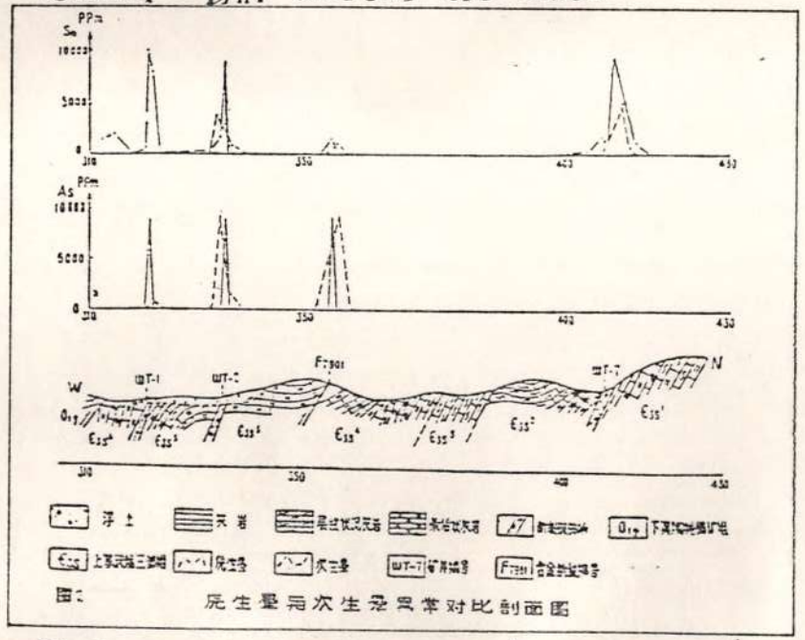
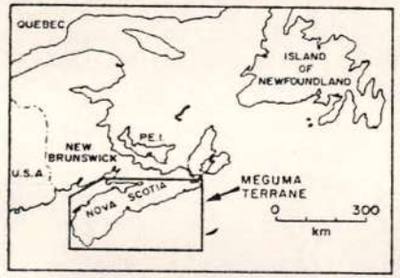


FIG.4. Cross Section of primdry and Secondary halos of SHANGDAN mercur ore zone

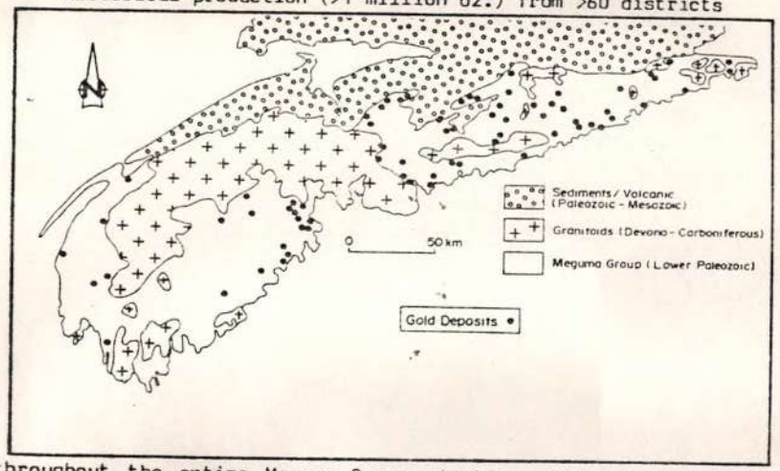
THE EMERGENCE OF A MAJOR, TURBIDITE-HOSTED GOLD PROVINCE IN THE LOWER PALEOZOIC MEGUMA GROUP, NOVA SCOTIA, CANADA

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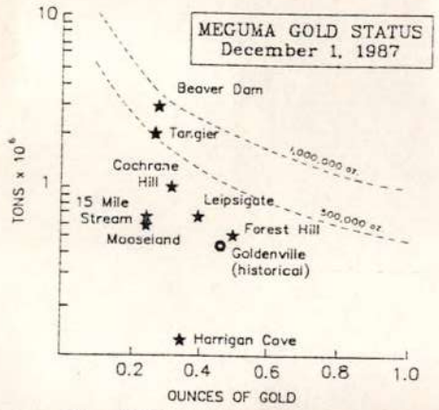
The Lower Paleozoic Meguma Group of Nova Scotia lies within the Meguma Terrane of the northern Appalachians (Fig. 1). This terrane consists predominantly of Paleozoic metasedimentary rocks with minor volcanics. The entire sequence was regionally deformed and metamorphosed (greenschist to upper amphibolite facies) during the late Devonian Acadian Orogeny. Large volumes of post-tectonic, peraluminous granitoids were emplaced ca. 370 Ma ago. Significant gold mineralization is hosted by the Cambro-Ordovician Meguma Group (Fig. 2) which consists of the lower, sandstone-dominated Goldenville Formation and overlying black, graphitic and pyritiferous Halifax Formation slates.



Historical production (>1 million oz.) from >60 districts throughout the entire Meguma Group signifies this as an important auriferous metallogenetic terrain. Conventional theories related the mineralized quartz veins to metamorphogenic processes coupled with hydraulic fracturing during the Acadian Orogeny. The apparent localization of deformed quartz veins in anticlinal domes was the evidence most frequently cited in favour of the "saddle reef" concept



The notion that the gold deposits are small, medium grade systems with limited continuity (both vertically and horizontally) has until recently discouraged exploration. However, the recent delineation of considerable ore reserve potential for these deposits (Fig. 3), in conjuntion with our recent field and laboratory studies, suggest that reassessment of these deposits is warranted.



The salient aspects of the Meguma gold deposits are summarized as follows: (1) they are localized in steep, frequently overturned limbs of anticlines and subordinate flexures which record post-Acadian shear overprints; (2) stratigraphy consists of variable proportions of psammite and pelite but quartz veins are usually hosted by pelitic lithologies; (3) presence of "dynamothermal" metamorphism which post-dated regional metamorphism; (4) development of pervasive, but mostly cryptic, alteration haloes (silicification most common) which overprint regional and dynamothermal metamorphic mineral assemblages in the wall rocks; (5) injection of voluminous amounts (up to 50-60%) of bedding-concordant and discordant quartz veins into active ductile-brittle shear zones; (6) confinement of economic ore to zones of discrete geometrical shape; and (7) presence of several ore shoots, potentially of different orientation, in a single deposit. It is estimated that deposits typically contain 0.5-3 million tons with 0.2-0.5 oz. Au/ton, but this may change considerably in the near future as additional exploration of the properties continues.

The veins are quartz dominated, but additional mineralogy consists of: (1) base metal sulphides (aspy, py, cpy, gal, sph, loel, stib); (2) rare native Bi and tellurides; (3) abundant silicates (biot, mus, plag, tour, chl, gar, amph, sphene); (4) carbonates (Fe, Mg and Mn varieties); and (5) apatite, scheelite, rutile and ilmenite. Plagioclase consists of an early, Ca-rich phase (An30-50) coexiting with biotite+tourmaline, and late albite which is stable with chlorite, muscovite, sphene and carbonate. The primary assemblage is inferred to have formed at >400°C, while the overprint formed at 300°C. Major element chemistry of both veins and wall rock minerals is very similar within a deposit, suggesting that the systems were characterized by high fluid/rock ratios. The presence of extensive wall-rock alteration and quite variable trace element chemistry of vein minerals is consistent with extensive disequilibrium within the vein systems. The similarity of S and O isotopic compositions of sulphides and silicates, respectively, within individual deposits regardless of paragenetic stage or host lithology also suggests fluid-dominated systems.

Many of the auriferous veins are characterized by the presence of ribbon or crack-seal textures, the latter having been interpreted

as indicating a metamorphogenic, hydraulic fracturing origin for the veins. Our investigation of this vein texture suggests it originated by progressive replacement of wall rock. The laminated nature of the veins is inferred to be stylolitic in origin.

The age of the mineralizing event is constrained by field relationships and absolute dating. The presence of "contact metamorphic" mineral assemblages which have been overprinted by vein-related alteration places an upper limit on mineralization (i.e. age of granitoids). $^{40}Ar/^{39}Ar$ dating of vein micas gives excellent plateau ages of 370 Ma, therefore corroborating the field relationships.

We interpret the features of the Meguma gold deposits to be Paleozoic analogues of precious metal quartz vein systems exploited in rocks of Archean age in the Superior and Slave provinces of Canada, and the Mesozoic lode systems of British Columbia, Canada, and the Mother Lode belt of California. In these deposits, the veins were emplaced via ductile shear zones which have impressive vertical and lateral continuity. The presence of extensive wall-rock alteration haloes indicates that fluids of exotic origin, probably derived during large-scale dehydration of the lower continental crust during batholith generation ca. 370 Ma ago, controlled the physio-chemical conditions at the site of deposition. The large size of deposits similar to the Meguma-type, including the Bendigo fields of Australia which produced ca. 10 million oz., indicate a vast potential for these previously ignored precious metal deposits. We suspect that as these deposits are exploited the Meguma Terrane will emerge as a significant and important gold domain and regain the status which it enjoyed at the beginning of this century.

Gold Mineralization in Northwest Pahang, Malaysia.

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Gold mining activities in Peninsular Malaysia started a few centuries ago but records on the production only existed since 1888. Since then to 1985, Pahang accounted for 88% of the total gold bullion (41.6 metric tonnes) produced and most of it came from the northwest region.

The location of the area is situated on the western portion of the Central Gold Belt in northwest Pahang which is bounded on both sides by the Western and Eastern Tin Belts (Figure 1). The boundary between the Western Tin Belt and the Central Gold Belt is marked by the Raub-Bentong suture zone whereas the latter and the Eastern Tin Belt is separated by the Lepar Fault zone, both which are major structures extending the length of the peninsular.

The oldest rocks in the Central Gold Belt (Figure 2) are represented by the Ordovician-Silurian to Devonian deposition of coarse clastics, argillaceous sediments, limestone, chert and minor volcanics which occur in the marginal belt forming the foothills of the Main Range Granite. By this time the Central Gold Belt subducted westward beneath the Western Tin Belt. The whole region was regionally metamorphosed during the Devonian. The Central Belt is underlian predominantly by Permo-carboniferous and Triassic clastics, volcanics and limestones. Significant acidic to andesitic volcanism occurred during late Permian times. Extensive carbonate platforms in northwest Pahang began to form during the Carboniferous times and continued into the early Triassic. The formation of carbonate platform peaked together with the volcanic activities in late Permian. Marine sedimentation was terminated by the late Triassic orogenic uplift which accompanied the intrusion of the Main Range Granite which form the backbone of the Peninsular. Ultramafic bodies were later emplaced in this foothills belt where deep seated faulting caused by the westward subduction. The earlier sediments underwent low grade regional metamorphism, mostly greenschist facies but locally may be up to amphibolite facies. The direction of subduction flipped from westward to eastward during the late Triassic. This resulted in the intrusion of granitoid bodies in the western Central Belt area. The strata were folded in a North-South direction resulting in the strata being moderately to steeply dipping in the East-West direction. North-northeast to north-northwest trending faults were also developed but these features were deflected in the vicinity of the granitoids.

These granitoid bodies, together with the gold mineralization, clearly define two zones which could be interpreted that the subduction migrated eastward and then the plutonic activities

diminished. The later granitoids could be Jurassic in age. Near the foothills, olistostrome and accretionary wedges were developed. Later Jurassic-Cretaceous continental clastics were deposited to the east of the area and were subjected to open folding and faulting in the East-West direction.

The types of primary gold mineralization present within the area are : 1) quartz reef, 2) stockwork, and 3) disseminated within the clastics. The mineral assemblage is commonly Au (low Ag), W, Sb, As, Pb, Cu and Fe. The former Raub-Australian Gold Mine, Tersang, Cheroh and Penjom mines produced the bulk of the primary gold from the north-south trending and steeply dipping carbonaceous shale and calcareous slate, normally within quartz and quartz-sulphides veins or reefs and within the crest of crenulation folds. Calcareous rocks may also host gold mineralization as in Padang Tengku and Merapoh. These type of veins are also present within a few of the granitoid intrusions. The gold mineralization is structurally controlled as indicated by the linear alignment of the mining centres in the North-South direction parallel to the pre-Triassic fault system. The Merapoh-Penjom gold mineralization does not carry stibnite whereas the Kuala Medang-Raub gold mineralization contains Sb.

Alluvial gold is currently an important source of gold and the fineness of the gold varies from 770 to 990 and averages 935. The gold grains are generally very fine grained (0.01 to 0.1 mm). The gold flakes are hackly and porous indicating that they are not transported far from the source. The alluvial profile are generally thin being not more than 7 metres in most areas but locally may have depths of more than 25 metres. The heavy concentrates, besides gold, are usually found to contain zircon, ilmenite, tourmaline, leucoxene limonite and epidote; magnetite, haematite, rutile, anatase, stibnite, scheelite, galena, sphalerite, chalcopyrite, pyrite, cassiterite, chlorite and garnet may be present. The thickness of the pay dirt is highly variable. The whole profile may be gold-bearing or the pay dirt may be confined to the top 15 cm above the bedrock. The bedrock are found to be limestone/marble, calcareous slate and schist.

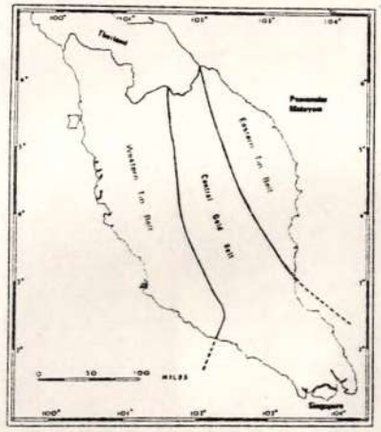
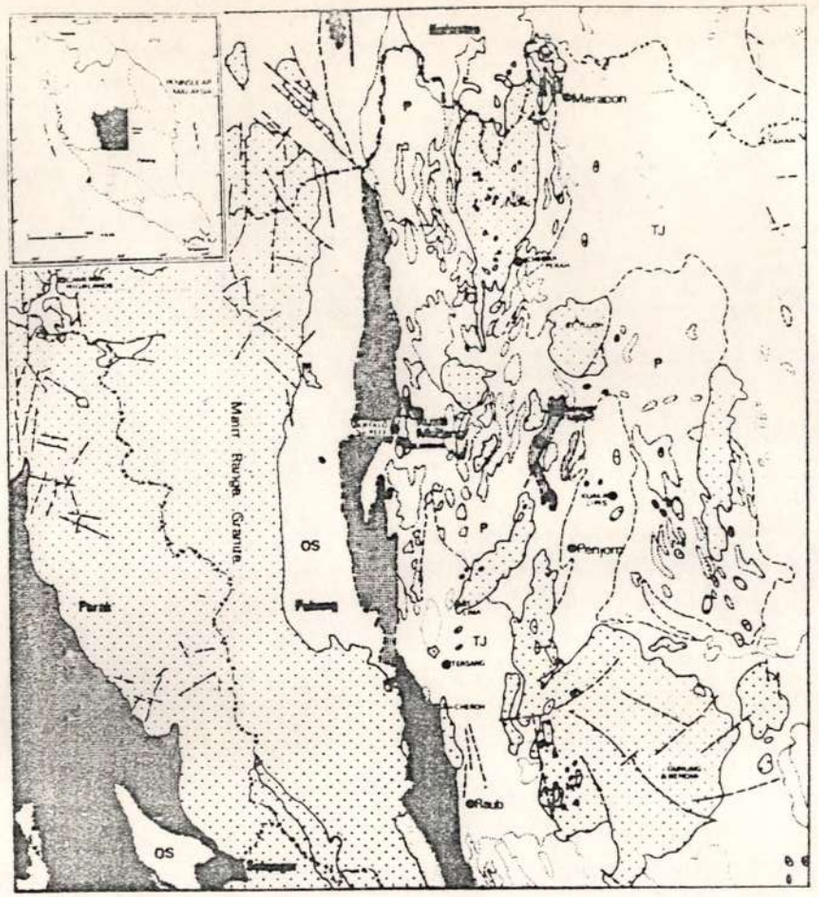


Figure 1. Division of three belts in Peninsular Malaysia.



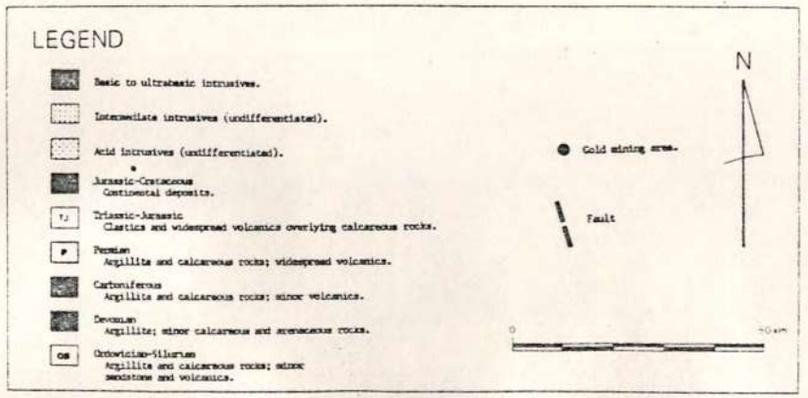


Figure 2. Generalized geologic map of Northwest Pahang showing the gold mining areas.

GOLD MINERALIZATION IN RELATION TO FOLD AND FOLIATION DEVELOPMENT IN CANADIAN APPALACHIAN WRENCH-FAULT TERRANES

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An important class of Atlantic Canadian gold deposits, including BP-Selco's Hope Brook Mine in Newfoundland, Seabright's Forest Hill Mine and Beaverdams Mine in Nova Scotia and the Gordex Mine at Cape Spencer, New Brunswick, occur near regional lineaments in Paleozoic rocks of the Appalachian Orogen. Most of these lineaments reflect ductile fault systems or tightly braided mylonite zones, the most significant of which record a protracted history of displacement and evidence of persistently high heat flow. Economically significant lineaments are characterized by (1) their common location above Precambrian or Cambro-Ordovician ancestral structures, (2) repeated volcanism and plutonism along the fault lineament, (3) polymetamorphism of some or all of the gold-bearing rocks near the fault lineament and (4) post-Devonian fault reactivation and lineament enhancement.

REGIONAL SETTING OF LINEAMENTS

Within the accreted southeastern margin of the Appalachian Orogen, tectonostratigraphic terranes are commonly bounded by large scale transcurrent faults or dextral megashears that delimit wrench fault systems varying between 10^3-10^5 km^2 in area. The principal shear planes or east trending master faults initially formed at a relatively late stage in Acadian (Siluro-Devonian) regional deformation; however, many were also ductilely reactivated by Hercynian (Carboniferous) movements. Orogenic flexures or megakinks were produced where wrench-generated, northeast trending, Acadian-aged, folds, foliations and thrust faults were rotated towards the ductile master faults. In Appalachian terranes governed by either Acadian or Hercynian wrench faulting, the regionally predominant periclinal folds and slatey to spaced foliations are upright. However, narrow transitions to recumbent structures occur where the regional strain increases as the suprastructure of the orogen passes downwards into or is pierced by its infrastructure. Shortening of the suprastructure caused limb thrusts, out-of-syncline thrusts and other features that accommodated inhomogeneous buckling. Although platey, veined or mylonitic rocks are locally gold-bearing along such structures, the amount of stratigraphical separation across ductile faults of Acadian or Hercynian age is commonly inconsequential.

TYPES OF GOLD MINERALIZATION

Gold deposits in the Appalachian Meguma, Avalon, Gander and Dunnage terranes occur preferentially in the suprastructure of the Acadian fold belt and are tectonically localized in slate belts composed of variable amounts of sedimentary and volcanic rocks. Less commonly, gneiss and schist belts near the infrastructure-

suprastructure transition contain gold mineralization. The slate belts host two end-member types of mineralization: (1) nugget gold in Bendigo-type, saddle-reef, quartz-carbonate lodes (for example, those in the sandy and shaley flysch of the exotic Meguma Terrane of mainland Nova Scotia) and (2) disseminated gold in Carolina-type, high-alumina, high-silica, sericitic schist zones (for example, those in pyroclastic and epiclastic deposits of the Gander Terrane of southwest Newfoundland). The stratigraphy, terrane-type, age and composition of the mineralized country rocks are largely incidental.

ORIGIN AND NATURE OF FLUIDS

Mineralizing fluids originated from, or were heated by, granodiorite or tonalite plutons and allied porphyries. In places, these granitoids are spatially associated with H_2O-, CO_2- and P-rich gabbro-diorite complexes and mafic dyke swarms, the loci of which are regularly spaced along some fault lineaments. All of these intrusive rocks probably formed in or passed through the deep basement and/or infrastructure of the orogen. They ascended in sequence at various stages of the regional deformation and were emplaced into the slate belts during Acadian, high-T, low-P, dynamothermal metamorphism. Pseudoporphyroblasts of sulphides, carbonates, aluminosilicates and phosphates (some containing rotated inclusion trails) record the unique physicochemical conditions locally prevalent during periods of fluid-controlled, synmetamorphic, synplutonic alteration. Regional metamorphism at the time of emplacement of the gold-generating, felsic-mafic, composite intrusions and gold-bearing, quartz-carbonate, crack-seal, vein arrays was generally in the greenschist facies, although some host rocks were metamorphosed in the amphibolite facies before or after the introduction of magma and fluids.

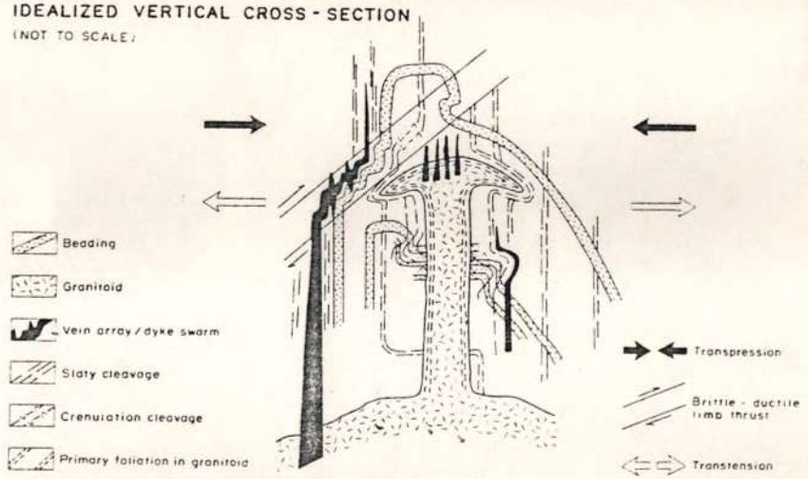
DEFORMATION KINEMATICS AND DYNAMICS NEAR GOLD DEPOSITS

In the Acadian and Hercynian wrench systems, viscoelastic deformation near gold deposits was accomplished by two complementary processes: (1) dilation and synchronous shortening of intrusive bodies and veins in localized parts of fault zones or fold hinge zones, and (2) a more widespread extension and flattening of the country rocks through the progressive development of coaxial folds and fabrics. Zones of large total strain are host to a greater variety and a larger number of syndynamic, synkinematic intrusions than zones that were never appreciably strained. Regardless of whether these zones are vertical or horizontal, quartz-carbonate veins and mafic-felsic sills and dykes are emplaced along and, to a lesser extent, across the foliation displaying the maximum anisotropy. Variably altered and mineralized, Acadian-aged, sheet-like plutons and sills marked by a central igneous-textured and a marginal protoclastic zone occupy foliation-parallel, en echelon, shear fractures in the ductile fault zones at the expense of their conjugate, cross-strike pair. While these rocks invariably suffer some of the strong regional deformation, gold veins and hypabyssal intrusions in the negligibly strained, simply folded areas between faults illustrate two, distinct, deformation styles. An autokinematic style of deformation affects Acadian dykes displaying syn-intrusion offset of host rock markers. Deformation of crystallizing magma between the walls of conjugate pairs of dilating dykes produced

sigmoidal internal foliations that, in the case of one set, are perpendicular to the regional cleavage. In contrast, gold veins containing cleavage inclusions and laminated, fibrous or vuggy crystals are deformed by several orders and orientations of folds, and occupy systematic fractures parallel to the AB-, AC- and BC-kinematic planes of the regional periclines.

ROLES OF TRANSTENSION AND TRANSPRESSION IN LOCALIZING GOLD DEPOSITS

Contemporaneous and cyclic, brittle-ductile episodes of horizontal extension (transtension) and horizontal shortening (transpression) were operative throughout the wrench systems but their effect on intrusions of all scales has special ramifications for the localization of gold deposits. Orthogonal and oblique extension across developing foliations controlled the geometrical shapes, the growth textures and some of the deformation features of the gold quartz veins and variably altered hypabyssal intrusions. For example,



in upright folds or faults invaded by vertical syntectonic intrusions, country rock layering as well as foliation-parallel veins and dykes were bent into flat orientations by extension and then rebuckled into steep attitudes by compression as progressive regional deformation focused on particular structures. Since these processes were continuous, some individuals in the vein arrays and dyke swarms were generated while others were being folded or boudinaged. In places, diapiric granitoids rose along fold axial surfaces and spread laterally beneath upright anticlines. Here, ductile horizontal stretching locally produced flat fabrics in the granitoids and distorted the once upright cleavage fans. It also caused the roofs of the granitoids and the adjacent parts of the fold hinge zones to fail in extension as space was created for vertical satellite intrusions emanating from the diapirs. Pulses of mineralization, alteration and igneous activity occurred during periods of extension intimately associated with fold and foliation development and fault movement.

GOLD IN THE LACHLAN FOLD BELT IN NEW SOUTH WALES

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The Lachlan Fold Belt (LFB) is a complex orogenic belt which contains a diversity of gold mineralization styles in a variety of geological settings. The bulk of gold production from New South Wales, estimated to total 523 t from 1851 to 1986, has come from the LFB. The LFB developed in Early to Mid Palaeozoic time when dispersed Precambrian complexes became cores of separate tectonostratigraphic terranes which underwent episodes of dispersal and accretion. Gold mineralization resulted from a wide range of processes during tectonic development, notably from volcanism associated both with rifting and with convergent arc development, from the intrusion of a range of igneous rock types during accretionary and post-accretionary stages, and from mobilization of auriferous hydrothermal solutions during regional metamorphism. An account of the tectonic development and mineral deposits of the LFB has been given by Degeling et al. (1986).

The major deposit types are described below and the distribution of deposits is shown on Fig. 1.

Gold deposits are situated in Late Ordovician to Early Silurian shoshonitic andesitic sequences of the Molong Volcanic Arc in the Parkes district (Clarke 1987). There are several types including epithermal deposits, for example Peak Hill (Fig. 1 deposit *1*); porphyry copper-gold (Goonumbla *2*); and veins in shear or fault zones (London-Victoria *3* and Lachlan line of lode *4*). To the south, a narrow belt of andesitic volcanics of (?)Ordovician-Silurian age flanking the Gilmore Suture in the West Wyalong-Temora district may represent a continuation of the Molong Arc (Suppel et al. 1986). The volcanics host a number of epithermal deposits, notably the Temora gold mine at Gidginbung (*5*) and the Dobroyde prospect (*6*).

Significant gold is contained in some volcanogenic base metal deposits in Mid to Late Silurian rift or basin felsic volcanic sequences in the Hill End and Captains Flat Troughs. Largest production came from Captains Flat (*7*).

A few gold fields are associated with serpentinite, by far the largest being at Lucknow (*8*) where gold-calcite veins are localized along a major faulted contact between andesite and serpentinite emplaced during the Silurian or Early Devonian.

Granitic intrusions are the source of substantial primary and alluvial gold production. In the west, large deposits are situated close to the Gilmore Suture in Late Silurian - Early Devonian granites at West Wyalong (*9*) and Adelong (*10*). In the east, large deposits are located in Early Devonian I-type granite at Majors Creek (*11*).

In the central-northern portions of the LFB deposits are associated with Early Devonian I-type granitoids of the Boggy Plain Supersuite (Wyborn et al. 1987), for example at Cargo (*12*), and with diorites, for example the replacement type Sheahan-Grants deposit, Junction Reefs (*13*).

Stockwork and massive sulphide deposits in Early Devonian sedimentary rocks of the Cobar Supergroup have been major producers (notably The New Occidental mine *14*, the largest single gold producer in New South Wales, nearly 20 t). The Great Cobar (*15*) and New Cobar (*16*) mines produced large quantities of gold as well as copper. The deposits are of uncertain origin, perhaps being formed from metamorphic-hydrothermal fluids during cleavage formation or from hydrothermal remobilization of exhalative mineralization. Deposits also occur in or near felsic volcanic rocks of the Cobar Supergroup, for example at Mount Boppy (*17*).

In the east, epithermal gold deposits are situated in Middle to Late Devonian subaerial felsic volcanic rocks of the Eden - Comerong - Yalwal Rift Zone at Yalwal (*18*) and Pambula (*19*).

The Kanimblan Orogeny during the Early Carboniferous converted the LFB into a neocraton. Vein deposits were formed during cleavage formation in either Kanimblan or Middle Devonian time at Hill End (*20*). The origin of vein and shear type deposits in folded sedimentary rocks, for example the Cowarra deposit (*21*) which is situated in Ordovician rocks, remains a subject of debate. In the northeast, Carboniferous post-kinematic granitoids may have been the source of gold mineralization in some deposits, for example the alluvial deposits of the Gulgong Gold Field (*22*), although genetic relationships remain uncertain.

Alluvial deposits are widespread and the source of a high proportion of total gold production. Most deposits are of fluvial type and Tertiary deep leads have been particularly productive in some areas.

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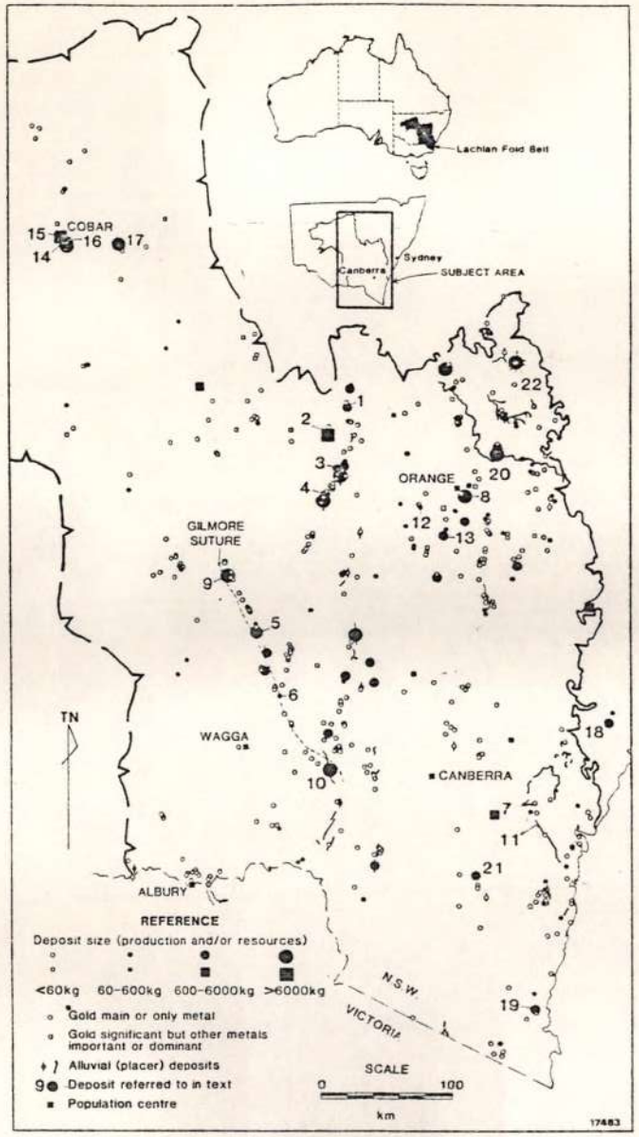


Figure 1. Gold Deposits in the Lachlan Fold Belt, in New South Wales

STYLES AND DISTRIBUTION OF GOLD MINERALISATION IN THAILAND.

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INTRODUCTION.

A comprehensive review of currently available literature combined with recent field inspections and consultation with staff of the Dept. of Mineral Resources, Thailand has allowed the compilation of a data-base on approximately 100 occurrences of gold mineralisation in Thailand. All deposits with sufficient available information have been classified in terms of current genetic models and the resulting distribution has been rationalised in terms of the regional geology and paleotectonics of Thailand. This approach has allowed delineation of the most prospective regions for discovery of new, economic gold deposits.

ABSTRACT.

Currently known primary gold deposits in Thailand are hosted entirely within rocks of Paleozoic and Mesozoic age. Available evidence indicates that there have been at least two periods of significant gold mineralisation. The first period coincided with, and was probably related to, a deformation/metamorphism event during late Permian? time. The second period is thought to be related to a period of Permo-Triassic volcanism. However, the ages of the volcanics are not well established and it is possible that some of the magmatic styles of mineralisation are upper Mesozoic or Tertiary in age. Outcrops of pre-Cambrian rocks are relatively scarce in Thailand and there are no reported gold occurrences within them.

The first gold mineralisation event gave rise to metamorphogenic style vein deposits similar to the "slate belt" styles found in Victoria, Australia and in the Otago Schists, New Zealand. The veins are typically hosted by major structures which crosscut large packages of moderate to strongly deformed greywacke type sediments which have undergone peak metamorphism no higher than greenschist grade. The veins are usually confined entirely within the structure forming an anastamosing pattern around numerous sheets and slabs of sheared wall rocks. The fineness of gold from this style of mineralistation is characteristically high. Values of 980 to 990 fine are almost ubiquitous and this factor may help to identify this style of source mineralisation from some alluvial concentrations.

Metamorphogenic style veins in Thailand appear to be confined almost entirely to the large, north trending fold belt which includes all of peninsula Thailand and most of the northern and western parts of the country. This area also contains most of Thailand's tin deposits and many of the occurrences reported are tin alluvials with minor amounts of gold. The geologic setting and presence of these tin deposits suggest that the western fold belt is tectonically unfavourable for styles of gold mineralisation other than metamorphogenic veins.

Although this style of deposit commonly yields high grades (10-40 g/t), their tonnage potential is usually limited and they almost always require expensive underground mining techniques. Furthermore, the isolated nature of the veins makes them poor candidates for alluvial sources. Consequently, peninsular and western Thailand are considered to be of low prospectivity for major gold deposits. The situation in the northern lobe of Thailand is somewhat complicated by the presence of some Permo-Triassic? volcanics. There are numerous gold occurrences in the area, but they are almost exclusively alluvial. This fact alone suggests the possibility of primary styles other than metamorphogenic veins and when combined with the presence of Permo-Triassic volcanics, the probability of intrusive related deposits is significant.

The second gold mineralisation event gave rise to a wide variety of deposits, most of which appear to be related to moderate to shallow depth porphyry intrusions of acid to intermediate composition. The intrusions and related volcanics are scattered throughout a north trending zone bounded to the east by the Mesozoic sediments of the Khorat Plateau and to the west by the Tertiary sediments fo the Great Central Plain. The zone may represent a relict subduction zone with associated calc-alkaline magmatism (Sanam Suensilpong, Pers. Comm. 1987). The basement rocks within the zone are almost entirely Devonian limestones and Carboniferous sediments which also contain significant carbonate units.

The abundance of limestones combined with intrusive related mineralisation systems has resulted in a large number of skarn style gold deposits. In fact, in almost every case where sufficient geological control is available, some skarn component has been discovered. One of the most intensively investigated deposits, Phu Lon, is essentially a porphyry-copper system which has intersected calcareous stratigraphy. As is commonly the case in porphyry-skarn systems, many styles of mineralisation are manifested throughout the deposits. The following styles have been observed: garnet, magnetite and epidote skarns, mesothermal to sub-epithermal veins, sheeted vein sets, stockworks and breccias. All of these styles have potential for large tonnage, bulk mineable deposits.

Although historically unimportant in Thailand, the porphyry related styles of mineralisation are likely to form the major targets for modern exploration programs. Recent exploratory work by the Dept. of Mineral Resources in Thailand has indicated that the recorded deposits represent only a small fraction of the mineralisation present within the north trending volcanic belt and that the potential for new economic discoveries is high.

ACKNOWLEDGEMENTS.

This work could never have been completed without the invaluable discussions and information supplied by Prasert Kumanchan (Chief of the Gold Research Program D.M.R., Bangkok). My sincere thanks must also go to Chamlong Pintawong and Sahat Muenlek (Metallic Mineral Survey Section D.M.R., Bangkok) for tireless hospitality and assistance in the field, and finally to Thanawut Sirinawin (Seatrad Centre, Ipoh, Malaysia) for diligent translations, without which much of the information in the database would not have been available.

GOLD MINERALIZATION IN THE CENTRAL BELT OF PENINSULAR MALAYSIA

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INTRODUCTION

Metallogenically, Peninsular Malaysia can be divided into three provinces or belts - a gold rich Central Belt is juxtaposed between two tin-rich belts. The Central Belt is separated from the Western Tin Belt by a suture which is in part marked by a sparsely discontinuous string of Alpine-type serpentinite emplaced inside Upper Palaeozoic to Triassic rocks consisting of schists and strongly folded deep water sediments. The demarcation of the eastern margin had always been in controvercy.

TECTONIC HISTORY

The gold mineralization in the Central Belt can best be understood by looking at its tectonic development.

Based on new metallogenic and petrogenetic evidences which require a reinterpretation of the tectonic history, the three belts are demarcated as shown in Figure 1. It is envisaged that by Late Paleozoic time, the Western Belt together with neighbouring Sumatra, West Thailand, Burma and parts of China constituted a continental fragment with a largely stable shelf environment. The Eastern Belt together with East Thailand and the present surrounding continental shelf areas constituted another fragment. A wide open ocean probably separated the two.

During probably Late Devonian or Early Carboniferous, a westward subduction of the oceanic lithosphere which carried the Eastern Belt, beneath the Western Belt along where the present suture line exists, was initiated. The Benioff zone migrated eastward as oceanic and terrigenous deep basin sediments derived from what could had been in part land mass of the Western Belt were accreted onto to the Western Belt margin. Shelf sediments then onlapped the accreted wedges at certain areas.

Further eastward migration of the Benioff zone, moved it away from the terrigenous influence of the Western Belt and new accretion wedges would now consisted largely of scrapped-up oceanic sediments. By Middle Permian and apparently stretching into Jurassic, a volcanic arc was developed by breaking through the accretional wedges and shelf sediment. The arc migrated eastward synchronous with the migration of the Benioff zone.

Another component of the Central Belt consisted of foreign terrane which originally represented smaller continental fragments rela-

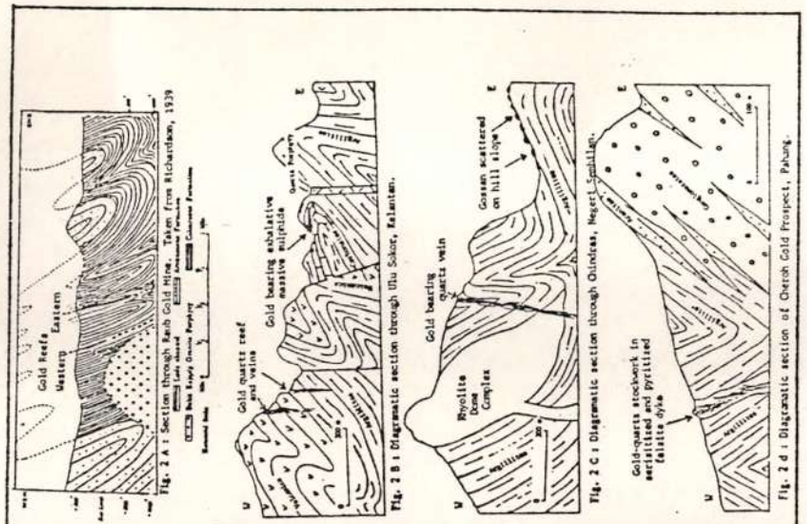


Fig. 2 a : Section through Raub Gold Mine. Taken from Richardson, 1939

Fig. 2 b : Diagramatic section through Ulu Sokor, Kelantan.

Fig. 2 c : Diagramatic section through Ouinkan, Negeri Sembilan.

Fig. 2 d : Diagramatic section of Cheroh Gold Prospect, Pahang.

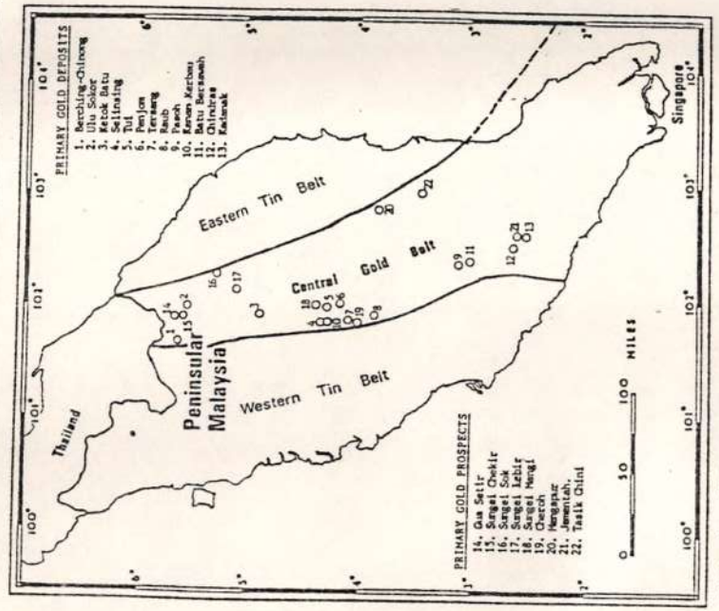


FIG. 1 : THREE METALLOGENIC PROVINCES OF PENINSULAR MALAYSIA AND LOCATION OF GOLD MINERALIZATION

ted to the Eastern Belt. Some probably formed islands while others formed platforms upon which chemical sediments accumulated. The westward subduction accreted these terranes onto the sedimentary wedges to become parts of the Central Belt. A few such terranes are recognised in the northern section while a significantly large terrane is recognised in the southern section of the Central Belt.

A short pause in the westward subduction is suggested to have occurred probably during Early Triassic. This was sufficient for isostatic readjustment which caused N-S block faulting in the accretion wedges, the precursor of the Central Belt, the Western Belt and possibly the Eastern Belt which had been brought ever closer to the Western Belt. When westward subduction recommenced, the Eastern Belt was brought into collision with the accreted margin (Central Belt) of the Western Belt. The collision brought about further folding and generation of granites largely within the Western and Eastern Belts. The peak of the collision was reached probably by Late Triassic when the three belts were fused into a landmass which constituted Peninsular Malaysia.

GOLD MINERALIZATION

Production of gold from the Central Belt in significant amounts prior to the Portugese conquest of Malacca in 1511 resulted in Peninsular Malaysia being known as the Golden Chersonee. Eventhough, the gold mining industry predated the tin mining industry, the exploitation of the former had been neglected due largely to the presence of the fabulously rich and easily exploitable alluvial cassiterite deposits which had occuppied and sustained the interest of the private and public sectors for the last hundred years. Within the last two years there is several fold increase in the exploration and opening up of new alluvial gold mines within the Central Belt.

Large areas within the Central Belt is mineralized with gold as indicated by neumerous occurrences of gold in drainage systems.

Primary gold mineralization in the Central Belt is limited to about 22 occurrences where presence of gold is proven (Fig. 1). Out of these, 13 have been mined in part or as a whole for their gold. Included in this group, the most significant of them being Raub from which more than 25 tonnes of gold had been produced and presently still supporting a small scale soft-rock opencut mine (Fig. 2A). The next in importance being Ulu Sokor (Fig. 2B) where about 1 million tonnes of largely massive sulphide ores containing between 2g to 5g Au per tonne is yet to be exploited. Among the 9 gold prospects, the newly drilled Mengapur prospect is a large tonnage low grade Cu-Au-Zn-Pb-Mo-W deposit with gold grade said to be from 0.4g to 1.0g per tonne distributed within certain zones.

STYLES OF PRIMARY GOLD MINERALIZATION

From the genetic point of view, the primary gold mineralization of the Central Belt can be divided into:

Styles/Types	Examples
1. Deep level gold-quartz reefs, veins and sheeted veins in high grade metamorphics.	Berching-Chinong
2. Structurally controlled reefs, veins and disseminated zones hosted in weakly metamorphosed sediment or greenstone terrain. Mineral assemblages consist of quartz-electrum-pyrite-stibnite-scheelite.	
A. In strongly folded and metamorphosed deep basin sediments.	Raub (Fig. 2A) Selinsing Kanan Kerbau
B. In metamorphosed limestone.	Tui
3. Gold mineralization as reefs, veins and replacements inside or related to structurally controlled intrusive dykes of granophyre, quartz porphyry, lamprophyre and other basic rocks.	Batu Bersawah Pasoh
4. Skarn type gold mineralization. Cu-Au-Mo-Zn-Pb-W association.	Mengapur (N.B. Requires more data to place it correctly. It seems to show some volcanogenic affinity)
5. Gold mineralization related to submarine volcanism.	
A. Related to rhyolite dome and dome-flow complex.	
(i). Feeder zone stockwork and bonanza veins related to feeder zone.	Cheroh (Fig. 2D) Tersang Chindras (Fig. 2C)
(ii). Proximal to distal exhalites (sulphides, sulphates and oxides).	Tasik Chini
B. Related to calc-alkali andesitic to rhyolitic explosive volcanism. Proximal Zn-Pb-Cu-Au exhalative massive sulphides.	Ulu Sokor

OTHER STYLES OF PRIMARY GOLD MINERALIZATION

It is expected that as more data become available some of these Central Belt gold occurrences have to be reclassified.

The majority of the primary gold occurrences are located in the northern section of the Central Belt. There is practically no evidence of primary gold occurrence in the southern section though gold is found in several localities in the drainage basins. The narrower northern section is believed to represent a more severe collision zone where some deep level metamorphics had been squeezed up and exposed. The southern section represents a less severe collision zone and much of the original elements of the Central Belt is expected to be still preserved.

The volcanic arc element in the Central Belt is quite extensive. Volcanicity is expected to young from the west towards the eastern margin. In some districts of the Central Belt, the volcanics appear to be not metamorphosed compared to the surrounding sediments. It is possible that volcanicity had continued to a much later age than previously thought.

The types of volcanicity recognised include:

(a). Andesite-dacite-rhyolite explosive submarine to subaerial type.
(b). Rhyolite dome and dome-flow complexes of mainly submarine environment.
(c) Subaerial strato-volcanoes.
(d). Subaerial strato-volcano-caldera complex with ignimbrite sheets and dykes.

Comparison of the Central Belt with Paleozoic-Mesozoic gold provinces elsewhere in the world, which show similar tectonic settings, indicates that a number of styles of mineralization are still lacking in the Central Belt. It is suggested that among them are epithermal systems associated with subaerial strato volcanoes and caldera complexes.

CONCLUSIONS

Important primary gold targets in the Central Belt include: (i) Raub type gold reefs and dessiminations, (ii) gold bearing exhalites and (iii) sulphide-gold bearing skarns. Based on historical reasons there is a slim chance of finding a large Raub type primary gold deposit. Chances of locating gold bearing exhalites and skarns over untested ground are still bright. Potential for locating a large volcanogenic epithermal system in the Central Belt is high.

----------ooOoo----------

Topic 2C

PALAEOZOIC CASE HISTORIES

PROSPECTING FOR GOLD MINERALIZATION IN BLACK SLATES IN THE JESENÍKY MTS., CZECHOSLOVAKIA

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Systematic prospecting for blind deposits of base metal and gold is in progress in the Jeseníky Mts. /NE margin of the Bohemian Massif/. The prospecting has been concentrated on two volcano-sedimentary zones of Devonian age enclosing districts of both types of ore deposits.

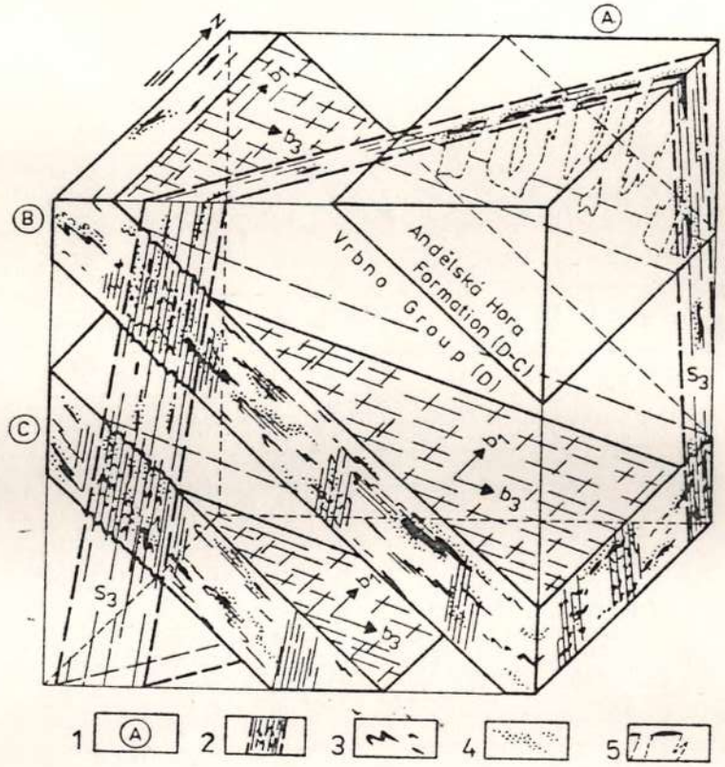
Gold-bearing mineralization of new type for the Bohemian Massif related with black slates was found in the historical Andělská Hora ore district. This gold district covering 30 square kilometers was one of the important in Central Europe. Veinlet and disseminated gold mineralization of Au - sulphidic quartz formation was discovered by a drill hole in the deep footwall /up to 700m below surface/ of vein and stockwork deposits mined in past /probably in the first millenium B.C. to the Middle Ages/. The established mineralization was found in dark carbonaceous mudstones polyphase metamorphosed in greenschist facies of upper part of the Devonian sequence /stratigraphically above the metavolcanics of the Zlaté Hory base metal ore district 25 km N from here/. Very irregular increased gold contents /0,X to X, ev. X0 ppm Au/ have been found in several layers of dark slates characterized by presence of: abundant Fe-Mg carbonate porphyroblasts, quartz and carbonate veinlets, increased amount of gold-bearing sulphides, intensive polyphase superposed fold deformation /crenulation cleavage, shear zones/, lithogeochemical haloes / of Au, As, Sn, Mo, Ba, depletion of Zn/ and gammaspectrometric potassium anomalies /over 3% of K/. The gold is found in pyrite and arsenopyrite association. It forms small grains and irregular agregates /mostly less than 0,1 mm in size/ with low contents of silver /5,6 to 17,8% of Ag/.

The sulphur of sulphides/prevails pyrite/ is of sedimentary origin / $\delta^{34}S$ within -22,3 to +9,6% /. Isotopic variability of carbon and oxygen from both vein and porphyroblastic carbonates is very low. The distribution of C_{org} content and character of organic matter suggests their importance duringconcentration of gold in slates. The origin of cleavage of superimposed folds connectedwith pressure solution of minerals might have led to the formation of discontinuities, to the migration of fluids and the genesis of stockwork and impregnation systems of quartz-carbonate, sulphide and gold mineralization.

The following methods were applied in prospecting for ores of the type discussed: geological, geomorphological,

mining - historical, geophysical, mineralogical and geochemical. Prospective beds of carbonaceous slates have been mapped using geophysical methods /induced polarization and resistivity/. The magnetic field of the district area is weak and steady. Maximum of positive gravity anomaly is situated near the center of the district. The mineralization has been found by drilling of the portions of IP anomalies accompanied by geochemical anomalies /in soil metallometry and lithogeochemistry/ and heavy mineral concentrate ones.

The major factors controlling the location of the gold-bearing mineralization of this type are the lithological, structural and metamorphic ones. Two morphological types of ore bodies are expected /see diagram/: 1. tectonically controlled steep veins and stockworks and 2. subhorizontal bodies of veinlet and disseminated ores. The mineralization has a lot of features similar to other gold ores known from slate belts, esp. in the U.S.S.R.. The established gold mineralization is polygenetic in origin, whereby tectonic and metamorphic processes probably had a decisive influence on their concentration from the host rocks. However, a different epigenetic origin of the gold outside the host sequence cannot be still ruled out. The evaluation of economic importance of the gold mineralization in black slates near Suchá Rudná is in progress.



Expected distribution of gold-bearing mineralization at the locality Suchá Rudná /a diagram/.

1/ A - flysch of the Andělská Hora formation, B and C prospective layers of metamorphosed mudstones, 2/ tectonic zones subparallel to cleavage of folds F_3, 3/ quartz veins with carbonates and some sulphides, 4/ veinlet and impregnation mineralization of sulphides, locally with gold, 5/ outcroping quartz - carbonate veins with sulphides and gold mined in past.

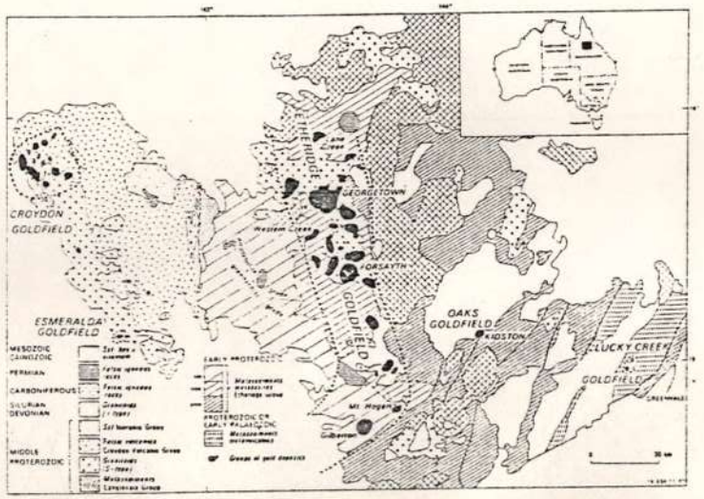
GEOLOGIC, ISOTOPIC, AND METALLOGENIC ASPECTS OF GOLD MINERALISATION IN THE ETHERIDGE GOLDFIELD, GEORGETOWN REGION, QUEENSLAND.

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The gold-quartz vein deposits of the Etheridge goldfield formed from hot, moderately saline (about 10wt% equiv. NaCl) fluids containing SiO_2, H_2O, CO_2, S, and metals, that were focussed into extensive fracture systems during a major episode of granitoid emplacement about 400Ma ago.

The deposits are mostly hosted by Proterozoic granites that intrude Proterozoic amphibolite grade metasedimentary and metabasic rocks. The goldfield is a 30 by 130km belt of deposits immediately west of the regional greenschist facies retrograde metamorphic front that is associated with extensive Siluro-Devonian batholiths. Deposits tend to be clustered where northeasterly batholith trends intersect this belt, and especially where those intersections coincide with areas of Proterozoic granite.

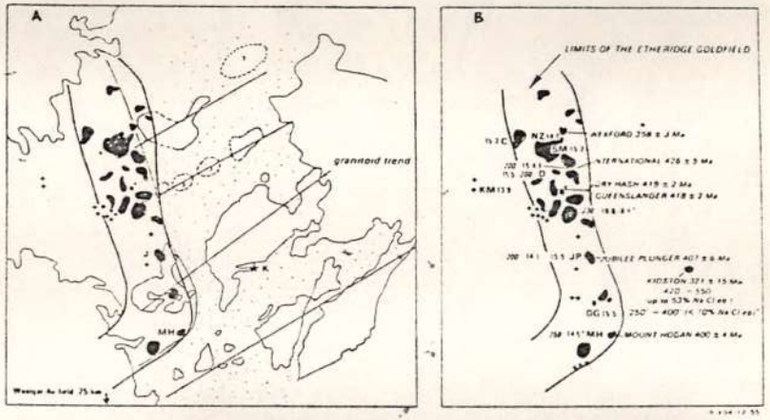


1. *Geology and goldfields of the Georgetown region, Queensland.*

The ore fluids altered granitic wallrocks to argillic and sericitic assemblages and deposited quartz, carbonates, and patches of pyrite, base metal sulphides, gold and silver.

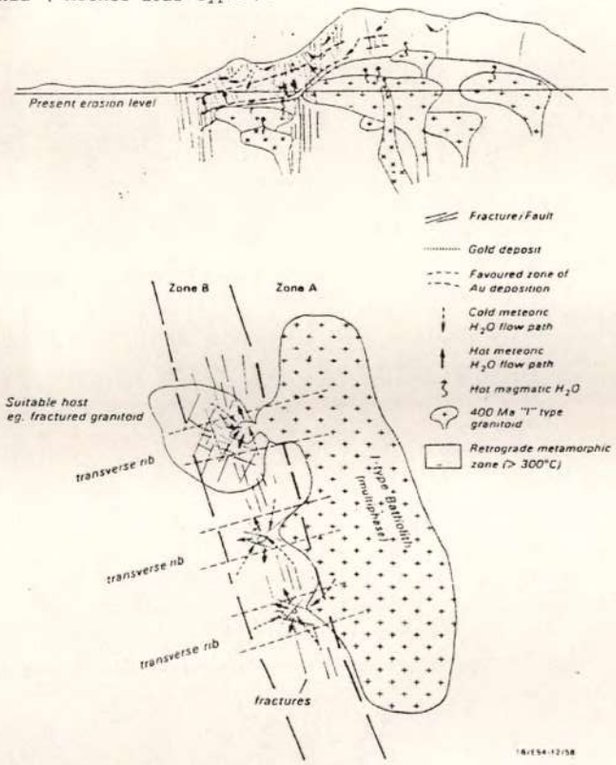
Oxygen isotope values of vein quartz from throughout the field indicate that the veins formed from fluids with $\delta^{18}O$ (SMOW) values of about 5 to 9 per mil. Microthermometric data from fluid inclusions indicate fluid homogenisation temperatures of about 200 to 350^{0}C. The highest temperatures correspond with the heaviest $\delta^{18}O$ values, and collectively these data suggest that the ore fluid may have been highly modified meteoric water, or had a significant magmatic component. Meteoric fluid (negative or low positive $\delta^{18}O$ values) was apparently involved in at least one deposit (Havelock: $\delta^{18}O$ fluid about 0 per mil, T_h230^{0}C). Other deposits have intermediate values suggesting a mixing of meteoric and magmatic fluids, or extreme modification of meteoric fluid.

K-Ar sericite ages (398 to 426 Ma) and a Rb-Sr sericite-whole rock isochron age (407 Ma) have been obtained from the altered wallrocks of six deposits distributed throughout the length of the field.



2. *Distribution of gold deposits (dark toned areas) relative to: A. Siluro-Devonian granitoids (note northeast trends) and greenschist facies retrograde metamorphism; B. Isotopic and fluid inclusion sample localities (C: Cumberland, NZ: New Zealand, SM: Spero Meliora, KM: Knights of Malta, I: International, DG: Dividend Gully, MH: Mount Hogan), and data (14.1 :^{18}O quartz, 200^0 :fluid incl. homog. temp., Kidston fluid incl.data from Mustard,H.,1984, Geol.Soc.Aust.Abstr.12,394-5).*

Many of the gold-quartz vein deposits of the Wenlock, Coen, Hamilton, Potallah, Alice, Woolgar, and Charters Towers goldfields are similar to the Etheridge deposits in size, nature, probable age, and geological setting, and may thus also be related to the emplacement of Siluro-Devonian granitoids in north Queensland. They have many features in common with the gold-quartz vein deposits of the western Sierra Nevada foothills of California ("Mother Lode type").



3. Schematic model for the environment of ore formation. Zone A: 400Ma 'I-type' batholith in associated greenschist aureole; Zone B: fractured zone of maximum uplift differential, and protruding 'ribs' from the main batholith. Highest probability of gold deposits is in zone B where transverse 'ribs' encounter a suitable host lithology. Zone A is deeply eroded, mostly as a result of uplift associated with emplacement of the batholith.

GOLD-COPPER MINERALISATION IN THE LOWER DEVONIAN I-TYPE BANIMBOOLA QUARTZ DIORITE, NORTHEAST VICTORIA.

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INTRODUCTION

The Banimboola Quartz Diorite (Bolger et al., 1983) is a Lower Devonian I-type granitoid, approximately 8 km in diameter and located 300 km northeast of Melbourne at Granite Flat, adjacent to Dartmouth Dam. The granitoid is grouped with a number of geochemically similar intrusions known as the Boggy Plain Supersuite (Wyborn et al., 1987) and is cut by various fractures, containing quartz, minor gold, and base metal sulphides which are possibly cogenetic with the late-phase aplite intrusives. Mining during the last century and the early part of this century concentrated on both colluvial deposits derived from the weathered granitoid and on the base metal fissures within the intrusive.

GEOLOGICAL SETTING

The Banimboola Quartz Diorite constitutes the southern extension of a number of Lower Devonian I-type granitoids and volcanics grouped together as the Boggy Plain Supersuite. Representatives of the Supersuite occur in a north-south trending belt over 500 km in length in the Central Lachlan Fold Belt.

The Banimboola Quartz Diorite intrudes Upper Ordovician metasediments and occurs within the Benambra gold metallogenic province (Ramsay and Willman, 1988). This province tends to be characterised by gold mineralisation containing high silver values, high sulphide contents, and high base metal contents. The intrusive is a medium grained granitoid with a high mafic content (30-40%) which is generally homogeneous and lacks a foliation. Plagioclase laths to 4 mm length are set in an assemblage of hornblende, ortho- and clinopyroxene, and biotite all varying to 3 mm in length with interstitial quartz and orthoclase. Felsic bodies within the pluton contain plagioclase phenocrysts to 3 mm (10%) set in a fine grained matrix consisting of approximately equal proportions of quartz and orthoclase. Wyborn et al. (1987) report the presence of quartz-tourmaline nodules up to 5 cm across within a leucogranite core.

MINERALISATION

Mineralisation within the Banimboola Quartz Diorite is structurally controlled and comprises auriferous quartz-sulphide fissure veins and breccias, with or without carbonate. Two vertical fissure vein sets (90-100° and 140-160°) attain widths up to 2 m. Alteration zones surrounding these fissures attain widths of 20-30m.

Breccias and veins, which appear to have undergone several phases of mineralisation, contain abundant sulphides with pyrite (to 50%) and chalcopyrite (to 30-40%) being the most common. Sphalerite, galena, tennantite?, and bornite are present in lesser amounts. Gangue includes quartz, sericite, siderite, and chalcedony. Alteration includes quartz-sericite, epidote, and actinolite-sericite-clay mineral assemblages.

Narrow auriferous quartz veins containing pyrite and chalcopyrite occur along the margins of aplitic dykes and intrusions at several localities striking 090-100°. Regional soil geochemical surveys suggest a spatial relationship between aplitic intrusions and gold mineralisation within the Banimboola pluton.

GRANITOID GEOCHEMISTRY

Analyses of the Banimboola Quartz Diorite indicate that the bulk of the composite pluton is high in total Fe, Ti, Mg, Mn, Ca, Ba, V, Cr, Co, Ni, and Cu in comparison to the average Lachlan Fold Belt I-type granitoid (White and Chappell, 1983). High absolute levels of Mg, Cr, Ni, Co together with K, Ba, Rb, Th support an origin from an incompatable element-rich mafic source. (Wyborn et al., 1987). Harker variation diagrams for the elements Fe, Mg, Ni, V, Mn, P suggest compositional variation through fractional crystallisation in contrast to restite unmixing as proposed for other Lachlan Fold Belt magmas.

SUMMARY

The Banimboola Quartz Diorite is a Lower Devonian I-type granitoid possibly derived through partial melting of a mafic incompatible element-rich lower crustal source. This composite pluton forms the southern member of a sequence of intrusions which stretch for over 500 km north to Dubbo.

Two fissure vein sets containing gold and base metal sulphides are developed on the western flank of the granitoid. Alteration includes quartz, sericite, epidote, and actinolite.

The mineralising fluids are envisaged as representing late-phase derivatives derived from the aplitic intrusives, which are assumed to be cogenetic with the pluton.

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GOLD BEARING ARSENOPYRITE ORES SPATIALLY ASSOCIATED TO THE MARCHE-COMBRAILLES SHEAR ZONE (MASSIF CENTRAL, FRANCE) : GEOLOGY AND GENESIS.

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The Combrailles area (north-western part of the French Massif Central) (fig. 1) is characterized from the Devonian to Carboniferous times by major magmatic, hydrothermal and tectonic activities, which are spatially associated with the Marche-Combrailles shear zone. Au-As-Sb deposits occur within highly faulted zones which crosscut the Visean basins and their surroundings. Three stages of different metallogenic importance have been recognized in the Villeranges district (Boiron, 1987) (table 1) :

1 - The whole Visean basin and at a lesser degree the surrounding rocks (the Gueret granite and anatexites) are affected by an early alteration process characterized by the following mineral assemblage (1) : chlorite-albite-anatase (± quartz, calcite, phengite, pyrite). Alteration result from a pervasive circulation of aqueous fluids, having low salinities (1-4 wt. % eq NaCl) at temperatures around 250-310 °C.

2 - Late tectonic reactivation of the Marche-Combrailles shear zone around 300-315 Ma produced strong macro- and microfracturing in the Villeranges basin as well as in the surrounding rocks, and favoured intense circulation of hydrothermal fluids. Solubilization, transport and deposition of metals by these fluids occured together with specific rock alteration along faulted zones.Different stages have been distinguished :

- discrete crystallisation of a pyrrhotite - calcite - ankerite (± galena - sphalerite - chalcopyrite) assemblage occured in chloritized tuffs in small veins. Pyrrhotite which is considered as an early Au-bearing phase (preore stage) in some instances, is not at Villeranges since its Au content is no higher than 50 ppb.
- strong hydrothermal processes affected faulted zones on several meters to few centimeters. It produced the alteration of the first assemblage (1) into the following one : phengite + ankerite + quartz + pyrite. Fluids associated to this stage have low salinities, and temperature was around 240 ± 30 °C.
- then, a diffuse network of quartz + ankerite veinlets crystallized together with the gold mineralization which consists of pyrite + auriferous arsenopyrite (fig. 2 A).
- final opening of faults and crystallization of massive stibnite ended the ore stage.

Ore fluids are purely aqueous solutions having low salinities (< 3 wt. % eq. NaCl) and provoked a complete alteration of the previous mineral assemblage into an illite + quartz + ankerite association. Arsenopyrite deposition occurred at temperatures around 180 ± 20 °C (fig. 2 B), at low pH as indicated by the complete alteration of the host rocks into a quartz - K-micas - ankerite association, at rather low fO_2 around that fixed by the pyrite - arsenopyrite - pyrrhotite triple point and the Ni- NiO oxygen buffer (Boiron et al, 1988) and high fS_2. Gold deposition results probably from a destabilization of Au-bisulfide complexes during the sulfide crystallization. Arsenopyrite crystals present strong heterogeneities in the gold distribution, and are characterized by important enrichments either at their periphery or within microcrack networks affecting their whole mass.

3 - Low temperature (T = 90 ± 20 °C) fluids circulated at last within the deposit during more discrete reactivation of the system, and are responsible of the crystallization of calcite and quartz, as late infillings of veins and tension cracks.

Thus, the Au-As-Sb ores in the Villeranges area result from a single hydrothermal sequence. Gold deposited at a combined state within sulfides (arsenopyrite and at a

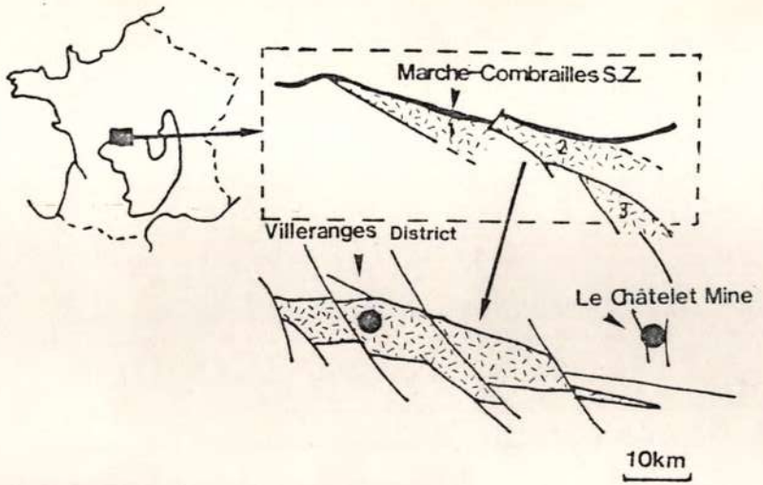


Fig. 1 : Schematic map showing the location of the Au occurences (●) and of the three Visean basins. (1 : Ladapeyre, 2 : Villeranges, 3 : Chateau sur Cher) spatially associated to the Marche-Combrailles shear zone (North-western part of the French Massif Central)

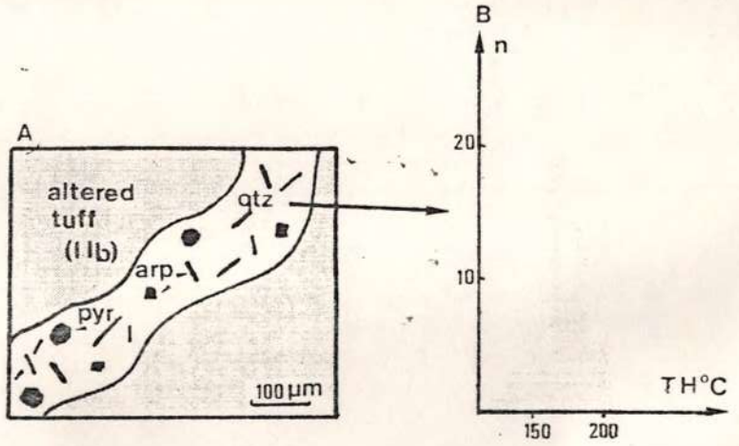


Fig. 2 : A, Microscopic aspect of an ore bearing veinlet : quartz and ankerite veinlets constitute a diffuse network within the altered tuff (mineral association IIb : quartz - illite - pyrite - ankerite). Veinlets result from synchronous crystallization of quartz -auriferous pyrite and arsenopyrite. B, Histogram of the homogeneization temperatures of primary fluid inclusions hosted by the Au-ore bearing quartz.

lesser degree pyrite) from aqueous fluids, in opened microfaulted zones. Such ore genesis is significantly distinct from other ones which characterized the gold bearing quartz veins described in the French Massif Central (Hubert, 1986, at Le Bourneix for instance). Main differences are :

- the large scale and the remarkably regular features of the ore deposition along the Marche-Combrailles zone. Parageneses, fluid characteristics are for instance very similar at Villeranges or Le Chatelet deposit in spite of small differences in temperatures of the ore deposition (180-280°C at Le Chatelet, this work confirming partly the data from Zappettini, 1983) ;
- the lack of multistage Au-ore deposition, and especially the lack of late reworkings of the Au-bearing sulphides which could have yielded to the Au-release and a consecutive enrichment in Au (as native gold for instance) ;
- the relatively low temperatures (170-250°C) of the Au deposition compared to those generally found in Au-bearing quartz veins.

STAGE I	Regional extension	chlorite - albite - anatase ± quartz ± calcite ± pyrite	280 ± 30 °C
STAGE IIA	Faulted zones	phengite - ankerite - pyrite	240 ± 30 °C
STAGE IIB	Mineralization	illite - ankerite - quartz a) auriferous pyrite and arsenopyrite b) stibnite	180 ± 20 °C
STAGE III		calcite - quartz	90 ± 20 °C

Table 1 : Recapitulative table of the different alteration stages which affected the Marche-Combrailles formations in the Villeranges district.

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GEOLOGICAL CHARACTERISTICS OF JIAPIGOU GOLD DEPOSITS, A TYPE OF LATE REWORKED DEPOSIT IN ARCHEOZOIC STRATA

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Occurring in Archeozoic Anshan Formation, the spatial distribution of gold deposits in Jiapigou is apparently controlled by fault system. The Anshan Formation is composed mainly of injection gneiss, biotite plagioclase gneiss and plagioclase amphibolite with magnetite-quartzite intercalations. Metamorphically, it belongs to amphibolite facies, with the plagioclase amphibolite being converted from tholeiite and the gneisses are originally calc-alkalic volcanic and volcano-sedimentary rocks formed 3100 Ma ago.

The ancient strata in this area have undergone repeated regional metamorphism and migmatization, accompanied always by extensive magmatisms. Based on isotopic age data at least nine episodes of tectonism can be recognized at 2800Ma, 2600-2400Ma, 2000-1800Ma, 1400Ma, 1000Ma, 700-500Ma, 270-230Ma (Hercynian), 180-120Ma (Yenshanian) and at Himalayan. Magmatism is found in association with most of these tectonic activities except for those at 2800 and 1400Ma. The tectonisms at 2000-1800Ma and Hecynian episode are the best developed. The former was responsible for the intensive metamorphism (reaching to amphibolite facies) of the Anshan Formation, which is unfavorable for the development of metamorphic rock type gold deposits. The latter led to extensive emplacements of granite and basic-ultrabasic rocks thus mobilizing the gold in metamorphic rocks, resulting eventually in the formation of gold deposits. The multiple episodes of tectonism, regional metamorphism, migmatization and magmatization indicate that Jiapigou gold ore field is tectonically localized in an activation zone within platform.

Detailed studies show that the ore-forming components are derived for the most part from the Archeozoic Anshan Formation and partially from the granites, as evidenced by the following observations:

(1) Ore lead in most deposits of Jiapigou area is ancient normal lead with modal ages between 1000-1400Ma which are consistent with the modal ages of lead in the metamorphic strata (1000Ma) but greatly different from those of the Hercynian and Yenshanian granites. It is clear, therefore, that ore lead was in most cases derived from the metamorphic rocks of Anshan Formation with only a few exceptions, such as Hongqigou deposit where lead ages range from 2000 to 1200Ma indicating a mixing of lead provided by the late granites and those from the strata.

(2) Sulfur has been isotopically homogenized to a great extent throughout the area. $\delta^{34}S$ of the ore-forming system is similar to that of Anshan Formation, being close to meteorite sulfur. This indicates that ore sulfur was mainly derived from the Anshan Formation which is originally volcanic rocks. In addition, sulfur isotopes show clear regional fractionation, reflecting the influence of late reworking hydrothermal solutions.

(3) Regular variations can be recognized in the ratios of Ag/Au, Ni/Co, S/As, Pb+Zn/Cu, Ti/Cr and Zn/Pb between the ore and the metamorphic rocks, suggesting a genetic link between them.

(4) As indicated by REE data (Wu Shangquan), gold is for the most part derived from the metamorphic rocks and the granite and gold-bearing veins were probably formed from the remelting (and differentiation) of the Anshan Formation.

(5) With a gold abundance about ten times higher than the average concentration in the curst, the Anshan Formation is highly probably the source bed of gold for the deposits.

Further evidence supporting an origin from the surrounding Anshan Formation for the ore-forming solutions comes from fluid inclusion studies. The CO_2/H_2O, Ca^{++}/Mg^{++}, HCO_3^-/Cl^- ratios and total ionic concentration and oD of inclusion fluids in quartz from the ores are similar to those obtained from the strata but differ a good deal from those measured from granites.

The Hercynian granite and gold-bearing veins are syntectonic products. The close similarity in oD values of inclusion fluid water from the granite and the gold-bearing veins to those from the metamorphic rocks of Anshan Formation indicates that the hydrothermal water may have originated from the Anshan Formation. In addition, similar REE patterns are also noticed between the granite and the metamorphic rocks (Wu Shangquan), suggesting a genetic link between them. Therefore, it can be said with some degree of confidence that the Hercynian granite and gold-bearing veins may have resulted from the remelting, or subsequent differentiation process, of the Anshan Formation at some later stages.

The gold deposits in Jiapigou were formed during the Hercynian as is evidenced by: (1) The ore veins cut through not only Archeozoic and Proterozoic strata and the 700-500Ma granite but also the strata of middle and late Paleozoic ages. (2) Mutual crosscutting is commonly observable between the ore veins and a large number of isotopically dated Hercynian dikes (syenite porphyry, diorite-porphyrite, diabase, aplite and etc.). For example, as observed in Erdaogou, a gold-bearing quartz vein cuts the Hercynian granodiorite (268Ma) and is transected by aplite dike (228Ma). (3) An age of 161Ma has been obtained from potash feldspar in the gold-bearing quartz vein (Wang Yiwen) but is considered by the authors slightly lower than should be. (4) The gold-bearing quartz veins are apparently later than the quartz veins formed during regional metamorphism in Anshan Formation as evidenced by the wide differences between them in vein attitude, mineral compositions, quartz characteristics and alteration.

Divergent opinions exist regarding the genesis of Jiapigou gold deposits, represented mainly by the Hercynian magmatic hydrothermal origin and the Precambrian metamorphic hydrothermal origin. As can be seen from the previous discussion, the relationship between the Hercynian granite and gold-bearing veins are that of brotherhood rather than that of parentage, and it is inappropriate to assign them to magmatic hydrothermal deposits. On the other hand, the gold-bearing veins were formed during a period of late tectonic activation when regional metamorphism had long been ceased. In this regard, therefore, the deposits are not of a metamorphic hydrothermal origin.

As is known the typical regional metamorphic hydrothermal gold deposits in Archeozoic greenstones, such as those in South Africa, West Australia and Canada, are found in stable shields and are characterized

by low grade metamorphism (greenschist facies), by quartz veins carrying little sulfides, by an assemblage of pyrite, pyrite-pyrrhotite and tellurides, by great vertical extension (sometimes attending a depth of 3 km while showing no signs of branching), by high Au/Ag and high grade of gold as well by isotopic ages ranging from 2400 to 2500 Ma. In contrast, the deposits at Jiapigou occur in activated zones of platform, with high grade metamorphism (amphibolite facies) and with sulphide-bearing quartz veins as the main type. They are characterized by a mineral assemblage of multi-metal sulphide-tungstate, by limited vertical extension (generally less than 0.5km), by vertical zoning in terms of $o^{34}S$, homogenization temperature of fluid inclusion, and metal concentrations, and by lower gold grade and Au/Ag ratio. All these features reflect that Jiapigou gold deposits are relatively younger in age. In addition, as has been pointed out, the ages of ore lead are younger than the metamorphic age of the metamorphic rocks but are mostly older than the hydrothermal events. Therefore, it can be stated that Jiapigou gold deposits have a different origin from those in stable Archeozoic strata in the world although all of them are hosted in Archeozoic greenstones.

In summary, the gold deposits in Jiapigou area are a type of reworked gold deposits which have their ore-forming components derived mainly from the ancient gold-bearing strata and were formed in response to the tectonic activation at a later stage after the metamorphism-migmatization. The gold deposits and the Hercynian granites in this area are syntectonic products, with both of them have their sources from the Anshan Formation and the gold-bearing veins localized at higher levels than the remelting granites.

SKARN HOSTED GOLD COPPER MINERALISATION AT BROWNS CREEK, NEW SOUTH WALES

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INTRODUCTION

The Browns Creek gold mine is situated 8 km west of Blayney, New South Wales. The deposit was probably discovered in the 1870's and is estimated to have produced about 60,000 oz of gold before mining ceased in 1914. The current phase of mining operations began in 1980. Between 1980 and 1985 the mine produced approximately 14,000 oz of gold. Gold production is currently 20,000 oz per annum at an average head grade of 4.5 g/tonne

REGIONAL SETTING

The Browns Creek gold mine is located within the Molong Rise in the northern part of the Molong-South Coast Anticlinorial Zone, an Ordovician and Silurian tectonic unit defined by the New South Wales Geological Survey (Markham and Basden, 1974). This tectonic unit is bounded to the east by the Hill End trough and to the west by the Cowra-Yass Synclinorial Zone (Fig. 1). Ordovician and Silurian sediments and volcanics of the Molong Rise have been intruded by a series of Silurian and Devonian granitoids. All these Palaeozoic rocks are overlain to the north by the partly eroded remnants of an alkaline shield volcano, represented byTertiary basalts, hawaiites and trachytes of the Canobolas Complex (Middlemost, 1981). Regional metamorphism is low grade (prehnite-pumpellyite facies).

LOCAL GEOLOGY

Gold mineralisation at Browns Creek occurs in skarns and clay zones developed close to the contact between the Cowriga Limestone and the Long Hill Diorite. In the mine area, the Ordovician volcanics form part of the Angullong Tuff and consist dominantly of pyroxene porphyritic, andesitic lavas and tuffs with minor volcanic breccias. A thick unit of limestone, known as the Cowriga Limestone (Bowman et al, 1977), occurs within the volcanic sequence.The limestone forms a triangular inlier in the hinge zone of an open anticlinal structure which plunges gently north-northeast. The limbs of this anticline dip at approximately 45 north and northeast and are cut by several northerly trending faults. The limestone is generally a very pure, massive, coarsely recrystallised calcite rock. Primary textures are poorly preserved. It lies conformably within the andesite sequence and is truncated to the south by faults and the granodiorite. The Long Hill diorite is a somewhat variable, granodiorite phase of the Carcoar granite. Petrological information presented by Burnham (1977), suggests that this is an I-type granite. Numerous dykes and sills of granodiorite intrude the andesite-limestone sequence. All rock types are cut by a series of thin north-trending aplitic dykes.Solution - weathering in the upper levels of the limestone has been intense and has resulted in the formation of solution cavities and karst - collapse breccias (some auriferous).

ALTERATION AND SKARN FORMATION

Skarn formation at Browns Creek appears to have been controlled both by structural features and by lithological contacts. In detail, skarn formation is not controlled by the margin of the granodiorite. The skarns are mineralogically variable and show several phases of prograde and retrograde development. Gold and copper mineralisation appears to post date most of the skarn formation and occurs preferentially in wollastonite-rich skarns.

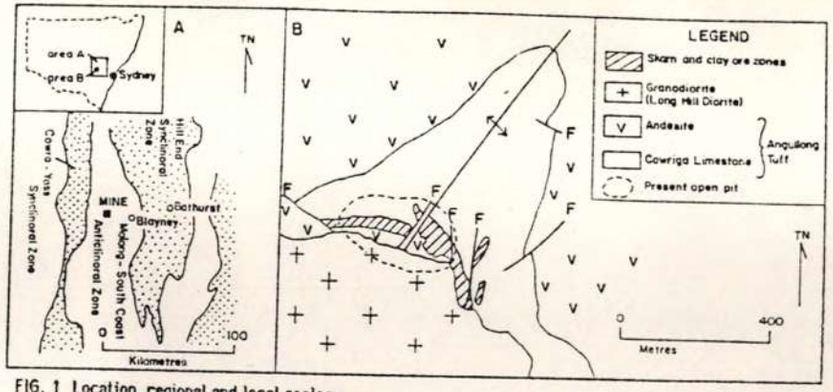


FIG. 1 Location, regional and local geology

The skarns can be divided into two broad types; stratabound skarn and vein skarns. The *stratabound skarn* is developed along the basal limestone - andesite contact. It occurs on both sides of this surface, replacing both limestone and andesite. Skarn derived from the limestone is characterised by assemblages of calcite, garnet and wollastonite with accessory quartz epidote and hedenbergite. Garnet (grossularite-andradite) occurs as large euhedral porphyroblasts which may show concentric zoning. Mineralogical banding is common and may be planar, strongly contorted or concentric. Towards the hanging wall, skarn development becomes patchy and restricted to veins. Stratabound skarn derived from andesite is generally wollastonite - rich and calcite poor. It is generally massive, consisting of interlocking sheaves of coarse wollastonite with accessory diopside, hedenbergite, vesuvianite, epidote and quartz present as scattered grains. Euhedral garnet is rare. Some finer grained varieties exhibit banding perpendicular to the long axis of the wollastonite fibres. This banding is defined either by wollastonite crystal boundaries or by compositional variations. Small lenses of banded pyrrhotite-arsenopyrite-quartz-diopside rock have also been noted. Zoning is observed towards the footwall of the stratabound skarn. The wollastonite zone is underlain by, and replaces, massive garnet.- hedenbergite skarn which is in turn underlain by bleached porphyritic andesite in which both groundmass and original pyroxene phenocrysts have been replaced by fine grained granular diopside, minor garnet and vesuvianite. The bleached andesite extends for a few centimetres along fractures into the underlying unaltered andesite. This zonation reflects an increase in Ca and SiO_2 and decrease in Na, K, Fe, Mg, and Al from the footwall andesite towards the relic limestone - andesite contact. These marginal skarn zones are generally only weakly mineralised. The *vein skarns* occur as northerly - trending subvertical zones of alteration formed in the limestone adjacent to faults or andesite dykes. They vary in width from a few centimetres up to 15 metres and are mineralogically and texturally similar to the stratabound skarns. The vein skarns identified to date have short strike lengths but are of much greater vertical extent. The vein skarns probably formed in localised, structurally controlled areas of high fluid flow, or greater permeability. The experimentally determined univariant P_{CO_2}-T curve for the reaction $CaCO_3 + SiO_2 = CaSiO_3 + CO_2$ (Harker and Tuttle, 1956) indicates that most of the skarn was probably formed at temperatures of 600°C or higher.

Retrograde skarn alteration has been observed in discrete areas. Dark green actinolitic amphibole occurs as veinlets replacing wollastonite skarn and locally in massive lenses. Retrograde chlorite has been reported by Taylor (1983). The volumetrically and economically most significant retrograde mineral phase is nontronite, an hydrated iron - aluminium silicate of the montmorillonite group. The nontronite occurs along the margins of large rounded boulders of wollastonite skarn, in the interstices between these relic cores of skarn and in narrow, faulted-controlled (?) shoots. It is a distinctive variegated or banded clay, commonly containing relic garnet grains and nodular accumulations of chalcedonic silica (informally referred to as "jasper"). It is ubiquitously rich in

gold (> 10 g/tonne) and was the main target of mining during the last century. The nontronite possibly replaced retrograde amphibole or chlorite, its restricted occurence indicating a much lower throughput of metasomatic fluids than occured during prograde skarn formation.

CLAY LODES

Clay hosted mineralisation forms a significant part of the Browns Creek deposit. Three types of clay ore are recognised:

i) Nontronite zones as described above, interpreted to have been formed by retrograde alteration of skarns.

ii) Massive clay zones in the upper levels of the deposit, probably formed by in situ weathering of skarn. The clay species have not been identified, however, the clays are texturally different to the nontronite.

iii) Clay breccias. These breccias are widespread on top of and adjacent to the limestone. They consist of very poorly sorted angular fragments of clay-weathered andesite, granodiorite or skarn, irregular masses of jasper and scattered large karst-weathered limestone boulders. The breccias are mineralised where weathered skarn is present as fragments and matrix material. Torrey et al. (1986) have described similar mineralised breccias at Red Dome, Queensland. Wollastonite in cobbles and boulders is altered to a cream coloured silicate that in part pseudomorphs the wollastonite. The mineral is xonolite, an hydrated calcium silicate. Boulders of massive pyrrhotite-arsenopyrite with skarn silicates have also been mined from clay breccias. A feature of one section mined in 1985 was the occurence of secondary marcasite, pyrite and associated iron sulphates, representing the transition zone from oxidising to reducing conditions The breccias are generally unstratified, however, sand and silt size laminae are locally present. Fragment types indicate very local derivation of much of the breccia. The close association of clay breccias and karst weathered limestone and the presence of disorientated blocks of bedded clay breccia indicate that much of the brecciation may be the result of repeated collapse during intense weathering. Some clay breccias, however, are texturally similar to "explosion breccias" and may have been formed in zones of forceful fluid injection. The role of supergene versus hypogene development of the clay breccias has overall not been clearly established.

MINERALISATION

Gold mineralisation occurs in two ore types, gold in the skarn and that associated with the clay lodes. The primary ore is skarn hosted and is closely , but not exclusively, associated with copper-iron and copper sulphide minerals. Clay lode ore has strong relationships to skarn and jasper (altered skarn) rock fragments in the various clay types. The best gold grades in clay ore are found in the nontronite variety. Minor titanomagnetite and rare scheelite have been observed.

The wollastonite-rich ore is characterised by clumps of sulphides, mainly bornite up to 2 cm diameter with inclusions of chalcopyrite, set within the rosettes of the calcium silicates or cross-cutting veiniets. The copper bearing sulphides in the garnet-hedenbergite skarn are more diffuse but some veins and clumps of 1 cm are seen. In more oxidised examples bornite occupies the central portions of the veins and is replaced by the copper sulphides. EMPA analyses of bornites showed the species to be a sulphur-rich variety. Sulphur rich bornite, first described by Brett and Yund (1964), is a feature of low temperature sulphide generation by either direct precipitation (Yund and Kullerud, 1966) or supergene reactions (Durtizac et al, 1970). In more weathered examples the typical exsolution laths of chalcopyrite are seen. The bulk of the bornite in the bornite ore appears to be sulphur-rich. The skarn related, sulphide boulders in the clay ore consist of pyrrhotite and arsenopyrite. They are cut by veins of chalcopyrite showing the assemblages pyrrhotite-arsenopyrite-pyrite to be earlier than chalcopyrite-bornite. The bismuth telluride hedleyite was found in these chalcopyrite veins. There is also some gold in the jasper (altered skarn).

Native gold occurs in fracture filling veins associated with bornite, copper sulphides, chalcopyrite, and hessite (Ag_2Te). Gold is also found in small fractures through the skarn without

sulphides, but this is a less common occurrence. Hessite is intimately associated with the gold. It is either in contact with the gold grains or lies in fractures that run to the boundaries of the gold/sulphides. Both gold metal and hessite may be younger than the copper mineralisation.Tellurium is present in the gold confirming an intimate association between gold and tellurium bearing minerals. The amount is estimated to be >1000ppm Te and in some samples up to 5000pm. The presence of hessite in association with gold is indicative of formation at relatively low temperature, the silver telluride species having a temperature of formation of approximately 200°C (Vaughan and Craig, 1978).

A proportion of the gold in the clay lode was "weathered" in that the grains were rimmed by a redder gold metal that proved to be up to 98% gold, 2-5% copper, and trace to absent silver. EMPA analyses of "normal" gold showed it to be on the whole 73% gold, 1-2% copper and the remainder silver., but the composition varied up to 85% gold, 1-2% copper, and 13-14% silver. There is, thus, hypogene and supergene gold in the deposit and the difference between the two is the loss of silver, and a relative rise is copper. There are also inclusions of fine silica in some of the gold grains.

Overall although the gold mineralisation at Browns Creek is hosted by skarns, the mineral assemblages and paragenesis indicate the gold to be a lower temperature overprint on the original skarn. This may well be a part of retrograde metamorphism, but it could also be a later hydrothermal event not necessarily related to the skarn-forming event. More work is necessary to clarify the timing of the mineralisation.

ACKNOWLEDGEMENTS

The management of BHP Gold Mines Limited is thanked for their support and permission to publish these findings. Mr Michael Hickey, the previous owner, commissioned the first mineralogical studies and encouraged the early research. Paul Meszaros and Mike Garman contributed to the early studies, and are thanked for their contributions. John Surman has provided important observations based on his work at the mine and is thanked for his valuable contribution to discussions. CSIRO Division of Exploration Geosciences is thanked for permission to use data generated by their CAMECA Electron Microprobe. Tony Ramsden and David French are thanked for their contributions.

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GOLD MINERALIZATION IN THE MONTE ROSA DISTRICT, NW ALPS

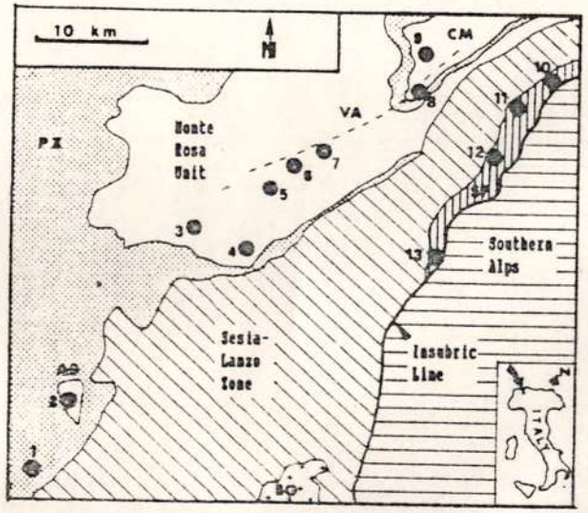
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The Monte Rosa area comprises one of the main gold district of the Alps, with a total production of not less than 20 tons gold. Mining activity was significant till 1961, and new exploration programs were carried out in recent years (Leonardelli, 1986). There is an abundant literature on the district, summarized e.g. in Diamond (1986) and Curti et al. (1987).

Geologically, the area belongs to the Western Alps (see e.g. Dal Piaz et al., 1972), and is characterized by several tectonic units overthrusted during the Alpine orogeny (Fig. 1).

The mineralization consists of quartz-Au-sulfide veins, occupying dilatant fractures and/or shear zones, hosted by diverse tectonic units (Fig. 1). Their spatial distribution is apparently controlled by two main factors:
- a tectonic control, represented by late-Alpine tectonic structures (Insubric Line and Vanzone antiform);
- a lithostratigraphic control, represented by polymetamorphic Hercynian granites and pelitic/psammitic sediments of the Pennidic crystalline basement (Arceza-Brusson, Monte Rosa and Camughera units).



AB = Arceza-Brusson window;
BG = Biella intrusion (Tertiary)
CM = Camughera-Moncucco zone;
PI = Piemontese ophiolites and metasediments;
SP = Scisti di Fobello-Rimella;
VA = Vanzone antiform;
Mineralizations:
1,2 = Val d'Ayas
3,4 = Val Sesia
5-7 = Valle Anzasca
8 = Val Bianca
9 = Valle Antrona
10 = Vogogna
11 = Val Toppa
12 = Val Segnara
13 = Campello Monti

Fig. 1 (simplified after Curti, 1987)

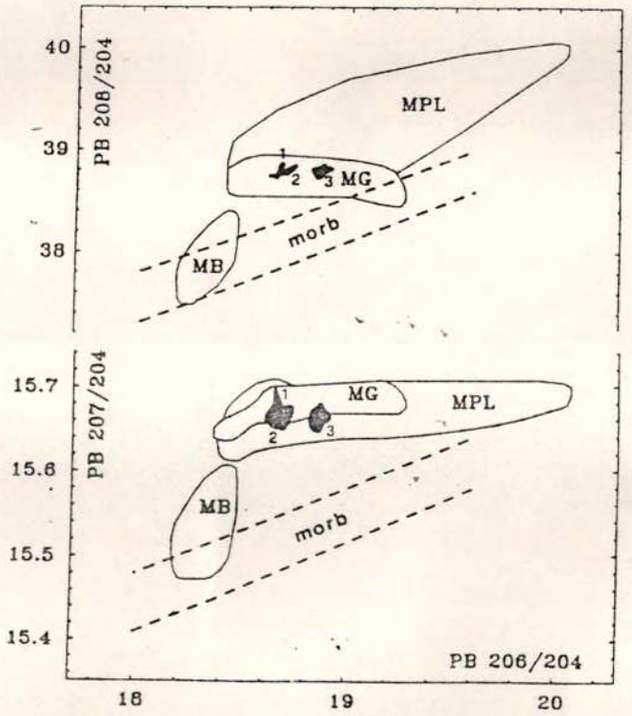
The Alpine metamorphism in the area is polyphasic, and peaked in the greenschist to amphibolite facies about 38 m.y. B.P. Field evidence and radiometric data (V. Ayas: Diamond, 1986) suggest that gold deposition postdates the metamorphic peak, and is associated with retrograde metamorphism.

Gold (and/or electrum) occurrence is mostly microscopic to submicroscopic, typically in strict association with sulfides (chiefly pyrite, arsenopyrite and galena). Pyrrhotite, sphalerite, chalcopyrite, scheelite and a variety of Ag-As-Bi-Sb minerals may also be present.

Quartz is the dominant gangue mineral, accompanied by variable amounts of carbonates, sericite, chlorite and other silicates. Wall rock alteration may be remarkable to moderate.

Pb-isotope data for ore minerals (Curti, 1987) define two distinct fields (fig. 2). The values for Val Toppa, Val Sesia and Val d'Ayas largely overlap, whereas the samples of Valle Anzasca are distinctly enriched in ^{206}Pb.

By comparison with the Pb-isotope signatures of various lithotypes in the area (Fig. 2), the Paleozoic metapelitic sediments and metagranites appear the best candidates as source beds for Pb (and, by inference, for Au) for all mineralizations.



MG = metagranites of Pennidic basement

MPL = metapelites of Pennidic basement

MB = metabasalts of the Piemontese zone

morb = mid-ocean ridge basalts

Black areas = ore lead (1 = V.Toppa, 2 = V.Sesia-V.Ayas 3 = V.Anzasca)

Fig. 2 (modified after Curti, 1987)

Most $\delta^{18}O$ values for vein quartz (Curti, 1987) fall between +13.5 and +15.5 per mil, suggesting equilibration of the ore-forming fluids in a metamorphic environment. Values for Val Toppa are distinctly lower (11.4 to 13.3 per mil), and were interpreted as evidence of contributions of unexchanged meteoric waters.

Fluid inclusion studies (Diamond, 1986; Curti et al., 1987) show that at district scale the ore-bearing fluids were of relatively similar nature, consisting of CO_2-bearing, moderately saline brines. They however were trapped under diverse conditions for each specific locality (Table 1).

Table 1 - Estimated compositions and trapping conditions of fluids in inclusions associated with gold mineralization of Monte Rosa.

	V. Anzasca	V. Toppa	V. Sesia	V. Ayas
X_{H_2O}	.90	.91	.87	.91
X_{CO_2}	.08	.08	.11	.06
X_{NaCl}	.02	.01	.02	.03
T, °C	400-450	300	350	300
P, kb	1-1.5	2	3?	1.2

The genesis of mineralization has been related to late-Alpine intrusive activity (Huttenlocher, 1934; Stella, 1943), the closest known manifestation of which is however not less than 20 km away from the mineralizations (Fig. 1). Field, isotopic and fluid inclusion evidence may be used to suggest that the ore-forming fluids were generated by metamorphic reactions within Paleozoic metapelites and metagranites, which were the most likely source of ore lead. Mass balance calculations (Curti, 1987) demonstrate that derivation of ore gold from the same rocks is also feasible. The differences in isotopic signatures and fluid inclusion characters in different areas of the district suggest that mineralization occurred in response to separate, although essentially similar, events.

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GEOLOGY OF THE WIRRALIE GOLD DEPOSIT, QUEENSLAND

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The Wirralie gold deposit was discovered in March 1986 during follow-up of anomalies from a combined bulk cyanide leach and minus 80 mesh stream sediment sampling programme in the eastern section of the Drummond Basin. The deposit is being developed with initial production scheduled for mid-1988.

Mineralisation occurs in the Upper Devonian - Lower Carboniferous Mount Wyatt Formation which in the deposit area is composed of epiclastic sediments with subordinate interbedded lapilli and crystal tuffs. The sediments consist of reworked volcanic detritus containing variable amounts of carbonaceous material and range from tuffaceous mudstones to cobble conglomerates. Some strata also contain pyritic clasts and possible silica sinters which suggest an early phase of mineralisation contemporaneous with sedimentation and volcanism. At Wirralie the Mount Wyatt Formation is exposed on an isolated hill as an inlier in the Tertiary Suttor Formation.

A network of quartz-chalcedony veins and quartz-breccia veins of at least four generations cut the host rocks. Veins vary from several millimetres up to several metres thick. Adjacent to some of the thicker veins there are breccias which consist of angular, silicified wallrocks set in a quartz matrix presenting in effect a "frozen explosion" fabric. Colloform banding in quartz, chalcedonic silica, fine cockscomb quartz in open vugs, amethystine quartz, bladed quartz replacement of carbonate, multiphase brecciation, as well as geochemical characteristics suggest an epithermal origin for the Wirralie mineralisation.

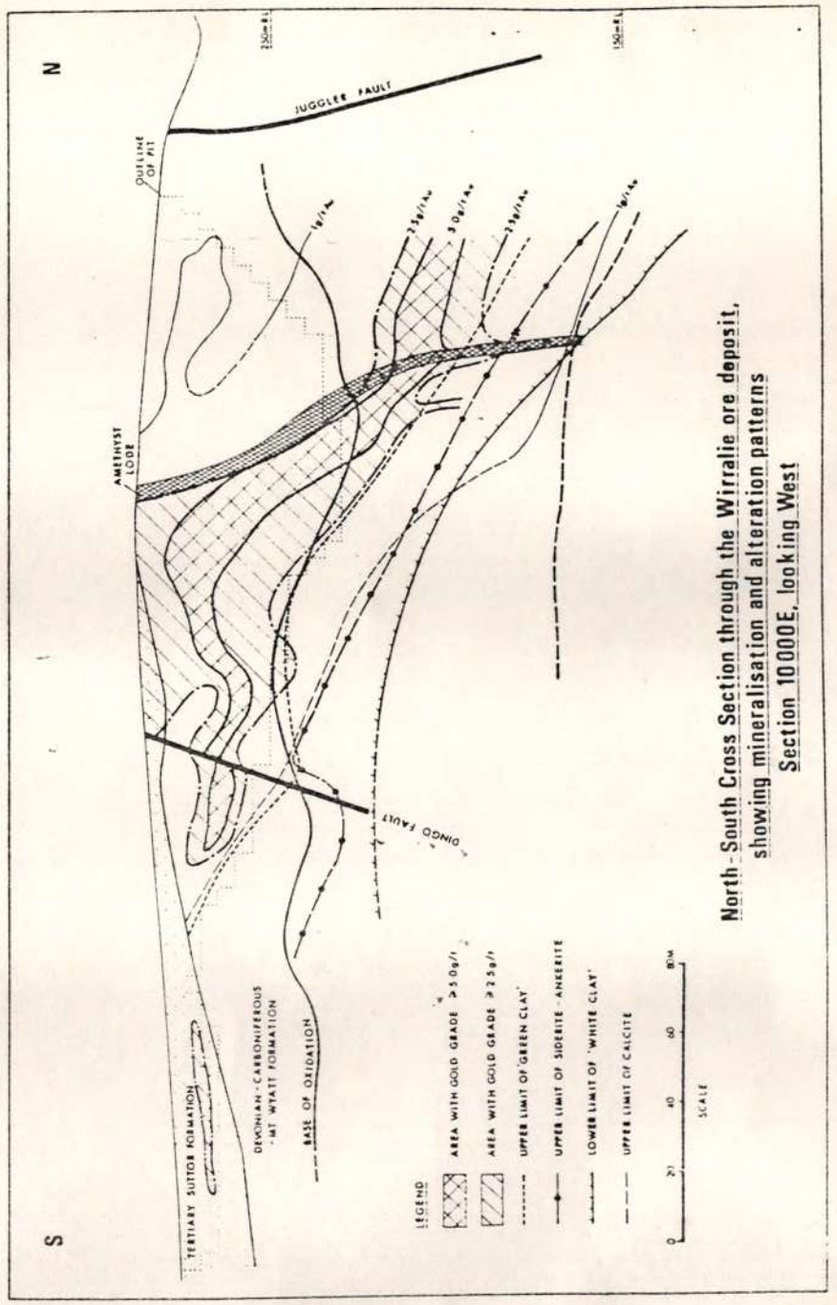
Economic gold mineralisation occurs in a tabular body crudely conformable to stratigraphy which dips northerly at about 25°. The northwest side of the deposit is defined by the Juggler Fault. Post-mineral movement along this northeast - southwest structure truncated the down-dip projection of the ore body. Within the zone of oxidation (weathering) 3.65 million tonnes of ore grading 2.8 grams per tonne gold occur in an area 350 by 125 metres extending from the surface to the base of oxidation (an average of 40 metres). Argentiferous gold (with an average grain size of about 25 microns) occurs in hematite and goethite, along quartz grain boundaries, and in relict pyrite. Gold is fairly uniformly distributed, possibly the result of redistribution during weathering. The gold to silver ratio is about 2.5 to 1. The amount of arsenic, antimony, and

mercury in the oxidised ore varies considerably but average values would be: 270 ppm arsenic, 11 ppm antimony and 0.31 ppm mercury. Rocks in the oxidised zone are rich in illite (with interstratified smectite) and kaolinite and contain variable amounts of quartz and limonite. The titanium minerals variably described as leucoxene, rutile and anatase are common accessory minerals.

Siltstone, sandstone and conglomerate of the Tertiary Suttor Formation unconformably overlie the Devonian-Carboniferous Mount Wyatt Formation. On the south side of the deposit ore-grade mineralisation occurs within the Suttor Formation. This mineralisation is thought to originate by the downslope movement of mineralised fragments during Suttor time in much the same way as mineralised scree has been transported away from the hill in recent times.

Down dip, below the base of oxidation, the mineralised zone persists as a zone of silicification and quartz and quartz-matrix breccia veining. Fine grained sulphides occur both as disseminations and in veins. Within a central higher-grade gold zone (greater than 5 grams per tonne) total sulphide content is 4 to 5 per cent. Peripheral to this zone gold assays are in the 1 to 5 grams per tonne range and total sulphide is approximately 2 per cent. Further away sulphide content as well as gold values gradually decrease. Pyrite is the dominant sulphide and it is generally arsenical. Fine grained bladed marcasite is common especially in the higher grade gold zones. Trace sphalerite (low iron), chalcopyrite, pyrrhotite, and a lead-antimony sulphosalt are also present. Quartz, illite, sericite, minor adularia and accessory anatase are the dominant alteration minerals in the hypogene zone. Gold has only been seen in pyrite and as a free grain in a quartz vein in the sulphide zone. The gold to silver ratio in the sulphide ore is 2 to 1. Arsenic averages about 430 ppm, antimony 7 ppm and mercury 0.9 ppm.

Below the gold zone the host rocks are affected by an alteration phase (possibly celadonite) which gives them a green colour. This colouration affects both epiclastic sediments and pyroclastic rocks and persists erratically above the base of oxidation at the southern end of the orebody. Overprinting this is a zone of "white clay" which occurs as replacement of feldspars, in veins and as fracture coatings. Much of the "white" clay above the base of oxidation is probably supergene but some of that below is hypogene. Disseminated and fracture controlled siderite-ankerite begin to appear 15 to 20 metres below the higher grade gold zone. Calcite appears at depth, filling the centres of open, vuggy quartz-pyrite veins or as discrete veins. There is a vertical zonation in vein assemblages: quartz-limonite±clay in the oxidised zone progressing downwards to quartz-pyrite±clay, quartz-pyrite-ankerite, quartz-pyrite-ankerite±calcite, quartz-ankerite±calcite, and finally just calcite. Carbonate minerals are absent in the oxidised zone.



North-South Cross Section through the Wirralie ore deposit, showing mineralisation and alteration patterns
Section 10000E, looking West

GENESIS OF VOLCANOGENIC EPITHERMAL GOLD-SILVER MINERALISATION, BUDAWANG RIFT, NEW SOUTH WALES

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The genesis of four volcanogenic epithermal Au-Ag deposits located within the Budawang Rift of South Coastal New South Wales, Australia have been investigated (Glaser, 1988). Co-genetic pyrophyllite deposits have also been studied.

Mineralisation is hosted within peraluminous rhyolites which comprise approximately 50% of the bi-modal (rhyolites and tholeiitic basalts) Budawang Volcanic Complex. All mineralisation occurs within the confines of the Budawang Rift of early Late Devonian age, with which mineralisation is temporally related.

The source of Au for epithermal style mineralisation has been studied in detail via Pb isotope studies (Glaser, Gulson & Keays, in prep.), and radiochemical neutron activation methods. The variation in erosional levels throughout the rift region has facilitated incorporation of all basement and rift-related rock types. Chemical tracer studies record a significant depletion of Au and Se in altered basalts relative to less strongly altered co-magmatic dykes and plutons, with ore zone enrichment in Au, Se, and Cr and V. This association, especially high Se, Cr and V in all ores, suggests the source of Au for mineralisation was the mafic component of the Budawang volcanic pile, with Au leached from flows comprising part of the "rock package" subject to hydrothermal alteration. Although Pb isotope tracer studies suggest an Ordovician meta-sediment source for the Pb in the ore zones, it is suggested that the Au in the deposits was derived from the mafic volcanic rocks in the rock package underlying and adjacent to the deposits. The rationale for this belief is that because the meta-sediments constituted a greater proportion of the convection cell systems than the volcanics as well as containing much higher primary Pb contents, they would have swamped out the Pb isotope signature from the basalts.

Based upon geochemical, isotopic, structural and lithologic investigations, the former division of the intra-rift volcanic rocks into three units (Boyd, Comerong and Yalwal Volcanics) has been abandoned, with the adoption of a new name to include all three co-magmatic rocks; the Budawang Volcanic Complex. The name Eden-Comerong-Yalwal Rift has also been abandoned, and the new name, Budawang Rift proposed.

The Pambula, Wolumla, Grassy Gully and Yalwal deposits are each located along the margins of separate rhyolite flow domes, located within cumulo flow dome complexes. All four deposits plus co-genetic pyrophyllite deposits occur along N-S trending faults of similar orientation and are probably genetically related to rift graben faults. The

Pambula and Wolumla deposits, plus at least two proximally located pyrophyllite deposits are situated adjacent to E-W trending cross graben block faults which pre-date rifting but which were reactivated by that event.

Fluid inclusion studied yield temperatures of mineralisation of between 320° and 380°C for the Au-Ag deposits, and 290°C for pyrophyllite. System fluids were highly saline, ranging from 12 to 17 wt.% NaCl equiv. for the Au-Ag deposits, to 9% for the pyrophyllite deposits. Salt species are NaCl dominant with variable amounts of CaCl. No carbon dioxide was documented in fluid inclusions. Depth calculations for mineralisation using the salinity corrected critical path of boiling fluids (most of the intra-rift deposits display evidence of phase separation) yield the following depths: Back Creek pyrophyllite 800-1000 m, Pambula 1200 m, Yalwal 1300 m, Grassy Gully 1450 m, and Wolumla >1600 m.

Ore mineralogy is dominated by electrum which displays a distinct Au:Ag compositional ratio for each deposit, and which conforms to a temperature-depth profile for the suite of deposits, with increasing Ag in the higher temperature deposits (Glaser, 1986). At Wolumla, other Ag minerals identified include native Ag, acanthite, stephantite, antimonpearceite, arsenpolybasite, pearceite, and proustite, cerargyrite, and the very rare selenide minerals naumannite and aguilarite. At Grassy Gully, trace amounts of the telluride minerals hessite and petzite were also identified. Ore associate mineral assemblages include chalcopyrite, galena, sphalerite, chalcocite, chalcostibite, tehtrahedrite, tennantite and arsenopyrite. The bulk of these minerals are co-depositional to electrum. Multiple episodes of pyrite have been identified in all goldfields, and always occur post brecciation and shearing, but pre-electrum and pre-electrum associate mineral deposition. Some pyrites display As and optical zonation patterns.

Ore geochemistry yields a vertical metal zonation pattern among the deposits, with the deepest and highest temperature deposit containing higher concentrations of base metals, Se and Ag. In the shallower deposits, correlation coefficients and metal ratios indicate a decoupling of base and precious metals, and a previously unrecognised behavioural aspect of S and Se in boiling epithermal systems.

Sulphur/Se ratios have been proven inconclusive indicators of magmatic fluid input to epithermal systems, although the high Se in these deposits and demonstrated Se depletion in the volcanic pile do support a volcanogenic gold source regime. It is argued that the demonstrated variations in S/Se ratios, enrichment trends, and correlation coefficients for these two elements between deposits results from temperature variations and phase separation. Consideration of fluid inclusion, ore geochemical and statistical studies suggest that S/Se ratios can be used to identify sustained boiling interfaces in epithermal systems. Samples deposited below the boiling interface have low S/Se ratios while those above it have high S/Se ratios. The fractionation of S from Se can be explained in terms of somewhat different physical-chemical properties of

these two geochemically similar elements: H_2S, which has a lower vapour pressure than H_2Se over a broad spectrum of temperatures, will preferentially partitioned into the vapour phase while Se becomes enriched in the residual liquid phase below the interface. At the same time, with a temperature decrease at the boiling interface, the stability field for H_2Se contracts in favour of deposition of metallic Se.

Lead isotope data does support the co-genesis of all four intra-rift Au-Ag deposits, and the three largest pyrophyllite deposits. When this information is integrated with fluid inclusion data and alteration mineralogy studies, sufficient evidence can be forwarded to support the contention that the current pyrophyllite deposits are the nearer surface manifestations of additional zones of Au-Ag mineralisation not as yet identified.

Alteration mineralogy is dominated by sericite and silica in the cores and adjacent zones associated with ore. This characteristic, in addition to the presence of selenides at Wolumla, a basement Pb source in the ores, absence of enargite and bismuthinite, and rhyolite flow host rock support an adularia-sericite classification as discussed by Heald et al. (1987). The occurrence of pyrophyllite in the two shallower gold deposits, and the presence of co-genetic pyrophyllite deposits near one of these deposits supports an advanced argillic alteration feature in the nearer surface zones of these adularia-sericite type systems.

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THE GLOBE-PROGRESS PROSPECT, REEFTON, NEW ZEALAND

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The Globe-Progress Prospect lies within the Reefton Goldfield where auriferous quartz veins are hosted by persistant, steeply dipping shear zones developed in a NNE-trending belt of weakly metamorphosed Ordovician turbidites (Fig.1). The environment is similar in many respects to the Bendigo Field, Australia.

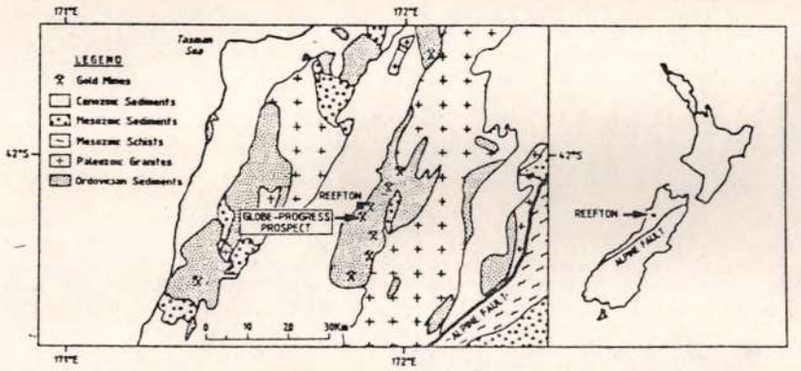


Figure 1. Location Diagram and Regional Geology

Quartz lodes were first discovered in the Reefton Goldfield in 1870. The total reported production to 1951, when the last mine closed, was 67,000 kg (2 Million oz) including 23,642 kg (733,000 oz) from the Blackwater mine (New Zealand's second largest producer) and 13,198 kg (418,000 oz) from the Globe-Progress Mine.

The Globe-Progress Mine was developed on a series of quartz shoots within a major shear which is discordant to the regional structure (Fig. 2). The shoots averaged 12 g/t Au and were mined to a depth of 432m where the shear flattens and is terminated by the Chemist Shop Fault (Fig. 4). CRA Exploration has discovered extensive disseminated mineralisation between and adjacent to the mined quartz shoots. This may represent a bulk-mineable resource.

The mineralisation occurs in strongly sulphidic pug zones and in disseminated sulphide-bearing sediments. Sulphide minerals are arsenopyrite, pyrite and minor stibnite. Gold mineralisation is typically accompanied by increased fracturing, shearing, quartz-carbonate veining and sulphide content plus weak pervasive

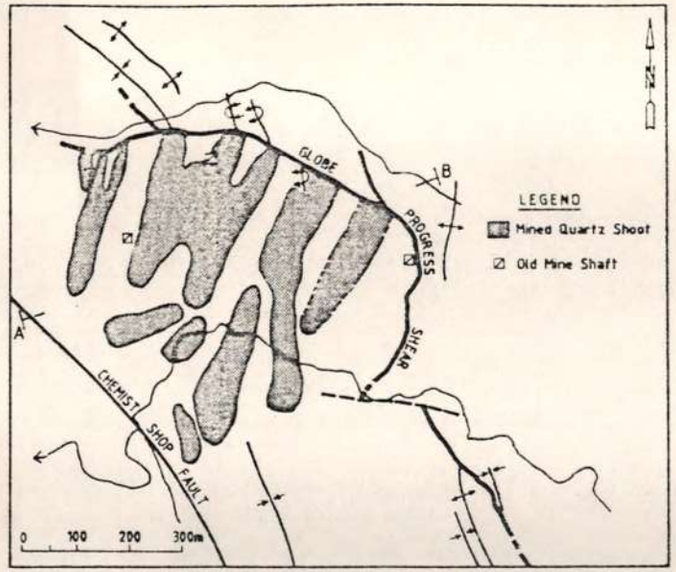


Figure 2. Globe-Progress Prospect Geology

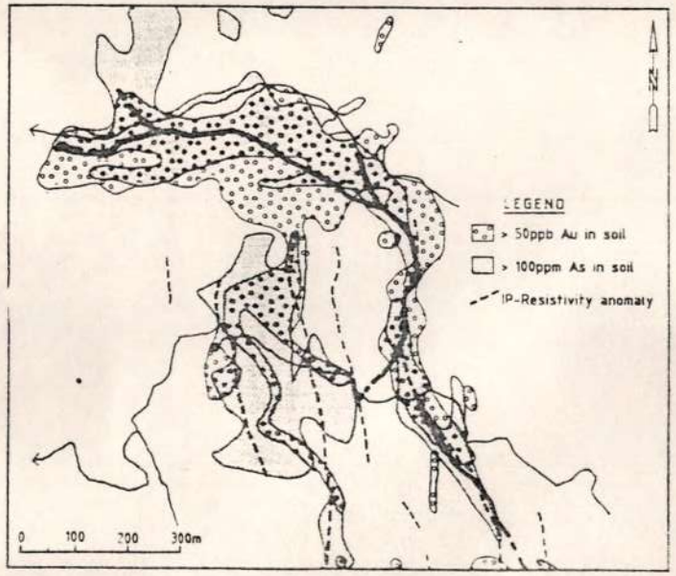


Figure 3. Globe-Progress Prospect Soil Geochemistry & Geophysics

alteration. Interpretation of the mine plans and surface geology indicates that the quartz shoots and the peripheral disseminated mineralisation are localised about the intersection of the major shear and tightly compressed, commonly sheared folds.

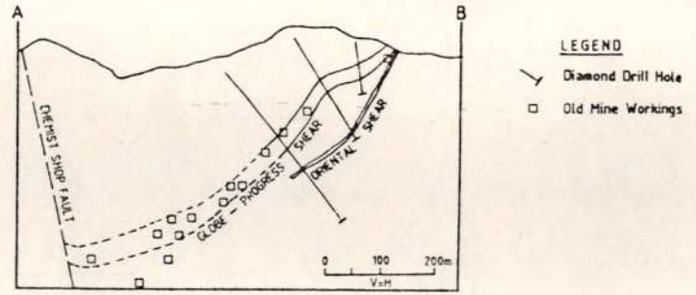


Figure 4. Section through Globe-Progress Mine

The structural localisation, simple mineralogy, lack of intrusive influence and metamorphosed turbidite host rocks are considered consistant with a metamorphogenic origin for the deposit.

The old mine workings are generally inaccessible, historical data is limited, and natural outcrop, particularly of mineralised shear zones, is sparse. Hand trenches and bulldozer cuts have provided invaluable geological information and surface assay data. Despite systematic detailed geological mapping it is not generally possible to make confident stratigraphic correlations between outcrops or drill holes due to the nature of the turbidite sequence and numerous minor shears. Structures are more easily traced at surface and in some cases can be correlated with those in drill holes.

The Globe-Progress Shear has been clearly defined at surface by gold and arsenic geochemistry in 'C' horizon soils and by a combined IP-resistivity survey (Fig. 3). Mineralisation is characterised by well-defined zones of low resistivity with local anomalous chargeability.

Soil geochemical surveys are a primary exploration technique in the Reefton Goldfield. Soil geochemical responses are subdued in the local areas of glacial or thick scree cover but IP-resistivity surveys have been successful in locating mineralisation in these settings. Both geochemical and geophysical anomalies are followed up by trenching to bedrock and drilling where appropriate.

An 18 hole (3400m) diamond drilling programme has outlined a significant gold resource in an environment related to, but distinct from that previously exploited. New potential has been opened up both at the Globe-Progress Prospect and elsewhere in the Reefton Goldfield.

BRITTLE STRUCTURE EVOLUTION AND PARAGENETIC STUDIES OF GOLD - SULPHIDE VEINS, CASSILIS, SWIFTS CREEK, VICTORIA.

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The Cassilis gold deposit in north-east Victoria comprises gold-sulphide quartz veins hosted by a sequence of multiply deformed pelitic schists and psammites of Ordovician age. Late Ordovician - Early Silurian regional deformation (D_1) folded marine turbidite succesions into upright, shallowly plunging, east-west trending folds. (F_1). A strong, penetrative, axial surface schistosity (S_1) is defined by an anastomosing foliation of sillimanite and K-feldspar about cordierite, biotite and andalusite. A second regional deformation (D_2) of Middle Devonian age produced open folds (F_2) with a near vertical axial plane, reorientating the F_1 fold hinge about 180 degrees. Development of a crenulation cleavage (S_2) is associated with D_2 and retrograde muscovite growth.

The Cassilis mine area is located on a north dipping limb of an F_1 antiform. Brittle deformation in the mine is indicated by the presence of fractures, faults and breccia zones. Fluid flow through some of these structures is evidenced by planar and irregular quartz veins/zones (Table 1).

Fractures, type I faulting, veins and dilational zones are predominently sub-parallel striking north, north-west therefore at high angles to the F_1 fold hinge, dipping steeply west but occasionally east. Breccia zones which contain the bulk of the mineralisation at Cassilis, have formed at intermediate angles between these brittle structures and F_1 folding, dipping either east or west. Type II faulting is (sub) parallel to the fold axis.

Breccia zones and faults showing strike-slip movement developed from shearing of the country rock. Textures and geometries shown by fracture types, veins and dilational zones (Table 1) indicate they developed by displacement normal to a fracture plane (i.e. extension).

The geometric relationships between brittle structures and F_1 folding may infer synchronous development of both. The possibility of brittle structures forming during F_1 folding at Cassilis can be determined through an analysis of existing stress fields.

Assuming extensional and shear structures formed synchronously at Cassilis, calculations of principal stress orientations show compression (σ_1) required to produce these brittle structures is subhorizontal from the north, north west and south, south east. Development of upright F_1 folds, striking approximately 075 degrees would have required compression from a similar orientation. Consequently, the compressive stresses (σ_1) needed to produce both brittle structures and F_1 folds were almost coaxial. The minor principle stress components (σ_2 and σ_3) have, however, exchanged position in both deformational events; σ_3 was vertical during folding but horizontal through brittle failure. This clearly shows fracturing was not synchronous with F_1 folding, as further evidenced by high-grade metamorphism during folding .

Fractures	Spatial Distribution	Geometries	Width	Evidence for fluid flow
Type I	Well developed in sets. F = 1:2 - 10:1 m S = 2 - 10 m	Planar, + curved down dip	<2 mm	± minor alteration
Type II	Irregularly developed F ≈ 5:1 m	Planar in sets Generally irregular	<1 mm	± minor alteration
Type III	Can occur in sets Spatially close to reefs F≈12:1 m	Generally strongly planar	<1 mm	Development of an alteration halo
Type IV	Irregularly developed Can form sets F = 6:1 m, S = 16 cm	Planar or irregular	0.5-3 mm	Deposition of amorphous material
Faults	Geometries	Movement	Width	Evidence for fluid flow
Type I	Strongly planar or irregular.Irregular surfaces,+slickenside	±strike slip Displacement ≈ 7cm	0.5-6 cm	Alteration of various intensities + cataclasis
Type II	Usually planar, irregular surfaces, + slickensides	Strike slip Displaces all above <8.5 cm	0.5-2 cm	Minor alteration within fault
Veins	Spatial distribution	Geometries	Width	Internal structure
	Irregularly developed Not restricted to reef zones	Planar can be irregular	0.1 1.5 cm	+ crustification of sulphide and gangue mineralogies
	Spatial distribution	Geometries	Width	Internal structure
Dilational zones	Irregularly spaced S = 2 - ≈ 35 m. ≈ (sub)parallel	Irregular zones locally	0.3-2.5 m	Disorganised conc. of dilational veins + disseminated sulphides Larger zones may contain brecciated country rock
	Spatial distribution	Geometries	Width	Internal structure
Breccia zones	Irregularly spaced S=1.5 - ≈50 m	Approximately planar	0.2-5 m	Strongly brecciated, may contain quartz/sulphide— assemblages

Abbreviations: F = frequency
S = spacing
≈ = approximately

Table 1 Descriptions of brittle structures.

Brittle structure evolution would require probable uplift and subsequent cooling following F_1 folding and prograde metamorphism. Associated with uplift, erosion and removal of overburden would cause reversal of the minimum and intermediate compressive stresses to give the stress configuration necessary for brittle structure development at Cassilis. A proportion of these brittle structures then acted as channelways for later fluids producing vein systems, dilational zones and mineralised shear zones. Episodic cataclasis is evident along these shear zones whereas sub-grain development in some shears is evidence for recovery/recrystallisation. This infers a lowering of the brittle field into the ductile field of deformation indicating the rocks were close to the brittle-ductile transition. This is consistent with an earlier interpretation of brittle structure evolution following cooling of the landmass after high grade metamorphism.

Lithological controls on brittle structures are evidenced by the general restriction of fractures to psammitic layers. Larger quartz filled structures (reef systems) are continuous through the interbedded metasediments although tend to "pinch out" when traversing pelitic layers.

Deposition of vein mineralogies is divisible into early and late paragenetic stages. Early mineral deposition comprises approximately 30 volume percent of total vein mineralisation and is characterised by pyrite, arsenopyrite, gold and minor quartz. Late sulphide/gangue assemblage consists of pyrrhotite, chalcopyrite, galena, sphalerite, quartz and minor sericite and comprises 70 volume percent of all veins. Quartz from this stage is volumetrically the most significant mineral deposited in the reef systems.

Alteration halos developed about mineralised structures comprise fine white mica +/- rutile intergrowths which are interstitial to quartz grains in mica psammites. In pelitic host rocks, thick sheaths of intergrown rutile and white mica (probably altered biotite) anastomose pseudomorphed porphyroblasts of cordiorite. Alteration of cordierite by white mica and minor chlorite is often incomplete. Fine grained white mica replaces K-feldspar, sillimanite and andalusite. Anhedral masses of carbonate are also observed in the alteration assemblage.

GOLD IN THE QUE RIVER, TASMANIA, POLYMETALLIC VOLCANOGENIC MASSIVE SULPHIDE DEPOSIT

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Que River Mine is one of four high grade, gold-bearing, Cambrian polymetallic volcanogenic massive sulphide deposits in the Mount Read volcanic arc of western Tasmania. Significant gold (5 to >20 ppm) is only reported from zinc-rich massive ore, and the best gold grades tend to occur toward the stratigraphic top of the orebody. The pyritic (more copper-rich) core to the main massive sulphide lens has, generally, only low (<1 ppm) gold grades. Minor anomalous gold (1 to 2 ppm) occurs in some of the more distal parts of the footwall stringer zone.

The major producing orebodies at Que River comprise two sub-vertical massive sulphide lenses (PQ and Pnorth lenses) occurring at the same stratigraphic level. These are folded into a tight asymmetric syncline which has been sheared along its western limb (Large et al., in press). PQ and Pnorth lenses are composed of banded high grade sphalerite-galena-pyrite-chalcopyrite ore with subordinate tetrahedrite and arsenopyrite and minor carbonate, quartz, sericite and chlorite. Free gold is observed in association with pyrite, galena and tetrahedrite. In the thickened central section of PQ lens (around section 7550 N) massive pyrite mineralisation containing anomalous copper grades occurs immediately above a zone of strongly developed copper-bearing pyrite stringer. This part of the orebody is interpreted as marking the principal focus of ore-fluid exhalation (Large et al., in press). The PQ-Pnorth lens system is zoned with respect to copper, lead and zinc (and gold) and the distribution of these metals provides evidence of stratigraphic younging direction around the fold structure. Gold grades of 5 to 30 ppm are concentrated towards the interpreted stratigraphic top of the folded lens. The best gold grades (5 to 30 ppm) are observed in highest grade zinc-lead ores (>25 wt% combined lead and zinc). Copper grades are low in the polymetallic ore (<2 wt%, and most <1 wt%) and gold grades are essentially independent of copper grades. For instance, the pyritic core to the PQ-Pnorth orebody described from 7550 N section has some of the highest copper grades of the Que River mineralisation (up to 5 wt%), yet it contains less than 1 ppm gold. Figure 1 summarises the gross metal distribution patterns in the (unfolded) PQ-Pnorth massive sulphide body.

An extensive zone of stringer sulphides occurs within altered volcanics (Whitford, et al., in press) over a strike length of at least 800 metres in the stratigraphic footwall to the principal massive sulphide lenses. The stringer mineralisation consists of an irregular network of sulphide veins, disseminated sulphides and blebby sulphides within silicified and sericitised volcanics. Pyrite is the dominant stringer sulphide, whilst galena and sphalerite are commonly

developed with pyrite within about ten metres of the massive ore lenses. Chalcopyrite-rich stringers are uncommon and largely restricted to immediately below the thickest part of the mined orebody near 7550 N section. In general, gold grades in the stringer zone are low (<0.7 ppm), however, some of the more distal parts of the stringer may contain up to 2 ppm gold.

A third important zone of massive sulphide mineralisation, not currently mined, is S lens. This lens occurs 130 metres east of PQ lens and comprises massive pyrite and minor massive galena-sphalerite with intense development of pyrite stringers and sulphide veining. It has higher copper grades and significantly lower zinc-lead-silver grades than PQ lens. Gold grades are generally low and independent of the base metal grades, although sporadic samples with both high gold (5 to 10 ppm) and high copper (>3 wt%) are observed.

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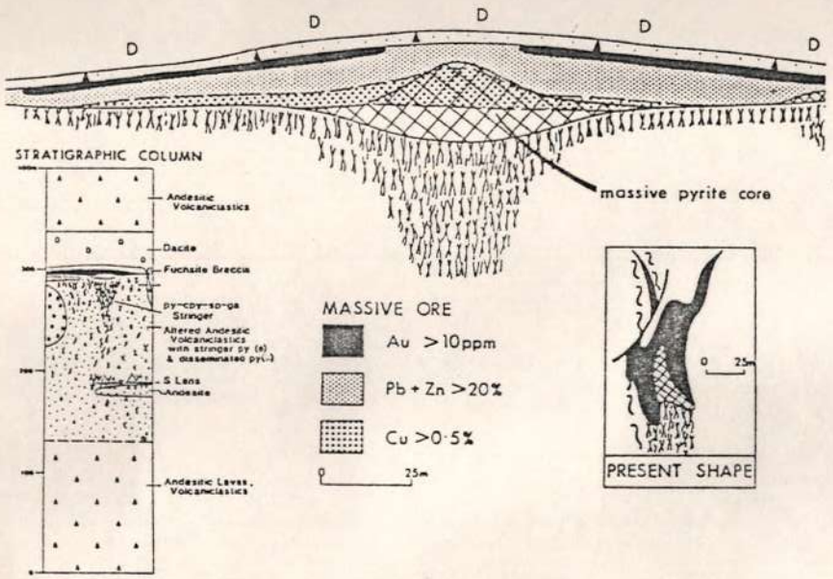


Figure 1. Stratigraphic column and pre-folding reconstruction for the Que River sequence.

THE UNION HILL GOLD MINE

MALDON, VICTORIA

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INTRODUCTION

Union Hill is situated at latitude 36°59'S, longitude 144°04'E on the northern outskirts of the township of Maldon, 120km northwest of Melbourne. It was the site of extensive underground reef mining from 1857 until 1906, producing some 180,000 oz gold.

An attempt to redevelop the site as an open cast mine in 1974 failed due to inadequate recovery plant. The mine was re-opened in 1987 by Triad Minerals N.L. on a two year trial basis. At an anticipated production rate of 15,000 oz gold per annum, it may become the second largest Victorian gold producer during 1988.

REGIONAL GEOLOGY

Maldon was a centre of continuous reef mining activity from 1857 to 1926. More than 30 reefs were mined to depths of up to 670m. Recorded production of 1,617,000 oz (54 tonnes) ranks Maldon historically as the fourth most productive reef field in Victoria.

The auriferous quartz reefs lie in a belt of tightly folded marine clastic sediments of Early Ordovician age (Lancefieldian Stage) adjacent to a pluton of Late Devonian granodiorite (the Harcourt Batholith). Contact metamorphism has produced hornfels of variable quartz-biotite-cordierite-andalusite assemblages as the dominant host rock lithology. Both the quartz and gold mineralisation predate the granodiorite intrusion.

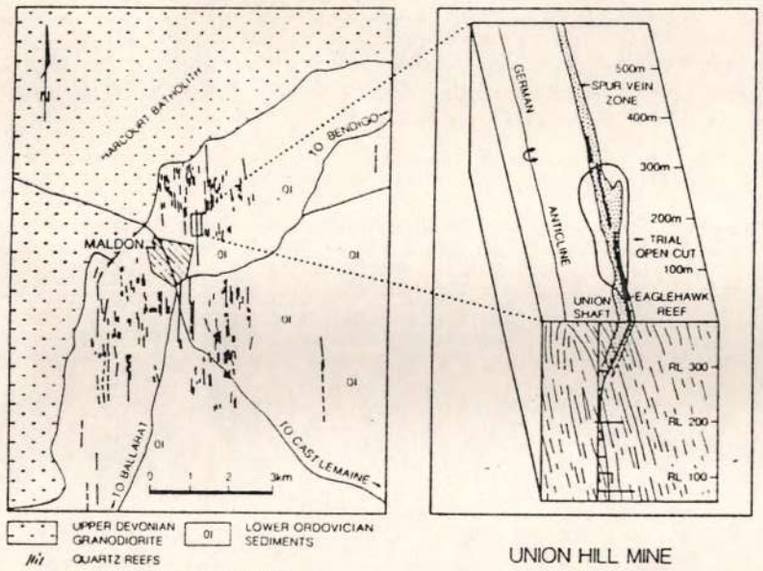
STRUCTURE

The principal ore structure at Union Hill is the Eaglehawk Reef which is persistent quartz reef 2 to 10m wide worked over a length of 1km to a maximum depth of 380m. It was one of the four most productive reefs on the Maldon Goldfield yielding 313,600 oz from selective stoping of high grade (average 28 g/t) ore.

The host rocks dip 65° to 85° east forming the eastern limb of an overturned anticline. The reef is roughly parallel in strike with the host rocks but dips 67° west across the bedding, down to 120m below surface where the reef reverses dip to become

a narrower and less productive bedded reef.

Auriferous spur veins extend up to 15m from the reef into both the hangingwall and footwall. The spur veins are up to 30cm thick but seldom persist more than a few metres along strike or down dip.



MALDON GOLDFIELD

UNION HILL MINE
BLOCK DIAGRAM

GOLD RESOURCE

In 1973 Lone Star Exploration N.L. recognised that the remnants of the Eaglehawk Reef and the adjoining zones of spur veins, which had not been mined far below surface due to their limited size, together formed a potential orebody amenable to open cast mining .

An ore zone 600m long averaging 30m wide has been delineated by percussion drilling to the water table (average depth 40m). A resource of 100,000 oz of gold contained in 2.5 million tonnes of ore averaging 1.2 g/t is indicated to an arbitrary depth of 60m. The orebody continues in depth, but urban development surrounding the site would limit the practical depth of open pit mining to 60m.

Drill analysis statistics suggest that 80% of the contained gold can be recovered by selective mining on 2m high benches using a 1g/t cut off.

During the trial mining period, it is planned to mine 150,000 tonnes of ore with a predicted head grade of 3.2g/t and a 2:1 waste/ore ratio. The unknown factor is the degree of dilution which will be experienced during mining, particularly in the zones of spur veins. The mined ore will be supplemented by 100,000 tons of ore stockpiled during the previous open cut development in 1974.

MINERALIZATION

Native gold occurs as grains usually less than 100 microns in diameter in association with clots of sulphide minerals in the vein quartz. The sulphide minerals in order of decreasing abundance are pyrite, arsenopyrite, sphalerite, galena, pyrrhotite and marcasite. Some pyrite and marcasite is secondary after pyrrhotite. Above the water table the major proportion of the sulphide has been replaced by secondary limonite. Limonite hosted gold grains may represent secondary gold in part.

Bismuth has been reported in the form of the rare mineral MALDONITE (Au_2Bi). Other accessory minerals include scheelite, native copper, and stibnite.

The ore is readily amenable to cyanide leaching, and between 30% and 60% of the gold in oxidized ore is recoverable by gravity concentration.

CONCLUSION

The Union Hill Gold Mine is one of the few examples in Victoria of an open cast mine established to recover some of the lower grade ore left at the site of previous extensive underground reef mining.

The most significant characteristic of the site in the context of open cast mining is the presence of persistent zones of largely unmined spur veins adjacent to the primary reef structures previously mined. Trial mining is in progress to determine the efficacy of selective mining to recover gold from the zones of the auriferous spur veins.

The gold is readily extractable by conventional gravity/C.I.L. technology. A plant with excess capacity has been installed to allow for flexibility in throughput according to the degree of dilution experienced during selective mining.

THE BRUNSWICK GOLD-ANTIMONY MINE COSTERFIELD VICTORIA

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DISCOVERY

The Brunswick Gold-Antimony Mine is situated on the Brunswick Line of Reef Workings named by Whitelaw in 1926, the only major workings developed outside the Main Costerfield and South Costerfield Reef workings some 400 metres to the east. The discovery of the reef line is attributed to the Bradley Family at some time subsequent to the discovery of the Costerfield Reef in 1860.

The lack of significant historic workings and recorded production from this line compared to the Main Costerfield reefs can be attributed to the absence of free milling gold in oxidized ore which, at the site of Coster and Field's original discovery of the field yielded an estimated 7000 ounces of gold.

EXPLORATION HISTORY

Although the London based Gold Exploration and Finance Company Limited conducted the first modern exploration of the Main Costerfield Mine in the mid 1930's, including 3000 feet of drilling and 5000 feet of underground development, it was not until 1966 that the Brunswick Mine area was explored when Mid East Minerals N.L. conducted geochemical and geophysical surveys and drilling.

Their diamond drilling delineated a mineralized vein in a shear zone at the Brunswick Mine. The company sank an exploration winze on the zone to a depth of 30 metres and estimated a geological ore reserve of 13,600 tonnes containing 9.8% Sb and 18.2 g/t Au. A development shaft was subsequently sunk to 48.7 metres and drives were developed at the 45 metre level.

Forsayth Mineral Exploration N.L. acquired the mine during 1973, deepened the shaft to 65 metres and excavated short drives at this level. They sampled the mineralized vein exposed on the 45 metre level and commenced construction of a treatment plant. Costerfield Mining Pty. Ltd. subsequently acquired the property, modified and completed the treatment plant construction and conducted some mining. An acceptable concentrate with high recovery could not be produced and operations ceased in 1975.

Between 1973 and 1977 the Department of Minerals and Energy conducted geochemical soil sampling and diamond drilling at the Brunswick Mine and in 1977 established the mine contained 10,382 tonnes of proven and probable reserves of ore with an average grade of 5.5% Sb and 22.9 g/t Au. Possible reserves were estimated at 27,000 tonnes.

GEOLOGICAL SETTING

The Brunswick Gold-Antimony Mine is situated on a north-trending shear zone in Lower Silurian siltstones and minor sandstones of the Costerfield Formation. These sediments, deposited on the western margin of the Melbourne Trough have been gently folded and form the core of the Costerfield-Redcastle Dome. The mine lies within the Warrandyte gold sub-province, and the mineralization is likely to have been associated with the development of the Central Victorian Magmatic Province in the Upper Palaeozoic.

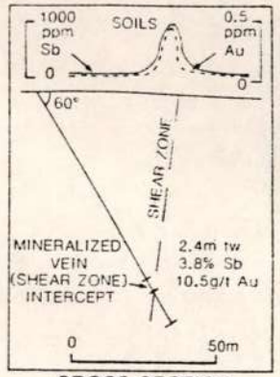
MINERALIZATION

Mineralization at the Brunswick Mine consists of stibnite-gold-pyrite-arsenopyrite veining and disseminations within a steep west-dipping shear zone up to 3 metres thick. Gangue minerals include quartz, calcite and barite, and both silicic and chloritic alteration are found in the wall rocks. Gold appears to be of two ages, an early phase of coarser gold in part enclosed in quartz and a later phase of finer gold located within stibnite at grain boundaries. Stibnite is generally found as distinct veins located within the shear zone but close to the walls, or as disseminated subhedral crystals in quartz-veined country rock within the shear zone and occasionally within stibnite.

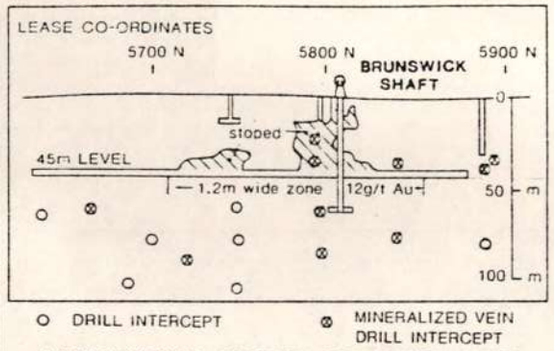
The ore shows evidence of localized dislocation metamorphism caused by repeated movement along the main shear zone. Individual stibnite crystals exhibit bending and kinking, and much of the stibnite has a fine-grained texture suggesting recrystallization. Brecciation, frequent changes in pitch of slickensides and localized foliation of siltstones within the shear zone are further evidence of repeated movement alohe the shear zone. The mineral assemblage, especially stibnite and barite, suggest a formation temperature of less than 200°C.

GEOCHEMICAL SIGNATURE

Previous work has shown that mineralization is reflected in 'A' horizon soils in both areas of residual and transported overburden. Current work has demonstrated that primary mineralization at the Brunswick Mine is strongly reflected by gold, antimony and arsenic values in pulverised 'A' horizon soils, with gold veing particularly effective in defining the strike extent of the Brunswick shear zone over a distance of approximately 1000 metres.



CROSS SECTION HOLE M4



LONGITUDINAL SECTION BRUNSWICK MINE

CURRENT PROGRAMME

During 1987 the Brunswick Mine was dewatered and geologically mapped. The shear zone on the main (45m) level was seen to vary in width between 1.8 metres and 3.0 metres and to be remarkably consistent in its strike direction except where displaced by a postulated strike slip fault south of the main shaft. Gold and antimony grades are highest to the immediate north and south of the postulated fault, suggesting secondary structural control to the mineralization within the shear zone.

A diamond drilling programme conducted by Australian Gold Development N.L. during the latter half of 1987 has increased reserves of gold-antimony ore at the Brunswick Mine and a programme of sub-levelling is currently in progress to further block out reserves of ore. A programme of trenching is under way to ascertain the potential for open-cut mining on the Brunswick Shear Zone and along other shear zones in the Costerfield area, and the existing on-site mill has been re-commissioned and concentrates produced for metallurgical testing.

LODE CONTROLS OF THE CHARTERS TOWERS GOLDFIELD

NORTHEASTERN QUEENSLAND

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The Charters Towers goldfield in northeastern Queensland produced over 206 tonnes of gold from gold-quartz veins hosted in Mid-Palaeozoic granodiorite, tonalite, diorite and to a lesser extent amphibolite-grade metasedimentary schist and meta-igneous rock. Northwest- and east-striking mylonite cross-cuts early granitoids in the Ordovician as did Silurian northeast- and north-striking diorite porphyry dyke swarms. Devonian granitoids post date these events and are generally undeformed. Mineralisation occurs in grouped, brittle moderate-dipping fissure zones with altered wallrock rafts and a complex network of quartz veins. Gold mineralisation is confined to the quartz in oreshoots and is accompanied by 10% sulfides.

Over 75% of the production came from four main vein systems in the central goldfield: the Brilliant, Queen, Day Dawn and Towers Hill vein systems. The Brilliant vein system is hosted in undeformed tonalite and contains oreshoots on a north-dipping main fissure and in shorter east-dipping hangingwall fissures. The Queen vein system was similar but is also hosted by the metamorphic rocks. The Day Dawn vein system is localised along a north-dipping dyke at the contact of two deformed granitoids in a brittly reactivated mylonite, where horizontal oreshoot plunges may be related to the original megascopic undulations in that structure. The Towers Hill vein system is restricted to one granodiorite type and has multiple ore controls.

Each main granitoid phase has a unique relationship with each vein system, where the primary fabric and igneous contacts influence the location and plunge of the oreshoots. Splaying, changes in dip, cross faults, and fissure intersections are the main lode controls. The largest vein systems are in zones where shallow-dipping mylonite was brittly reactivated and in fissures in younger undeformed granitoids. Each vein system lies in a separate structural domain, usually where older east-striking structures are preserved. These older structures may have tapped fluid at depths and were coincidentally oriented perpendicular to dilational stress during mineralisation.

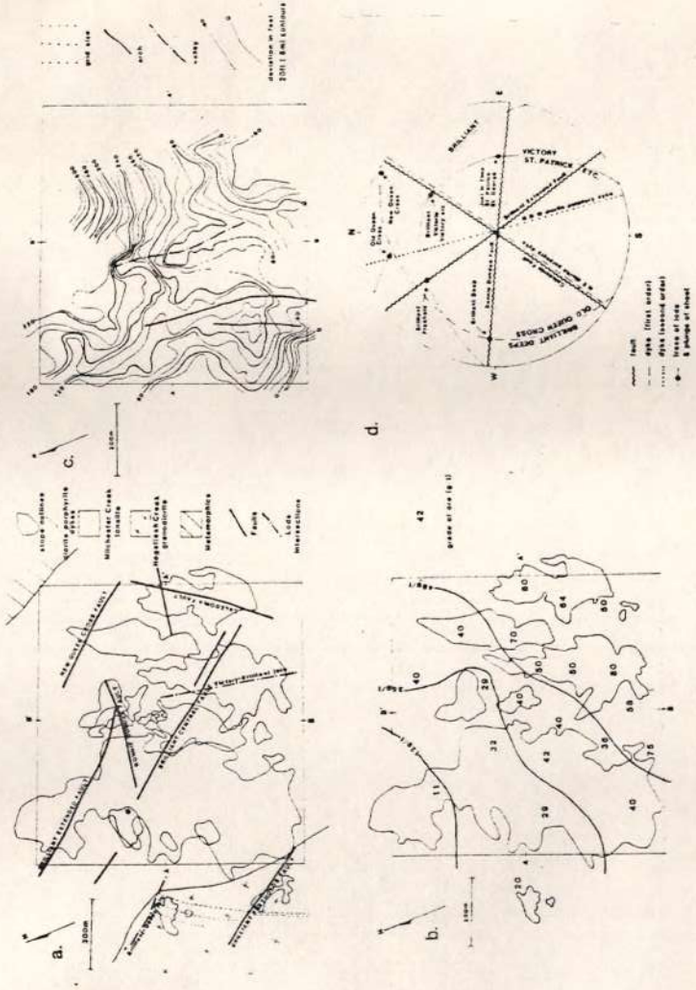


FIGURE 1 Geology and lode control elements of the Brilliant vein system; a) geologic contacts, dykes and faults; b) grade contours of mines (g/t Au); c) Connolly diagram of main fissure, d) structural elements of the Brilliant vein system on an equal angle stereonets, showing plunges of shoots.

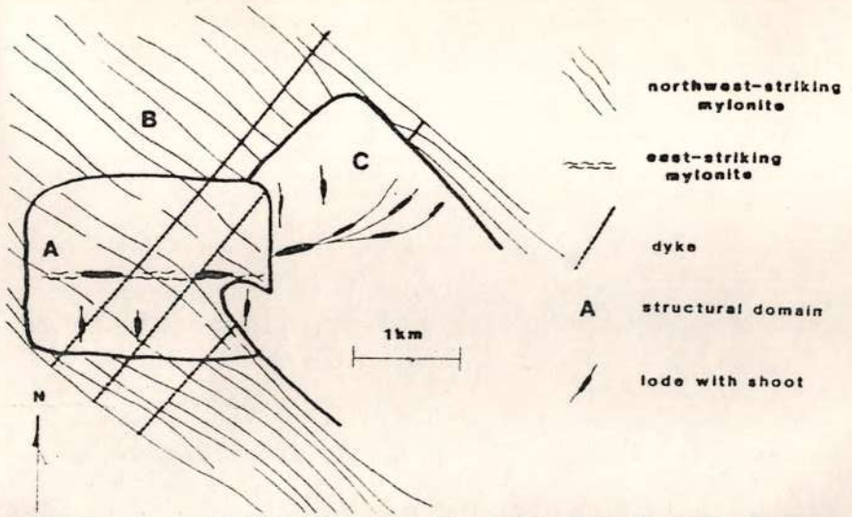


FIGURE 2 Model of ground preparation for the Charters Towers goldfield: Structural Domain *A* represents the Hogsflesh Creek Granodiorite and the northern contact of the Towers Hill Granodiorite which both preserve early east-striking, north-dipping foliation and mylonite; Domain *B* represents the foliation trajectories and pervasive overprint of northwest-trending, vertical mylonite and the northwest-trending foliation in the Charters Towers Metamorphics; Domain **C** represents the undeformed Millchester Creek Tonalite. During mineralisation, the only fissures to dilate and act as substantial fluid conduits were in east- and north-trending fissures in domains A *and C*. The northwest-trending mylonite in domain *B* and the northeast-trending dykes were generally closed to mineralisation. In this way, sequential domainal fabric development in the granitoids provided a heterogeneous fabric which underwent selective dilation and reactivation.

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LODE CONTROLS OF THE HODGKINSON GOLDFIELD

NORTHEASTERN QUEENSLAND

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The Hodgkinson goldfield contains over 50 separate lodes which have produced 9.7 tonnes of gold from ore averaging 37 g/t. The gold-quartz lodes are spatially separate from tin and base metal mineralisation associated with Permo-Carboniferous granitoids in the province. Host rocks consist of sub-greenschist metamorphic grade shale, conglomerate, sandstone, spilite, chert and melange. Oreshoots average 100 X 30 X 1 m in size and are contained in cross-cutting quartz filled steep-dipping shear zones. Mineralisation in the quartz consists of gold with minor arsenopyrite, pyrite, galena, and sphalerite with rare calcite. Scheelite and stibnite are associated locally but are not necessarily proximal or coeval. Alteration is minor and restricted to centimetre-scale phyllic selvedges adjacent to the veins and veinlets.

Most of the lodes and veins occur within six main 1.5 X 0.25 km mineralised areas which may indicate separate areas of fluid flow and precipitation. Ore controls differ in melange- and sandstone-hosted lodes but several features are common to all the oreshoots. Most of the lodes occur within zones of dilation that are caused by splaying, refraction through carbonaceous shale-sandstone contacts, or by rolls and changes in strike and dip. Lithologic contacts may act as areas of permeability and chemistry contrast which focus fluid flow and precipitation. Tensional veins are common between parallel shear zones and curved spur veins occur both in the hangingwall and footwall of the main fissure. Intersections and contacts may have enchanced local fluid flow in many of the areas.

Host rock, quartz veining, sulphide mineralogy, alteration and ore controls are consistent with features of other *metamorphic-hosted* and *slate belt* type gold deposits. The sub-greenschist metamorphic grade, and absence of mineralised syntectonic veins, suggest that the gold veins were emplaced at a higher level than most similar deposits. Melange host rock is also not common in other deposits.

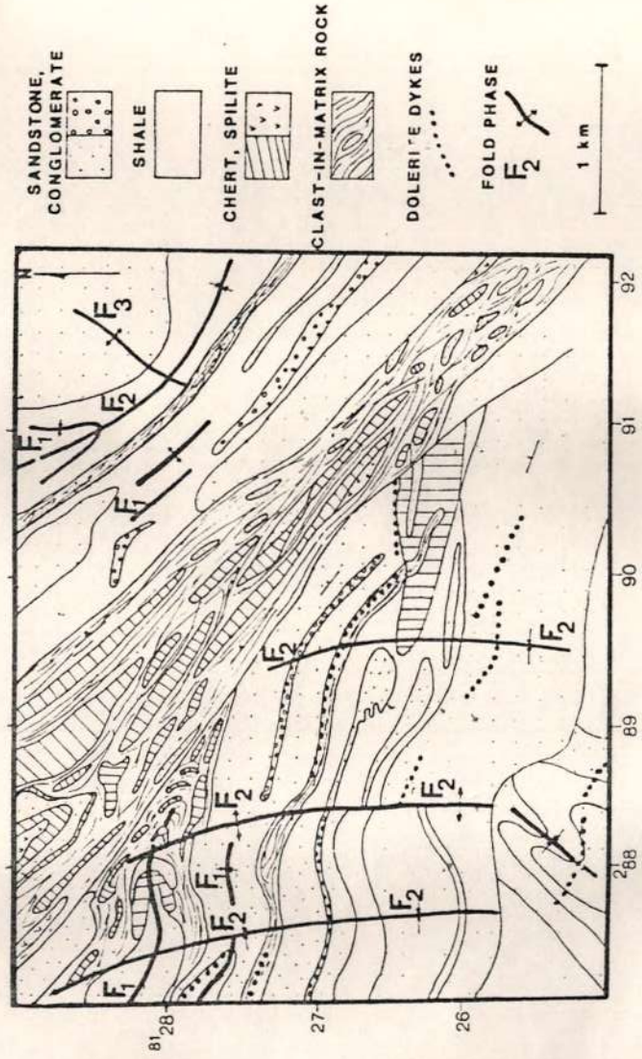


FIGURE 1 Geology of the Hodgkinson Goldfield.

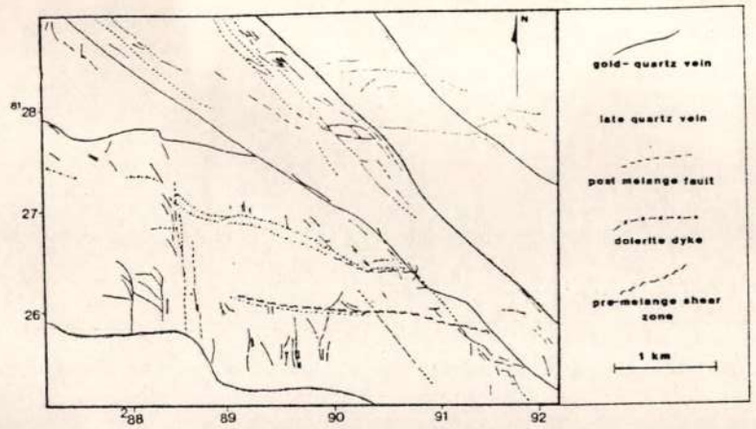


FIGURE 2 Structural elements in the Hodgkinson Goldfield

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RHYOLITE CREEK VICTORIA

A LOWER PALAEOZOIC EPITHERMAL GOLD PROSPECT

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INTRODUCTION

Located in mountainous forest, close to the snow line, this prospect may be the largest and oldest epithermal system currently known in Victoria. It is owned and operated by a joint venture between BHP Gold Mines Ltd. and Hardrock Exploration Pty. Ltd.

To date, core drilling aggregating approximately 1,000 metres in five holes has provided encouragement with one hole having 31 metres averaging 0.5 g/t gold, 50 g/t silver, and another 13 metres of 1 g/t gold. A commercially viable deposit has not yet been defined.

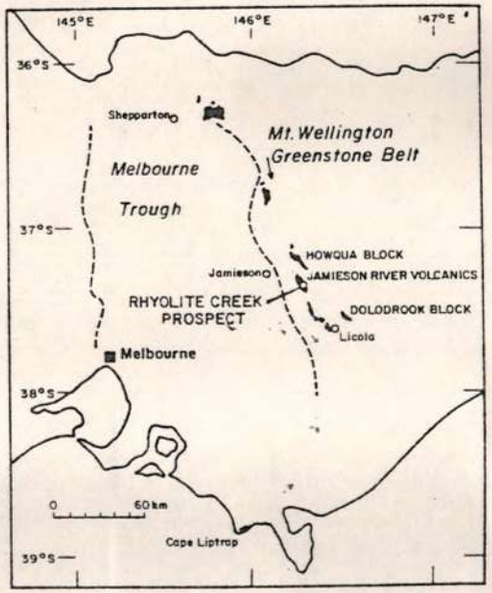


Figure 1. Rhyolite Creek Gold Prospect, Regional Geological Setting

GEOLOGICAL SETTING

The prospect limits are defined by pervasive alteration of the Jamieson River Volcanics (Cambrian volcanics and associated epivolcaniclastic rocks).

The Jamieson River Volcanics outcrop in an exotic horst along the Mt. Wellington Greenstone Belt which bounds the eastern margin of the Siluro-Devonian Melbourne Trough (Fig. 1). They have a calc-alkaline orogenic magma association, distinguishing them from boninitic/MORB lavas (at Howqua) and ultramafic rocks (at Dolodrook) found elsewhere along the Mt. Wellington Greenstone Belt. More subtly, the Jamieson River Volcanics Suite at Rhyolite Creek is also distinguished from the dominantly hornblende andesite lavas and breccias immediately to the south near Licola township (Crawford, 1982).

Lithologically the Jamieson River Volcanics at Rhyolite Creek comprise lavas of clinopyroxene andesite, sodic rhyolite, dacite and related epivolcaniclastic sediments containing detrital volcanic quartz and volcanolithic fragments.

Two deformations have affected the sequence at Rhyolite Creek. Mid Devonian Tabberabberan compression resulted in a SW 35° dipping cleavage sub-parallel to bedding. Later, Carboniferous - Kanimblan compression produced upright chevron folding of the first cleavage and locally a strong crenulation cleavage.

Both deformations have affected the epithermal alteration.

Late quartz diorite dykes cut and post-date the mineralization, alteration and at least the first cleavage. These dykes are not related to epithermal mineralization.

ALTERATION AND GEOCHEMISTRY

Vast areas of volcanics are affected by obvious pyrite/pyrophyllite stockwork alteration (Fig. 2) the largest being about 1000 x 600 metres. In more localized areas, soils (-80 mesh, A horizon) are anomalous in gold (0.1-0.8 g/t) and silver (1-14 ppm), the largest being about 400 x 300 metres.

Early silicification, and quartz microveining typically replace feldspar phenocrysts in rhyolite with mosaic quartz. Later, cross cutting pyrophyllite is intimately associated with pyrite, fine carbonaceous matter (? graphite) and secondary jarosite in both microveins and disseminations. The fine carbonaceous matter commonly forms a dusty shadow around the mosaic quartz silicification and is absent from quartz microveins.

Coarse younger pyrophyllite, grown during S_1 shear strain into a prominent foliation is commonly cut by the S_2 crenulation (Fig. 3).

Soil geochemical patterns suggest the mineralising system may be concentrically zoned over a 1.5 km diameter from Au/Ag/Ba with Pb/Cu to As at the periphery. This annular zoning, most clearly displayed by copper, also cuts the volcanic-epiclastic boundary.

MINERALIZATION

The most intense alteration and better gold/silver anomalies typically lie near the lava and epiclastic contact. Hole RCK3 tested the largest such zone (Fig. 2). Here the contact between epivolcaniclastic shale (with rhyolite fragments) and rhyolite lava is a 10 metre wide subvertical shear. Beyond this contact more competent pyritic altered rhyolite breccia exceeds some 150 metres in thickness, of which 75 metres carried 0.2 g/t gold. The richest section, some 31 metres just north of the sheared shale contact, averages 0.5 g/t gold and 50 g/t silver including 1.1 metres of 1.7 g/t gold.

Breccia textures are typically of fitted stockwork veins flattened during shear strain and generally carrying 10-30% pyrite/pyrophyllite with occasional 1 metre thick massive pyrite zones.

A second style of mineralization comprises lenses of massive sulphide which are siliceous breccia hosted, entirely within epivolcaniclastic sediment, e.g. hole RCK2 intersected 13 metres of 1.1 g/t gold in a gossan (Fig. 2).

The Rhyolite Creek style of deposit is analogous to other pyrite/pyrophyllite-rich epithermal gold systems in the Lachlan Fold Belt; at Temora, Peak Hill and near Junee, all in New South Wales. These deposits may have a common genesis having been deposited from high sulphidation, high temperature, acid and probably magmatically derived fluids (N. White pers. comm. and Hedenquist, 1986).

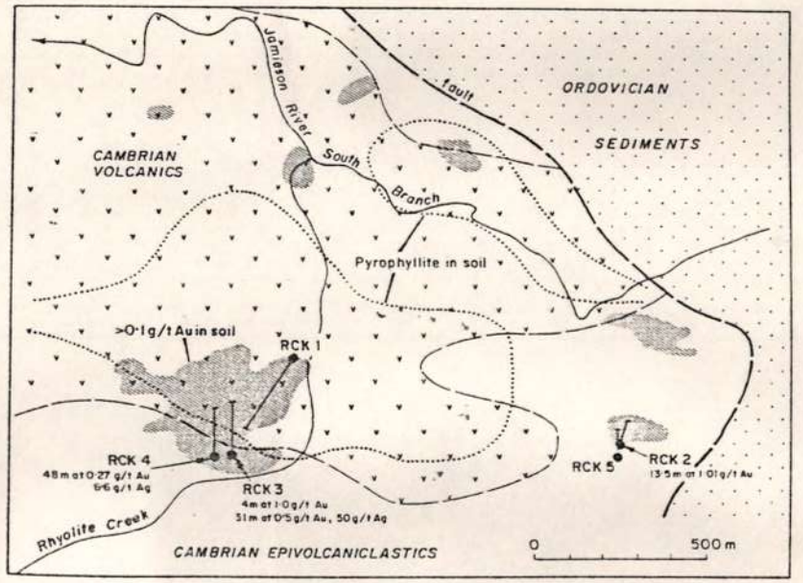


Figure 2. Rhyolite Creek Grid, Geology, Alteration and Mineralization

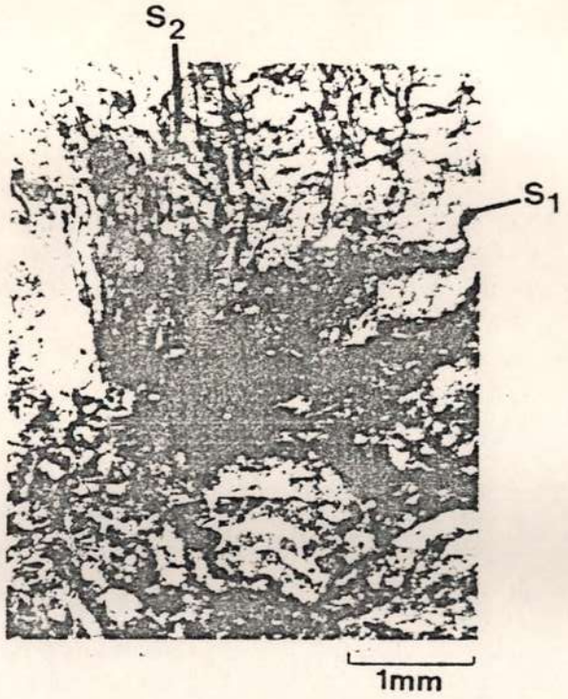


Figure 3. A prominent crenulation cleavage (S_2), highlighted by remobilized graphite, cutting an earlier fabric (S_1) of aligned pyrophyllite, graphite and jarosite

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Structural Control on Gold Mineralization at Stawell, Victoria.

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The Stawell goldfield is located in the western portion of the Palaeozoic Lachlan Fold and Thrust Belt (LFTB) (Fig. 1). The geology of this portion of the LFTB is dominated by northwest trending Cambro-Ordovician turbiditic sediments that rest on Cambrian volcanics with tholeiitic and andersitic affinities. This sequence has been subjected to a Lower to Middle Greenschist facies regional metamorphism. Overlying these rocks are the weakly deformed Silurian-Devonian Grampians Group. The turbidite sediments hosting the mineralization are in the Stawell Zone, a tectonostratigraphic province bounded by faults (Fig. 1). The structures in



FIG. 1 Location of the Stawell Zone. Palaeostresses determined from slickenlines on faults in Footwall basalts

the Stawell Zone are characterised by a progressive transition from early ductile deformation and subsequent granite emplacement to late brittle deformation. Deformation events D_1-D_3 predate the emplacement of the granites and were synchronous with regional fold-forming events and movements along discrete décollement surfaces to produce thrusts that involve an early westward sense of shear and later eastwards translation of tectonic units. These are associated with emplacement of slivers of Cambrian volcanics at higher stratigraphic levels within the younger Cambro-Ordovician turbidite cover sequence. Deformation event D_4 is characterised by west dipping shears that also juxtapose crustal segments of different metamorphic grade and history and may coincide with the emplacement of the Early to Middle Devonian granites and felsic dykes. All these deformation features are characterised by linear, roughly northwest-southeast trending folds and thrusts. They are followed by

deformations D_5-D_6 which are oblique strike slip faulting events with associated reverse and normal faults.

The Magdala gold mine, which was reopened in 1981, provides a good insight into the complex history of the Stawell Zone. Figure 2 shows

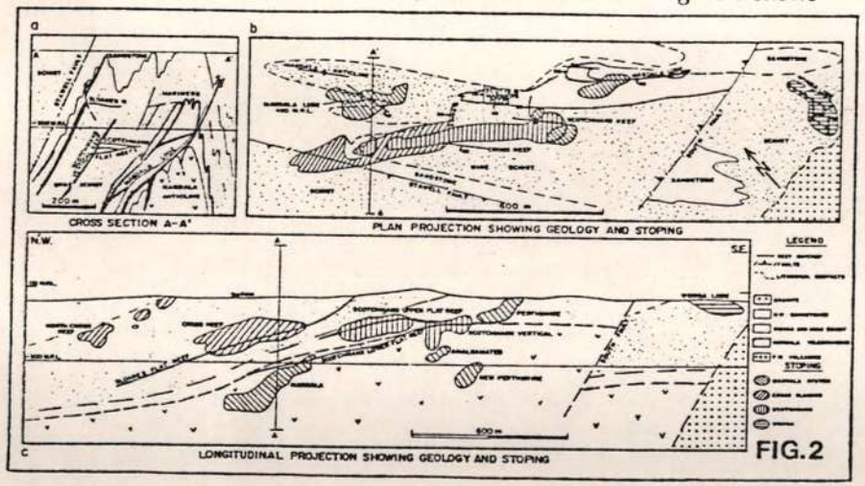


FIG.2

that the overall geometry, as seen in a simplified cross-section, is controlled by the "Magdala Anticline", a 15° northwest plunging structure that has been produced by piercement of a footwall volcanic sequence into the overlying metasediments. The footwall volcanics consist of meta-pillow basalt remnants, interflow sediments and breccias in fault contact with the hanging wall sequence. The volcanics are internally duplicated and disrupted by north to northeast dipping thrusts. Slivers of fault-bounded, generally northeast dipping, volcaniclastic and turbiditic material within the footwall volcanics (Waterloo structures) represent localized zones of high shear strain. These high strain zones probably represent thrusts and as such the "Magdala Anticline" is probably a thrust related duplex. West of the footwall volcanics is a mixed unit of cherts and volcanic sediments, termed the Magdala zone that is overlain by a strongly crenulated sequence of shale and sandstone. East of the "Magdala Anticline" is a structurally simpler stratigraphic sequence that contains only little gold mineralization.

Gold mineralization in the Magdala mine is confined to the structurally complex multi-deformed western side of the "Magdala Anticline" and occurs either in quartz-pyrite-pyrrhotite-arsenopyrite enriched thrust-parallel shear zones (Magdala lode) and associated strain accommodation structures such as Riedel shears and tension gashes or in flat to vertical quartz reefs along thrust surfaces (Cross and Scotchman's lodes). The ore body geometry is complicated by the syn- and post-mineralization reverse thrusts and later brittle events with dextral and

sinistral oblique strike-slip or normal faulting. The orientation of the principal stress vectors (Fig. 1) associated with these reverse faults (σ_1, 133/02), strike slip (σ_1, 195/02) and normal faults (σ_1, 282/76) suggest varying episodes of deformation.

Within the contact aureole of the Stawell granite is the Wonga Lode. The orebody geometry follows a D_4 system that dips southeast and plunges south, the reverse of the Magdala Lode. Gold mineralization is confined to a discrete fracture pattern within this shear system as either biotite-quartz-arsenopyrite or sericite-carbonate-arsenopyrite lodes overprinting the contact metamorphic assemblage.

Structural Control on Gold Mineralization at Walhalla, Victoria

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Gold bearing quartz vein mineralization can be related to the structural history observed in the well bedded distal turbidites of the Early Devonian Walhalla Group. A regionally penetrative north-south trending axial planar cleavage and upright, open to close folds with sub-horizontal fold axes were produced during east-west compression (Tabberabberan Orogeny). An east-west extensional event is associated with the emplacement of mafic dykes, the Woods Point Dyke Swarm, and precedes the development of a major shear system.

The gold mineralization is confined to a steep (70°) west dipping shear zone with predominantly reverse movement, which displays both dextral and sinistral senses of movement that involve many local structural complexities, and are bounded by distinct hanging and footwall

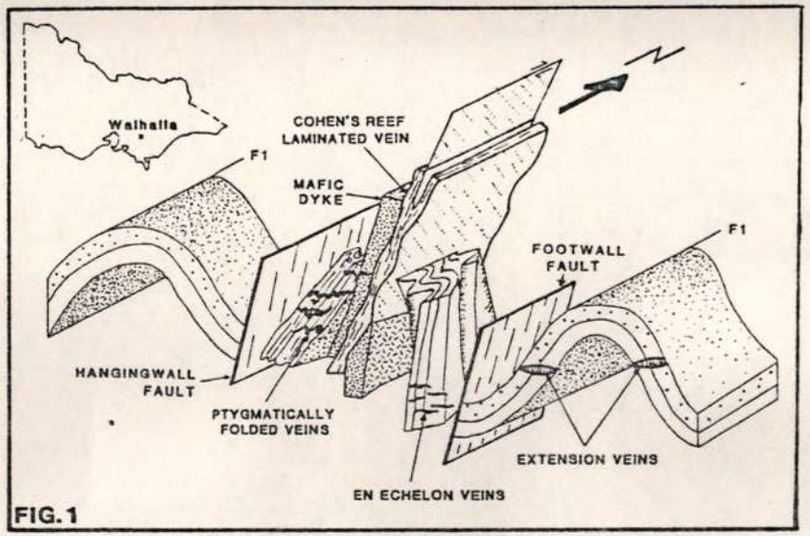


FIG. 1

faults (Fig. 1). Within this zone is a second set of later reclined, close to tight folds that plunge steeply to the north and south. It is the high angle reverse faults which were utilized as conduits for hydrothermal fluids that preferentially localize mineralization to laminated quartz veins. In the initial stages of reverse faulting, en échelon vein arrays were developed

but became deformed during prolonged shearing to produce ptygmatic veins. Laminated quartz veins within high angle reverse faults contain arsenopyrite and pyrite in vein margins and gold in fractures that cross-cut continuous quartz crystals. Gold, galena, chalcopyrite and sphalerite may also be deposited adjacent to or within fractured arsenopyrite and pyrite. Late-stage, cross faults developed in a regime of north-south compression post-date the laminated quartz veins and mineralization.

The most famous of the reefs in the Walhalla area was the Cohen's Reef system which was worked to a vertical depth of 1120 m and produced approximately 46,059 kg of gold. The highest grades of gold (Fig. 2) are

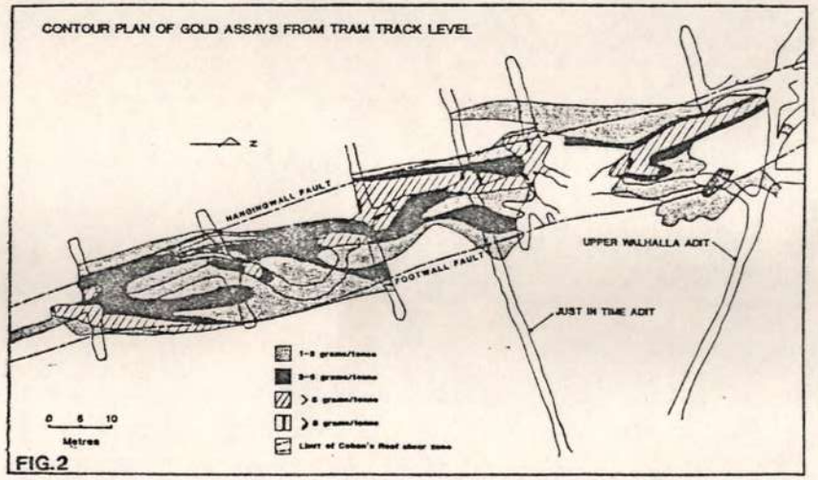


FIG.2

confined to the zone of intense deformation. Cohen's Reef is a single laminated quartz vein system at depth, but at higher levels bifurcates into a series of subparallel quartz reefs (Fig. 1). The spatial distribution of the gold mineralization can be related to brittle-ductile movement events along the margins of major mafic dykes confined to the shear zone. These events post-date the early extensional and stockwork quartz veins that are particularly well developed in the sandstones. Other mineralized veins are en échelon vein arrays initiated during the early stages of reverse faulting that become deformed during prolonged shearing to produce ptygmatic veins. The shearing was also responsible for the development of a cleavage in the mafic dykes that are generally unmineralized except where they are truncated by tension gash veins.

GEOLOGICAL AND LITHOGEOCHEMICAL EXPLORATION FOR GOLD IN THE LAGALOCHAN AREA, ARGYLLSHIRE, W. SCOTLAND

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The Lagalochan centre occurs in the Kilmelford district about 2.5 km to the east of Kilmelford village. The eruptives at Lagalochan are part of the Kilmelford intrusive suite which is composed of ten individual small bodies of diorite, quartz-diorite, granodiorite, porphyrite and volcanic breccia cropping out in an area of 50 km^2.

Tectonically, the Kilmelford area is in the strongly deformed marginal part of the former North Atlantic continent about 200 km north of the suture zone which is thought to lie between the Lake district and the Southern Uplands. Field observations, petrography and petrochemistry of major, trace, and rare earth elements suggest that there were probably two episodes of magmatic activity at Kilmelford. During the first episode the majority of the dioritic bodies were emplaced, shortly followed by the emplacement of a porphyritic phase of andesitic composition. The second episode is characterised by emplacement of porphyrites of dacitic composition. The Lagalochan eruptives were formed during this second stage of magmatic evolution at Kilmelford. The geochmistry of the major elements shows that the Kilmelford rock suite is alkali-calcic in composition and it resembles igneous rock suites in the New Guinea 'continental arc'. The high contents of K, Sr, Ba, Rb, Zr and Ce, together with a high K_2O/Na_2O ratio, give these rocks a shoshonitic character.

FIELD GEOLOGY AND PETROGRAPHY The igneous rocks at Lagalochan consist of a large body of porphyrite with a mass of pyroclastic rocks to the north. The boundary between porphyrite and agglomerate in the eastern part is displaced towards the south for 500-600 m relative to that of the western part by the NNE-SSW-trending Lagalochan fault. Near Lagalochan cottage this fault intersects an E-W-trending fault. Porphyrites in the area occur as an elongate stock-like mass and locally as conformable sheets intruded into the Dalradian sequence. The rocks contain 30-50% of phenocrysts, mainly plagioclase, mica and quartz. Subhedral plagioclase of oligoclase to andesine composition makes up to 75% of the total volume of phenocrysts. The principal ferromagnesian mineral is biotite which occurs as small flakes, in many cases hydrothermally altered. K-feldspar phemocrysts are occasionally seen. The matrix is pale pink to reddish, very fine-grained and contains mainly plagioclase and quartz. The rock chemistry shows that the Lagalochan porphyrite falls within the compositional field of dacites as defined by Ewart. Several bodies of breccia are observed in the area. They occur near the boundary of porphyrite and agglomerate, at the contact of porphyrite and the Dalradian country rocks, within the porphyrite itself. The rock is reddish or greenish with rounded or altered xenoliths of country rocks of 0.2-7 cm in diameter. Under the microscope the matrix of the rock is seen to be composed of alteration assemblages of epidote + chlorite + sericite, or chlorite + carbonate + clay minerals. The existence of numerous xenoliths and their setting

in a matrix made up of alteration assemblages suggest a breccia extensively altered by hydrothermal fluids. The Lagalochan agglomerate to the north of the porphyrite occupies an area of 1 km^2. The term 'agglomerate' is used here to represent a consolidated pyroclastic deposit. Blocks or fragments in the agglomerate are generally subangular and derived from Dalradian country rocks. The wide range of lithologies observed include crenulated phyllite, quartzite, vein quartz, amphibolite, porphyrite and early agglomerate. The matrix present is composed of comminuted material of the same composition as the fragments and is affected by hydrothermal alteration.

HYDROTHERMAL ALTERATION Hydrothermal alteration is widely developed in the area. It produced a variety of mineralogical changes in the original porphyrite. The principal mineral phase, plagioclase, shows a range of alteration products. The most common effect is sericitisation. In many cases the sericitisation is accompanied by the formation of epidote, carbonate and clay minerals. Biotite is seen to be replaced by an assemblage of sericite+ sagenitic rutile+ sphalerite +carbonate+ opaque minerals. In other samples the alteration assemblages are simpler, including sericite+chlorite, sericite+pyrite or sericite only. Amphiboles are preserved only as pseudomorphs replaced by chlorite and opaque minerals. The K-feldspars, where altered, have a brownish cloudy appearance and are probably partly replaced by clay minerals. Carbonate is a phase found in abundance during hydrothermal alteration and is ubiquitous as a replacement of other silicate minerals as well as in later veins and veinlets. Hydrothermal quartz occasionally developed in the matrix is chracterized by a mosaic texture and chalcedony fills vesicles in with silica being released by alteration of primary silicates. A simple geometrical pattern of alteration does not seem to be present at Lagalochan. Phillic to argillic alteration covers almost the whole area. Nevertheless, the western part of the Lagalochan porphyrite does show a difference in the alteration assemblage from that of the eastern part. In the western part propylitic (chlorite-epidote+carbonate) alteration is seen at more than one locality, whereas little epidote is observed in the eastern part. The alteration in the eastern part is dominated by formation of sericite, clay minerals and secondary quartz, together with carbonate. Thus the eastern part lies in phyllic-argillic facies of alteration rather than in phyllic-propylitic zone. This may be an effect of the movement on the Lagalochan fault. As the eastern part was down-thrown relative to the western part, the stronger argillic mineralogy in the eastern sector was exposed representing a slightly higher level of the alteration on this side of the fault.

LITHOGEOCHEMICAL SURVEY AND RELATED POLYMETALLIC MINERALIZATION The hydrothermal alteration in the Lagalochan eruptive centre is associated with enrichment of sulphide minerals. Field observation shows that sulphide minerals, mainly pyrite together with chalcopyrite, are widely distributed. They occur as disseminations, fine veinlets and coatings on joint surfaces. The abundance of sulphide minerals varies with the lithology and structure. The hydrothermal/volcanic breccia usually contains high contents of sulphides, dominately pyrite (up to 10 modal %). The amount of sulphide minerals decreases markedly in the central and northern part of the agglomerate body. Among the country rocks amphibolite and limestone of the Dalradian sequence are most favourable for sulphide mineralisation. Structure has a strong control on the distribution of sulphides. Examination in reflected light shows that the principal sulphide minerals at Lagalochan are pyrite, chalco-

pyrite, galena and sphalerite with a minor amount of molybdenite. Bornite, pyrrhotite and arsenopyrite are also present. Textural relationships suggest that there may have been a pervasive mineralization event during which chalcopyrite, together with molybdenite, galena and sphalerite, were disseminated through the rock. This was followed by emplacement of galena sphalerite, bornite and molybdenite in veins and veinlets.

A lithogeochemical survey was undertaken following geological studies of the area. Anomalous levels of indicator elements, including Cu, As, Ag, Rb, Cd, Pb and Zn, occur in the Lagalochan area. The anomaly is strong, and the element association suggests that it represents the halo or supra-ore zone of a mineralized system. The copper anomaly is weaker than in the Carn Dearg area, suggesting a deeper source for the anomaly or less intense mineralization. The stronger anomalies of Ag, Rb, Cd, Pb and Zn in the Lagalochan area compared with those in the previously drilled areas in the district favour the former hypothesis. Strong copper anomalies occur only in the western part, whereas strong silver anomalies occur in many samples from the eastern part, which suggests that the ore may lie at a shallower depth in the west. This is consistent with the conclusion reached from geological mapping that the fault is downthrown to the east. The anomalously high levels of As and Ag, together with anomalies of other chalcophile elements, indicate that the Lagalochan area may be an exploration target for gold as well as copper. Gold was determined, therefore, in rock samples, which included porphyrite, hydrothermal breccia and Dalradian epidioritic materials. Samples were selected on the basis of the spetial distribution and associations of indicator elements as well as on that of geology. Samples were dissolved in a solution of bromine in hydrobromic acid, the gold being extracted from the acid solution by methyl isobutyl ketone, which was atomized and then analysed by atomic absorption spectrometry. Approximately 25% of the samples from Lagalochan were found to contain gold in amounts greater than the 0.05 ppm detection limit. The highest value recorded was 0.67 ppm in a sample of hydrothermal breccia. The samples were also found to contain elevated levels of silver

Thus, the results of the present geological and lithogeochemical study suggest that the Lagalochan area is prospective for gold mineralization; evaluation is currently being undertaken by commercial groups.

Topic 1D

MESOZOIC - TERTIARY REGIONAL STUDIES

LARGE-SCALE VERTICAL METAL ZONING IN MOTHER LODE-TYPE SYSTEMS

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Gold deposits of Mother Lode-type are characterized by: 1) occurrence along major steeply-dipping faults; 2) association with intense CO_2- and K- or Na-metasomatism; 3) enrichment in Au, Ag, and the 'Au-suite' elements As, Sb, Hg, Te, W and Mo, and; 4) a lack of enrichment of Cu, Pb and Zn. Mother Lode-type deposits have historically been the most productive category of gold deposits except for of those of the Witswatersrand. Deposits of this type occur in rocks of Archean to Cenozoic age, persist over strike lengths of tens to hundreds of kilometers, and to depths of more than 2 km. Individual mines or districts do not exhibit vertical zoning of either ore grade or mineral assemblages.

Four areas, representing different erosional levels of Mother Lode-type systems were studied to document large-scale vertical zoning (from deepest to shallowest): 1) the Dahlonega Belt of northeast Georgia (≥20 km), an important district in the 19th century, with lode and placer production of 20 tonnes; 2) the Mother Lode Belt of California (7-10 km), a major source of Au, with total production of >450 tonnes; 3) the Manson Creek area (<5 km) of central British Columbia, which contains numerous gold occurrences and is an active placer camp, and; 4) the Pinchi Mercury Belt (≤2 km), an important source of mercury during WW II, also in central British Columbia. Depths during alteration were estimated on the basis of mineral equilibria in alteration zones, fluid inclusion data, and depths of emplacement of pre- and post-mineralization plutons.

The lack of base metals in these mineralized systems indicates that the mineralizing fluids were of low salinity; fluid inclusions from the Mother Lode-type deposits considered here (Albino, unpub. data) have ice and chlathrate melting temperatures indicating the fluids were of negligible (<0.5% eNaCl) salinity. Gold ores containing relatively abundant base metals occur in close association with Mother Lode-type deposits in some areas, and the fluids responsible for these deposits have higher salinities, from 3-6% eNaCl (Albino, 1986 and in prep.). The extremely low salinity of fluids from Mother Lode-type deposits indicates that Au and other metals could not have been transported as chloride complexes, but were likely in the form of bisulfide complexes. The solubility of Au, As, Sb and Hg thio-complexes has been discussed by Seward (1984) and Barnes and Czamanske (1967).

Although absolute contents of ore metals vary along each belt, trends with increasing depth include decreases in Sb, Hg, W and Mo concentrations and a slight increase in Te; As content varies little with depth. Ratios between metals also change in a regular way with depth, such that Sb/As and Hg/Sb are higher in shallow mineralized zones (Figure 1). As/Sb appears to be more sensitive to depth in the

deeper portion of the systems, whereas Sb/Hg is relatively constant except for the Pinchi Belt samples. Au is most abundant at intermediate depths (7-10 km), decreasing gradually with depth, and decreasing sharply in near-surface mineralized zones (Figure 1); distribution of higher Au contents is controlled in part by changes, with depth, in rheology of the host rocks.

In all areas, abundances of As, Sb and Hg tend to be correlative with each other, while Au concentration is apparently independent of trace metal content. Abundances and ratios of metals in deposits associated with the Larder Lake-Cadillac Break of the Superior Province (Archean) are very similar to those of the Mother Lode; this is consistent with the apparent similarity of P-T conditions during mineralization, which are based on isotopic thermometry (Kerrich, 1984) and alteration mineralogy.

Trace metal zoning (As deepest, Hg shallowest), is compatible with metal transport as bisulfide complexes, with deposition controlled at least in part by decreasing temperature. The strong correlation of As, Sb and Hg suggest that a similar mechanism (cooling combined with pH increase?) controlled their deposition. Conversely, the lack of relationship between the concentration of Au and these metals indicates that Au precipitation was influenced by other factors, although the association of Au enrichment with wallrock sulfidation suggests that Au was also carried in the form of a bisulfide complex.

These results have important implications for Au exploration, namely: 1) concentrations, and especially ratios of the Au-suite elements, provide an indication of depth of erosion of the mineralized structure, and; 2) intermediate erosional levels are most likely to host economic Au deposits. The occurrence of Mother Lode-type Au deposits in the Dahlonega Belt further indicates that the fluids responsible for this style of mineralization are derived from depths of >20 km, and are not the product of devolatiliation at the greenschist-amphibolite transition as has been suggested by some authors.

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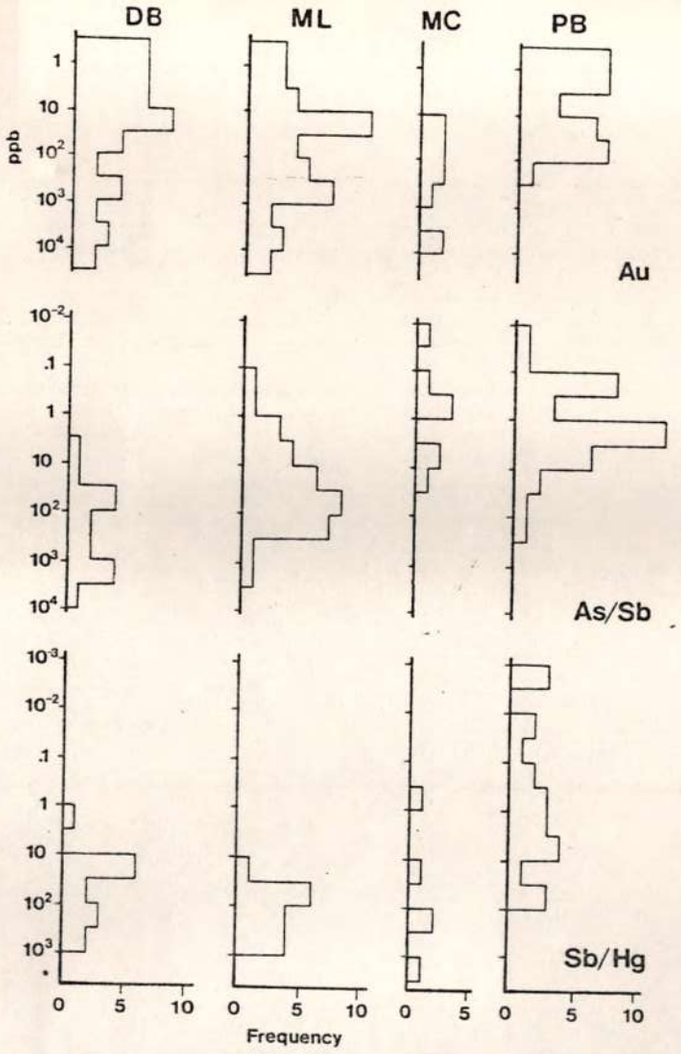


Figure 1. Histograms of Au abundance, As/Sb, and Sb/Hg ratios of mineralized samples from Dahlonega Belt (DB), Mother Lode Belt (ML), Manson Creek area (MC), and Pinchi Mercury Belt (PB). See text for discussion (note logarithmic scales).

BULK-MINEABLE GOLD DEPOSITS OF THE WESTERN UNITED STATES

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Abstract

Bulk-mineable gold deposits in the western United States contain reserves of more than 55 million ounces of gold and produced more than 3 million ounces (93,300 kg) of gold per year. They can be divided into five main deposit types: porphyry-related gold deposits, sediment-hosted gold deposits of Carlin type, metamorphic-hosted gold deposits, volcanic-hosted gold deposits, and hot-spring gold deposits. Each deposit type can be further divided into several deposit subtypes. For example, porphyry related gold deposits can be subdivided into copper-gold stockwork deposits, alkalic porphyry copper-precious metal deposits, calc-alkalic porphyry gold deposits, and gold-bearing skarn and metasomatic deposits related to porphyry systems. Examples of porphyry-related gold-silver deposits are: Zortman-Landusky and Golden Sunlight in Montana. Robinson, Fortitude, McCoy and Cove in Nevada; and Bingham Canyon in Utah. Some porphyry-related deposits such as the Robinson, Bingham Canyon and Battle Mountain districts, have been major copper producers and nearly all have associated base-metals and significant amounts of sulfides, principally pyrite. There seems to be little reason to doubt the close genetic relationship between the porphyries and the associated base-metal and gold-silver deposits. Major sediment-hosted gold deposits in the western United States occur mainly in Nevada and include the world-class gold deposits located within the Carlin and Getchell trends. Several important analogies exist between vein-type Archean gold deposits and sediment-hosted gold deposits of Carlin type including location along major lineaments, similar ore fluid chemistry, and similar major-element geochemisty. It seems probable that genetic models recently proposed for the origin of Archean lode deposits, i.e., derivation of ore components and fluids from either felsic magmas or from metamorphic dehydration aureoles around felsic plutons, also apply to Carlin-type deposits. Current reserves in the Carlin Trend alone exceed 777,587 kg of gold, and the recent discovery of major gold reserves at depths in excess of 400 meters at the Goldstrike deposit suggests that much more gold remains to be found within the trend.

Metamorphic-hosted gold deposits include those of Mother Lode type and Mesquite type, located prinicpally in California and Arizona. The Mother Lode deposits occur as large quartz veins and stockworks in a diverse suite of metamorphic wall rocks including ultramafic rocks, gabbro, slate, chert, and mafic volcanic rocks. Recent studies of deposits in the Mother Lode belt strongly suggest that the gold-quartz veins were derived either directly from felsic magmas or from fluids derived by devolatization reactions in the thermal aureoles of felsic plutons (Weir and Kerrick, 1987).

A number of bulk-mineable gold deposits and prospects in south-eastern California and western Arizona occur in high-grade metamorphic rocks. Two deposits of this type, Mesquite and Picacho, are currently being mined. The metamorphic rocks occur in the lower plates of regional detachment faults. Genetic models for the deposits range from an origin related to peraluminous, two-mica granites to ore fluids derived from basin brines of Tertiary age which leached metals from the metamorphic wall rocks and migrated upward along the basin margin faults into the low-angle detachment faults.

Volcanic-hosted deposits such as Paradise Peak, Borealis, Buchhorn, and Round Mountain in Nevada; Thunder Mountain in Idaho; and Cripple Creek in Colorado are significant producers of gold and silver in the western United States. Volcanic-hosted precious metal deposits can be subdivided into three main deposit types; 1) high sulfur or acid sulfate; 2) low sulfur or adularia-sericite and 3) alkalic. Each deposit type has a characteristic suite of alteration minerals, gangue minerals and metallic minerals. Paradise Peak and Goldfield in Nevada are excellent examples of high-sulfur deposits; and Cripple Creek in Colorado is the type example of an alkalic, volcanic-hosted gold deposit.

Hot-spring gold deposits in the western United States occur in areas of Tertiary or Quaternary volcanism and are a variant of volcanic-hosted precious metal deposits. The type example of a hot-spring gold deposit is the McLaughlin Mine in northern California which is on the margin of the Clear Lake volcanic field of Quaternary age. Hot-spring gold deposits are characterized by the presence of siliceous sinter, typically interbedded with hydrothermal explosion breccia and fallback breccia, and by the common occurrence of surficial, acid-leached zones. The sinter usually contains anomalous amounts of mercury, thallium, arsenic, and antimony, but precious metals typically occur in stockwork veins and silicified zones beneath the sinter. Gold-silver mineralization in fossil, hot-spring systems is normally restricted to a vertical zone of 300 meters or less extending downward from the paleosurface.

PRECIOUS METAL MINERALISATION IN THE EL SALVADOR REGION, NORTHERN CHILE

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The El Salvador region (26°-27°S; 69°-70°W) lies on the western slopes of the Andes and includes the southern part of the Atacama Desert. The southern boundary of the region is marked by a transition from a steeper dipping (30°) northerly segment of the subduction zone to a flat-lying (5°) southerly segment (Jordan et al. 1983). The El Salvador region is richly mineralised and over 400 mines have been worked. Most of these have been small operations but the area does include the El Salvador copper mine and the abandoned Potrerillos porphyry copper mine. Current exploration interest is centred upon a number of epithermal precious metal prospects (e.g. Silica del Hueso, Esperanza, La Coipa).

GEOLOGICAL EVOLUTION OF THE EL SALVADOR REGION

The geological evolution of the region can be related to the constant subduction, since the late Palaeozoic, of the Pacific plate eastwards under the South American continental margin. Three stages can be distinguished:

i) Palaeozoic magmatic arc: rocks of this stage include forearc sediments in the Coastal Cordillera and continental sediments of andesitic-rhyolitic provenance in the Andean ranges. In the late Palaeozoic these rocks were intruded by granitic bodies.

ii) Mesozoic arc-backarc pair: during the Permo-Trias the Palaeozoic magmatic arc was split and by the early Jurassic a shallow ensialic backarc basin was the site for carbonate sedimentation and the eruption of pillow lavas. An andesitic magmatic arc was established to the west of the basin but during the Mesozoic this belt of magmatism migrated to the east and enchroached upon the basin. Intrusion of granitic bodies also occurred, particularly along a major crustal fracture zone: the Atacama Fault Zone (AFZ). Basin closure and the development of a thin-skinned tectonic zone along the eastern margin of the basin occurred during the middle to late Cretaceous.

iii) Cenozoic continental magmatic arcs: to the east of the closed basin a Cenozoic magmatic arc was established. Volcanism in the Cenozoic is principally in N-S striking belts which 'young' progressively towards the east. Thick piedmont gravels resulted from the rapid uplift of the Andes, particularly during the Oligocene-Miocene.

PRECIOUS METAL MINERALISATION

Precious metal mineralisation occurs throughout the El Salvador region and is not restricted to narrow, longitudinal belts in the style

described for the distribution of porphyry copper deposits (Sillitoe 1981). Although precious metal distribution is not restricted in the geographical sense, there is an age restriction in that there is no mineralisation recorded with the Palaeozoic magmatic arc. Paucity of mineralisation also characterises the Palaeozoic sequences to the north of the El Salvador region (Boric et al. 1988). In contrast, precious metal mineralisation is widespread in the Mesozoic and Cenozoic successions in the El Salvador region.

Mesozoic precious metal mineralisation

Precious metal mineralisation is principally located along the Atacama Fault Zone (AFZ) and in a NNE-striking belt some 75km long centred upon Inca de Oro. The latter belt is about 50km east of the AFZ and subparallel to that fault zone.

The AFZ strikes parallel to the Mesozoic magmatic arc and is one of the most spectacular structural features of the sub-Andean ranges extending for more than 1000km through Northern Chile. In the El Salvador region it hosts a wide range of deposits which include vein and breccia-hosted Cu-Fe deposits, Fe-P deposits, and carbonate-hosted Ag deposits. Gold is a common by-product metal in all these deposits ranging from 1-2g/t in Fe-Cu veins to 6g/t in massive quartz veins. In the Porvenir-Remolinos district at the southern end of the AFZ in the El Salvador region, Au is the major metal with workings currently exploiting the oxidised zone which contains up to 3-4g/t Au. Silver grades are around 5g/t.

In the belt centred upon Inca de Oro strongly propylitised andesitic rocks of Cretaceous age are host to quartz vein stockworks, silicified zones, and massive quartz veins, all of which carry precious metal mineralisation. Primary ore usually consists of sulphide-rich material, principally containing pyrite and chalcopyrite with rare sphalerite and galena. Native gold is associated with the chalcopyrite and grades are usually 1-2g/t Au. Much of the current exploitation is concentrated on the oxide zones of vein systems which contain 5-10 g/t Au. At the southern end of the belt in the Tres Puntas-Chimberos district silver is the dominant metal occurring in carbonates and silicified volcanics; grades are in the range 300-700g/t Ag. In the past bonanza ore at 2-3kg/t Ag has been worked from pockets and mantos. The style of mineralisation in the Inca de Oro belt indicates a porphyry stockwork containing Au and Ag. In the northern part of the belt granitic rocks occur beneath the propylitised volcanics. Workings along the belt have rarely penetrated deeper than the oxide zone (c. 130m) and the extent of mineralisation at depth is unknown. The belt can be regarded as a favourable target for high-tonnage, low-grade copper and gold orebodies.

Cenozoic precious metal mineralisation

Porphyry copper deposits in the El Salvador region are relatively enriched in Au compared to porphyry deposits elsewhere in Chile. Gold grades at the El Salvador mine are in the range 1-2g/t Au and during its lifetime the mine has produced about 551kg of gold. The Potrerillos porphyry copper deposit is located about 60km SE of the El Salvador mine. It too was relatively enriched in Au carrying up to 0.3g/t Au. The most interesting feature at Potrerillos is the occurrence of the Silica del Hueso epithermal precious metal deposit 500m topographically above and 1.2km east of the main Cobre porphyry copper body. Gold mineralisation at Silica del Hueso occurs within steeply-dipping, silicified zones, and in tabular, silicified zones in Jurassic carbonate host-rocks (c.f. Carlin-type deposits). Advanced argillic alteration characterises host rocks on the margins of the silicified zones

(Codelco 1987). At Silica del Hueso and in the top of the Potrerillos orebody fine gold (less than 2 microns) is disseminated through highly silicified rock (probably originally carbonate) and altered feldspar porphyry. Codelco (1987) report 16 x 10^6 tonnes of ore at Silica with Au ranging from 1.68g/t to 7.71g/t. The proximity of the Potrerillos and Silica del Hueso orebodies, the similarity of host rocks, and the occurrence of Au-bearing silicified zones in both deposits argue strongly for a cogenetic hydrothermal system. Age dating (Quirt et al. 1969; Olsen 1983) appears to confirm this assumption. In both deposits, mineralised samples fall within the range 39-35Ma, given this it seems very unlikely that the Potrerillos and Silica del Hueso orebodies are the products of two unrelated hydrothermal systems.

About 20km east of the porphyry copper belt early Miocene volcanic centres dominante the high cordillera of the Andes. In the more deeply eroded centres epithermal precious metal mineralisation is under investigation at the Esperanza and La Coipa prospects. At Esperanza most of the mineralisation is located in steeply-dipping, highly silicified, northerly-striking zones and in strongly silicified, tabular bodies. Primary mineralisation is very rare and Ag, the principal metal, usually occurs in secondary form as chlorides and bromides along with native silver, iodargyrite and argentojarosite. Gold is mainly confined to cross-cutting, subvertical, northerly-striking silicified zones up to 10m wide.

At La Coipa an old silver mine exploited vein and disseminated mineralisation in dioritic and quartz-rich porphyry bodies. Ore consisting mainly of pyrite, chalcopyrite, and arsenopyrite contained up to 149g/t Ag and 1.5g/t Au. At the new prospect mineralisation occurs in funnel-shaped, silicified zones within Miocene volcanics. Again much of the mineralisation occurs in secondary form in the porous, dacitic volcanics. The principal ore minerals are Ag chlorides and bromides, cerargyrite, argentojarosite, and electrum. Mineralisation at La Coipa and Esperanza is probably of early Miocene age.

CONCLUSIONS

Tentative conclusions would suggest that hydrothermal mineralisation in the region has continued without a break from the Mesozoic onwards, though with a continuing eastward shift of the hydrothermal front and that porphyry copper deposits pass up into epithermal precious metal deposits.

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GEOLOGIC SETTING AND CHARACTERISTICS OF LODE-GOLD DEPOSITS IN THE REDDING 1 X 2 DEGREE QUADRANGLE, KLAMATH MOUNTAINS, CA.

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The southern Klamath Mountains in the Redding 1 X 2 degree quadrangle consist of four arcuate belts of accreted eugeosynclinal rocks, which contain both volcanic and sedimentary units of Paleozoic and Mesozoic age. The tectonostratigraphic terranes are separated by eastward-dipping thrust faults. The accreted terranes are intruded by granitic plutons and associated hypabyssal rocks of Devonian through Cretaceous age, which form another series of eight belts composed of bodies of equivalent age and which have been divided into pre- and post- amalgamation catagories. The terranes also contain mafic to ultramafic intrusive complexes, particularly along and adjacent to, tectonic contacts between them. Regional metamorphic grade of the volcanic and sedimentary rocks varies from unmetamorphosed to amphibolite facies.

More than seven million ounces of gold have been produced in the three eastern most belts from metamorphic fissure veins in a variety of host rock lithologies. Most of the highly productive lode-gold districts are situated between pre- and post-amalgamation plutonic belts and are located within a few kilometers, at most, of the contact between host rocks and one or more granitic plutons. Most of the districts have two or more petrographically distinct sets of intermediate to felsic hypabyssal dikes and sills that are spatially associated with, and frequently contain, gold-bearing quartz veins. These hypabyssal rocks are believed to be offshoots of the larger plutonic bodies.

The French Gulch-Deadwood district (largest producer in the Klamath Mountains) and nearby Whiskeytown district are local-scale examples of the relationships among plutonic belts, plutons, and dikes. The most productive mines are situated between the Early Devonian Mule Mountain stock, (pre-amalgamation) and the Early Cretaceous Shasta Bally batholith (post- amalgamation). The gold-quartz veins are closely associated with dikes and sills, which are composed of quartz porphyry, quartz diorite, dacite, and diorite.

The regional and local settings of the lode-gold deposits in relation to plutonic belts and individual plutons and their hypabyssal offshoots suggest that two (or more?) intrusive granitic events, one pre- and the other post-amalgamation, may have been necessary for the concentration of mineable quantities of gold in the southern Klamath Mountains.

In the Redding quadrangle, gold-bearing quartz veins occur in a variety of settings: (1) In greenstone, with or without metarhyolite of Devonian age, where the host rocks are within the greenschist facies in the Old Diggings, Shasta-Redding, and several other districts in the Eastern Klamath terrane; (2) In greywacke and argillite of Late Devonian to Early Carboniferous age that are in thrust contact with underlying Devonian greenstone, and also along the thrust contact itself. These veins are associated with dikes and sills of diorite, quartz diorite, and quartz porphyry. Examples are found in the French Gulch-Deadwood, Minersville, and Whiskeytown districts in the Eastern Klamath terrane; (3) In slaty argillite and chert of Late Paleozoic or Triassic age as in the Harrison Gulch and Hayfork districts in the Hayfork terrane; (4) In Paleozoic (?) hornblende schist and gneiss of amphibolite facies grade, associated with pegmatite and aplite dikes. Examples are found in the Canyon Creek-East Fork and Bully Choop districts in the Central Metamorphic terrane; (5) In the Devonian Mule Mountain stock and coeval Devonian rhyolite in the Shasta-Redding district in the Eastern Klamath terrane; (6) In the intrusive Early Cretaceous Shasta Bally batholith in the South Fork district in the Eastern Klamath terrane.

Quartz veins in all these settings are medium to coarse grained and contain variable amounts of wall rock fragments and subordinate calcite. The sulfide content is generally low, with pyrite being the most common form, and is commonly concentrated in the wall rock inclusions and in the wall rocks immediately adjacent to the veins. Other sulfide minerals, in order of decreasing abundance, are arsenopyrite (particularly in argillite-greywacke-hosted veins), galena, sphalerite, pyrrhotite, and molybdenite. Gold tellurides are present only in greenstone-hosted veins. Elemental gold occurs in quartz and pyrite.

Wall rock alteration adjacent to quartz veins depends on host rock lithology. In greenstone and metarhyolite, sericitic assemblages occur. Hornblende schist is chloritized. Dikes and sills have sericitic, chloritic and (or) albitic assemblages with local silicification and carbonatization. Except for local silicification, wall rock alteration in argillite-greywacke is not obvious.

Trace element associations in the veins vary between districts and show no relationship to host rock chemistry. Ag content of quartz veins in the mineralized districts of the Klamath Mountains is generally low (less than about 10 ppm) with Ag/Au usually less than 1. The South Fork district is an exception, with Ag abundances in Ag-Pb-Zn-Cu-rich veins ranging from 50 to 5000 ppm and Ag/Au greater than 100. Arsenic is highest (greater than 1000 ppm) in argillite-greywacke-hosted veins. Te (2 - 20 ppm) and B (50 - 300 ppm) are highest in greenstone-hosted veins. Cu (10 - 100 ppm) and Pb and Zn (both 10 - 1000 ppm) are highest outside the South Fork district in hornblende-schist-hosted veins.

Other than immediately adjacent to veins, standard wall rock geochemistry is not a good guide to ore. However, chondrite-

normalized rare-earth-element patterns show changes in shape as far as 500 meters from large vein systems in greywacke-argillite and greenstone, and may prove useful for exploration in such rocks.

Lode Gold Mining Districts of Redding 1X2 Degree Quadrangle, Klamath Mountains, California

Eastern Klamath Terrane

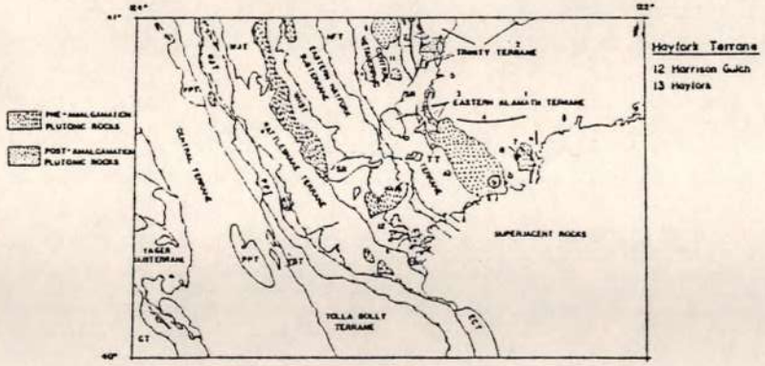
1 Backbone
2 Dog Creek (Delta)
3 Eastman Gulch
4 French Gulch-Deadwood
5 Minersville
6 Old Diggings
7 Shasta-Redding
8 Whiskeytown
9 Southfork

Central Metamorphic Terrane

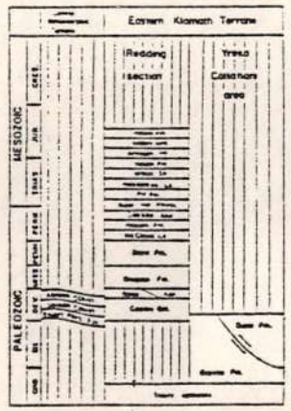
10 Bully Choop
11 East Fork-Canyon Creek

Hayfork Terrane

12 Harrison Gulch
13 Hayfork



AFTER FRATICELLI, ALBERS, IRWIN, AND BLAKE (IN REVIEW)



Comparative Stratigraphic Columns of the Eastern Klamath Terrane and the Central Metamorphic Terrane (After Irwin, 1981, and Lanphere and Irwin, 1987)

Thickness not to scale

VEIN MINERALOGY, PRODUCTION, Au/Ag - DIFFERENT DISTRICTS

Old Diggings district:

Production - Approximately 200,000 oz Au (Hotz, 1971)
Mineralogy - Pyrite, chalcopyrite, Au and Ag bearing tellurides, free gold.
Au/Ag - 1.0

French Gulch-Deadwood (includes Minersville and Eastman Gulch) district:

Production - Between 800,000 oz Au (Hotz, 1971) and 1,500,000 oz Au (Clark, 1963).
Mineralogy - Pyrite, galena, sphalerite, arsenopyrite, and rare chalcopyrite. Free gold in quartz and in sulfides.
Au/Ag - 8.9

Canyon Creek- East Fork district:

Production - 110,000 oz Au (Hotz, 1971)
Mineralogy - Pyrite, galena, sphalerite, free gold in quartz, and also associated with sulfides.
Au/Ag - 1.4

Harrison Gulch district:

Production - Approximately 200,000 oz Au (Hotz, 1971)
Mineralogy - No published information, in spite of large production from the Midas mine. Probably similar to French Gulch.
Au/Ag - 3.1 (very limited data)

Hayfork district:

Production - Approximately 5000 oz Au (Hotz, 1971)
Mineralogy - Pyrite, galena. Free gold in quartz, some in pyrite.
Au/Ag - 20 (very limited data, very low Ag)

South Fork district

Production - Approximately $1,000,000, mostly from Ag. Low Au production.
Mineralogy - Tetrahedrite, galena, sphalerite, pyrite, native Ag, native Au, chalcopyrite.
Au/Ag - 0.003

Geochemistry of selected high grade quartz vein samples from lode gold districts of the Klamath Mts., CA.

Mine	Au	Ag	As	Hg	Te	Cu	Pb	Zn	B
Old Diggings District									
Reid	70	50	<5	0.7	21	200	<5	<5	300
French Gulch-Deadwood district									
Summit	75	70	1100	0.02	2.1	5	20	10	50
Brown Bear	50	3	>10000	0.02	0.7	5	20	5	20
Canyon Creek-East Fork district									
Enterprise	86	23	658	1.8	—	21	267	165	20
Ozark	76	27	3126	1.0	—	12	60	56	10
Harrison Gulch district									
Midas	34	7	400	0.1	1.0	20	15	<5	10
Hayfork district									
Kelly	22	0.5	190	0.06	1.0	<5	30	5	10
South Fork district									
S.F.-Chicago	4.3	300	10	>10	0.05	700	2000	10000	10

Bicentennial Gold 88, Melbourne, May, 1988

Geochemical Summary, French Gulch district - Quartz Veins

Area	Au	Ag	Hg	Cu	Pb	Zn	Sb	Host Rock
Center (21)	0.2	225	0.02	11	10	12	28	Arg/Gy/Dk
East (4)	0.5	71	0.02	9	7	5	14	Arg/Gy/Dk
West(Br.3.) (3)	2.1	6772	0.02	11	27	2	27	Arg/Gy/Dk
Eastman * (2)	10	30	0.06	39	77	58	12	Grnst/Dk
Total (10)	0.04	*	<0.02	7	6	9	17	Arg/Gy/Grnst

Geochemical Summary, French Gulch Mining District
Wall Rocks and Host Rocks

Rock Type	Au	Ag	Hg	Cu	Pb	Zn	Sb
Argillite (Background)	<0.05	4.5	0.09	41	21	82	99
Argillite (Wall rock)	<0.05	56	0.04	32	17	68	77
Greywacke (Background)	<0.05	2.6	0.05	28	13	54	58
Greywacke (Wall rock)	<0.05	16	0.03	28	13	36	50
Greenstone (Background)	<0.05	2	0.02	58	6	49	15
Greenstone (Wall rock)	<0.05	9	0.01	50	6	44	13
Dike-Feor (Background)	<0.05	10	0.03	15	15	42	54
Dike-Feor (Wall rock)	0.05	98	0.03	10	13	31	34
Dike-Qtz (Background)	<0.05	10	0.02	15	30	30	150
Dike-Qtz (Wall rock)	0.21	512	0.02	6	13	17	73

Arsenic Contents of Eastern Klamath Dikes

	Average	(No)
Background:		
Biotite-Feldspar Porphyry	1	(4)
Feldspar-Quartz Porphyry	10	(7)
Sirdseve Porphyry	1	(2)
Associated with gold bearing quartz veins:		
Biotite-Feldspar Porphyry	1700	(1)
Feldspar-Quartz Porphyry	14	(1)
Sirdseve Porphyry	152	(4)

Geochemical Summary, Old Digging district

Rock Type	Au	Ag	As	Hg	Cu	Pb	Zn	Sb
Quartz Vein	0.9	1.5	< 5	0.14	12	< 10	< 5	36
Wall Rock Greenstone	0.07	0.4	< 5	0.02	67	< 10	45	47
Host Rock Greenstone	<0.05	<0.5	2	0.02	58	< 10	49	15

Geochemical Summary, Canyon Creek-East Fork district

Rock Type	Au	Ag	As	Hg	Cu	Pb	Zn	Sb
Quartz Vein	2.5	1.5	45	1.2	12	17	30	13
Wall Rock Gneiss	0.03	0.09	9.1	0.9	34	2.6	55	14
Host Rock Gneiss	0.02	0.04	2.4	<0.5	33	1.3	27	22
Igneous Rock	0.01	0.06	2.3	<0.5	17	1.7	14	16

THE CHARACTERISTICS OF EPITHERMAL MINERAL OCCURRENCES IN THE BENGKULU PROVINCE, SUMATRA

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ABSTRACT

The characteristics of 13 epithermal mineral occurrences in the Bengkulu Province, including the Lebong Tandai mine, have been reviewed. Epithermal mineralization is structurally controlled in veins and breccia lenses in Miocene andesitic volcanics, and is spatially related to brecciated margins of dacite intrusions. Mineralization is shown to have occurred before uplift of the Barisan range in Sumatra. The mineralized systems are in general classified as low sulphidation type, characterised by high Ag/Au ratio, base metals, As, Sb sulphosalts, Se, and propylitic wallrock alteration (chlorite - epidote), with important K-metasomatism. Of particular interest in the area, is the former Lebong Donok mine, which apart from being historically the richest gold mine in Indonesia (41 tonnes gold), has important similiarities to the Hishikari deposit in Japan.

GEOTECTONIC SETTING OF GOLD-BEARING AREAS IN CENTRAL AMERICA

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The volcanic belts, one of which is the Central American segment of the Pacific gold-bearing ring, are characterized by complex heterogenous structure and polygene mineralogeny that is largely explained by the position of this segment of the earth crust in the continent/ocean transition zone with high tectonic and volcanic-plutonic activities.

Of a great importance in distribution of gold mineralization is a tectonic zonation transverse the Cordillera structures accounted for by the block structure of the territory. One of the blocks with variable geologic history and metallogeny, is the Central American block bounded by the Clipperton-Cayman fault in the north and a system of Galapagos faults in the south. The Central American block is cut by transverse faults responsible for the complex inner block zonation emphasized by sedimentation pattern, sedimentary thickness, magmatism, variably high levels of prevolcanic rocks, which altogether played a significant role in formation and localization of different types of gold mineralization and gold placers.

On the basis of information available on the Pacific volcanic belts both in the American and Asia segments, and data obtained by the authors from the analysis of the metallogeny in the Central American segment, it appears possible to recognize three types of geotectonic setting, two of which being known for the richest sources of the most economically important gold placers in the region.

1. Massifs and uplifts of the prevolcanic basement built up by pre-Jurassic variably metamorphosed commonly carbon-matter-rich flishoid rocks intruded by early Cretaceous granitoids. The ore bodies are represented by quartz-pyrite-chalcopyrite-arseno-pyrite and quartz-pyrite-chalcopyrite-galena-spalerite poor-sulphide veins almost conformable to the host rock bedding (the veins of the pre-activization stage).

2. Relatively uplifted parts of the massifs tectonically activized in the Cenozoic, which are composed of Cretaceous-Neogene sedimentary-volcanogenic formation intruded by granitoid bodies, stocks and dikes of Paleogene-Neogene age. The fragments of the volcanic zones on the consolidated basement are represented by andesitic, trachy-andesitic and occasional andesitic-liparitic formations. The ore bodies are represented by quartz veins, metasomatites with gold and polymetallic mineralization, stockworks with copper-porphyric gold-bearing mineralization. Significantly thick crust of weathering developed on this type of deposits in conditions of ascending neotectonic movements has become a source of small but sometimes rich gold placers such as those in Nicaragua and Costa Rica.

3. The third type of setting is the Cordillera volcanogenic belt trending along the Pacific coast. The deposits are confined to the Pliocene paleocalderas situated on the crossings of the long-life east-north-east trending faults (transverse) and north-west (Cordillera) trending faults. The ore bodies (quartz veins and silicified shear zones) localize in a system of ring and linear fractures breaking weakly erroded paleocalderas. The multi-stage history of the deposits is reflected in complicated mineral composition of ore containing significant silver and less than 1% sulphides. Gold occurs as fine dispersed specks. The deposits of this type are of little value as a source of placers.

GOLD-ANTIMONITE DEPOSITS IN MARINE SEDIMENTS OF THE EASTERN CORDILLERA OF THE BOLIVIAN ANDES

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Introduction

In the central and southern part of the Eastern Andean Cordillera of Bolivia more than 500 antimonite deposits are known. They form an antimoniferous belt which overlies the famous Bolivian tin-silver province (AHLFELD & SCHNEIDER-SCHERBINA 1964). Antimony contributes 5 - 10 % of the Bolivian export volume.

In many of the antimonite deposits gold is a byproduct, just a few mines produce only gold. The antimonite-gold mines belong mainly to the medium and small scale mines of Bolivia, which are mostly held by private owners. Since the breakdown of the international tin market in 1985 Bolivia is on the way to a diversification of mining production. Antimony and gold are increasingly important for displaced miners in the Andean Highlands.

Fig. 1 shows the distribution of antimonite and gold antimonite deposits in Bolivia



Fig. 1: Geotectonic sketch map of Bolivia with the locations of antimonite and gold antimonite deposits

Geological setting of the gold antimonite deposits

The Eastern Andean Cordillera is formed mainly by lower Paleozoic sediments which were intruded by intermediate to acid batholiths and subvolcanic stocks in the Permian, Triassic and Tertiary. The sequence of sandstones, siltstones and black shales more than 10 km thick formed in an intracratonic mobile belt. The detrital supply probably came from an area of erosion west of the basin (ZEIL 1979). The rocks are unmetamorphosed or only weakly metamorphosed.

A brief stratigraphic classification is possible by graptolites, brachiopodes and trilobites. Typical fossils are feeding trails of undeterminable animals.

The sediments show a flyschoid interbedding of sandstone, siltstone and black shales in dimensions of some cm to several meters. In the Ordovician series sandstones dominate while in the Silurian mainly siltstones and black shales occur.

The black shales are locally rich in sulphides, particularly disseminated pyrite and arsenopyrite. Relictic framboidal pyrite suggests that pyrite was precipitated in the sediment.

The gold antimonite deposits are all situated within the Ordovician and Silurian sedimentary sequence.

Regional tectonics and mineralizations

During the late Paleozoic the sedimentary basin of the Eastern Cordillera was affected by compressive tectonics. Large syncline-anticline structures with relatively low grade of compression were created. Faulting related to the compression tectonics such as diagonal faults and ac-faults in folded structures are common.

The mineralized quartz veins are frequently bound to ac-faults and saddle reefs (Fig. 2). Ore textures suggest a syndeformative formation of the mineralized veins in most cases. There are also deposits bound to fractures formed during the Tertiary and Quarternary. These deposits are mainly related to regional faults parallel to the Altiplano border and show some indications of hot spring activities.

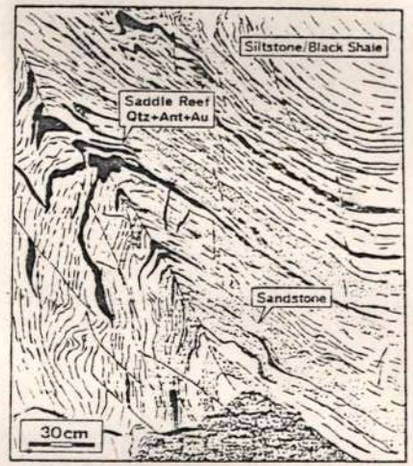


Fig 2.: "Saddle reef" gold-antimonite mineralization; Candelaria - San Juan Mine

Geochemistry and Mineralogy

The chemical composition of the ores is characterized by Sb, Fe and Au. Contents of Zn, Pb, Ag are not of economic importance.

The ore minerals occuring in the quartz carbonate veins are antimonite, pyrite, arsenopyrite, jamesonite, sphalerite, chalcopyrite, galenite, berthierite and complex sulfosalts.

Native gold is always found together with late antimonite, jamesonite, pyrite or sphalerite in fractures of quartz or carbonate. Gold is intergrown in the following forms:

Gold quartz intergrowth: mostly inclusions of gold are found in milky quartz. Rarely euhedral gold crystals grew in cavities of quartz gangue.

Gold antimonite intergrowth: gold forms very complex forms of intergrowth with antimonite. Gold is found in fractures in antimonite, grown on its surface, as minute inclusions in fine grained antimonite and in a symplektitic texture. The gold antimonite intergrowths are the most frequent and very problematic for gold recovery.

Gold pyrite intergrowth: gold fills mostly fractures in cataclastic older pyrite or forms minute inclusions in late pyrite.

Gold sphalerite intergrowth: gold is grown on fractures of older sphalerite together with younger sphalerite.

Gold/silver ratios

Microprobe analyses show that two compositional groups of gold can be divided. Gold associated with antimonite is lower in Ag (0 - 1.5 %) than gold intergrown with quartz, sphalerite or pyrite (1.6 - 6.5 %) as seen in Fig. 3. This fact suggests a partitioning of Ag between gold and the intergrown minerals. Generally gold shows a high degree of fineness with gold/silver ratios ranging from 15 to 99.

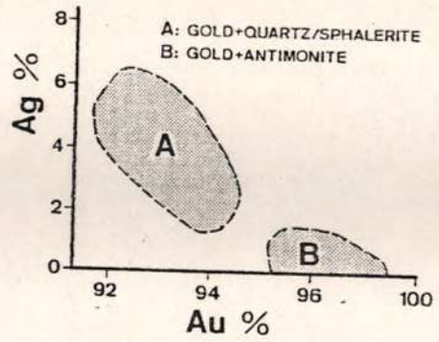


Fig 3.: Au/Ag contents of native gold from Bolivian gold-antimonite deposits

Fluid inclusion study

Preliminary fluid inclusions investigation shows two types of inclusions. The most common inclusions are water rich, and have a range of homogenization temperature from 130 to 200 °C. Mixed CO_2-H_2O inclusions occur in some samples with a homogenization temperature of about 275°C.

Hot springs related with gold antimonite deposits

AHLFELD (1974) gives a review of the correlation of hot springs with antimonite deposits in Bolivia. Within our study in some localities recent formation of antimonite from hot springs could be proved. Trace element analyses by ICP-MS showed elevated gold contents (100 ppb) in some precipitate samples from Bolivian hot springs.

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A STUDY OF THE CHARACTERISTICS OF GOLD DEPOSITS ADJACENT TO THE WEST PACIFIC COAST

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Several types of gold deposits are distributed along the west Pacific coast. Two belts enriched with gold deposits were formed. These are divided according ro the deposits' distribution pattern, inner belt or outer belt.

The formation of the belts is directly related to the subduction that occured along the Benioff belt between the Pacific and the Asiatic Plates. As the subduction depth increased, the chemical composition of the magma in the arc island province changed from tholeiite series to calc-alkali or alkali series. The center of igneous activity moved gradually from oceanic area to continent.

Analysis of the special lithological association formed in the upper area of the Benioff shows obvious subductions in the belts. As a result of the plates colliding and subducting, two belts enriched with gold deposits were formed.

In the inner belt, different types of gold deposits are distributed as a island arc. The island arc, most clearly from the Kamchatka penninsula passing Japan, Liuqiu, Taiwan, and ending at the Philippine island, is thousands of kilometers in length and narrow in width along the western coast of the Pacific ocean. The formation of deposits is dependent on Tertiary volcanism, which includes a series of magma from basic to acid. The gold deposits were formed in the Cenozoic period. The chatacteristics of the outer belt, however, were controlled by deeper and larger faults and by Procambrian formations. The belt extends from Siberia through Northeast China, through parts of Northern, Eastern, and Southern China. It is longer and wider than the other belt. The genesis of gold deposits is varied and complex. The formation of deposits is related closely to Mesozoic acid-middle-little intrusive bodies. Moreover, the metallogenic procees continued a long time.

The genesis of gold deposits on one hand is closely related to the geochemistry characteristics of gold; on the other hand, the Tectonic form of the belts determined the genesis series, the distribution pattern, and the metallogenic epoch of the deposits. The belts are in the active background where the Pacific and Asiatic plates collided. There is great deal of igneous intrusive in the area. There is also Archaean greenstone. Proterzoic metamorphic rocks, andother gold-bearing bodies distributed in the area.

The genetic types of gold deposits in the belts mainly are:

1. The gold deposits in Archaean greenstone belts (volcanic exhalative gold deposits related to felsic volcanic rocks. Gold deposits associated with Zn-Cu type massive sulfidedeposits). These are different from those in other areas of the world in

characteristics. These kind of gold ore bodies mainly occur in different gold-bearing rock associations. They are riband dimica-ceous-plagioclase leptynite, banded chlorite-biotite-hern-quartz schist, magnitite-hornblend quartzite, biotite leptynite, etc. The original rocks are felsic tuff intercalated with a little lava siliceouiron.

The ore bodies are mainly vein in shape. The paragenesis of ore minerals is simple, mainly sulfeside of Fe, Cu, Pb, Zn, and gold and silver--the gold located mainly in pyrite, Galena, chal-conyrite, etc.

These types of gold deposits are distributed in the outer belt, especially in China's Northeast, and in the Eastern of China. Typical deposits include: Jiapigou gold deposit in Jilin province, Wulong gold deposit in Liaoning province, Linglong and Jiaojia gold deposits in Shandong province.

2. The gold deposits in BIF. They are stratum in the shape of ore bodies. The ore minerals were controlled or influenced by the wall rocks. The gold deposits are fewer in number and they are limited strictly by BIF, which are composed of fine quartz crystal and magnetite. The gold occurs in the native and lies in the space of intermineral granular.

These types of gold deposits are mainly distributed along the edge plate in the outer belt. Dongfeng shan gold deposit in Hei-longjiang province of China is typical.

3. The gold deposits in volcanic rocks or sub-volcanic rocks. These deposits are more widely distributed in the area, especially in the inner belt. Volcanism plays an important role in the for-mation of deposits. The post-products of volcanism are fluids which contain large amounts of metallogenic material, which, when combined with gold, change into a coordination compound. The che-mical and physical conditions are then suitable for precipitation.

The shape of the deposits is controlled by the internal structure of the volcanic or sub-volcanic rocks--mainly irregular veins. The typical wall rock alternation is cryo-feldspar. The ore mineral association is complex; mainly Telluride, sulfurate and hydro-oxide of Au, Ag, and other metal elements.

These are typical of larger gold deposits, such as the Kagoshima gold deposit in Japan, and Jinguashi gold deposit on the island of Taiwan.

4. The gold deposits in conglomerate. This kind of deposit is rare in this area; there is only one small deposit in Jilin province of China.

5. The gold deposits in rocks of the genetic types associated with thermal groundwater. There are few of thesedeposits. They are small in scale and low in production. The characteristics of these deposits are that they have fine native gold granular, are disseminated in texture, have a lower tenor in gold content, etc. These deposits are controlled by lithological factors; calcareous rocks and fine-granular malmstone are favorable. They are result of active thermal groundwater passing through gold-bearing rocks, washing the gold out of them. When heated by regional hot currents, the chemicals of gold are transported in a mobile hydro-solution,

most probably in the form of thiosulfide $[Au(S_2O_3)_2]^{3-}$ and cholrite $(AuCl_2)^-$ and $(AuCl_4)^-$ complex compounds, and form hydrothermal gold deposits.

Bologna spar is the typical alternation in these deposits. These deposits are found only in the outer belt belonging to China. Jiaoman gold deposit in Guangxi is typical.

6. The gold placer deposits in the Quarternary system. These types of deposits are more widely distributed. In this area, the distribution pattern of the deposits is related closely to micro-geomorphic characters and endogenous deposits distribution.

There are six types of gold deposits in the west Pacific coast. The metallogenic belts are spatially associated. They are related to the Archaean rocks and reformed by volcanic activity, igneous intrusion, metamorphism, thermal groundwater circulation and other geological functions.

In the adjacent west Pacific coast there is a great future for prospecting new gold deposits.

Geology, Gold Deposit Types, and Mineral Occurrences in the Yukon Tanana Uplands Schist Terrane, Alaska and Yukon Territory: A Review

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The Yukon Tanana Upland Schist Terrane of southwestern Yukon Territory and east central Alaska has produced in excess of 20 million ounces of gold since 1896. Production has come primarily from Pliocene and Pleistocene alluvial and residual placer deposits in the Klondike, Fairbanks, Circle, Eagle, Sixty Mile, and Livengood mining districts.

The polymetamorphic terrane includes an area approximately 240,000 sq. km. The terrane is composed of Precambrian and Paleozoic metasedimentary and metavolcanic rocks that range from lower greenschist to amphibolite, ecologite and granulite facies. The terrane is bounded on the north by the Tintina Fault and on the south by the Denali Fault. These strikes slip systems have displacements of 418 km and 430 km, respectively.

Recent investigations have delineated the following eight types of lode gold mineralization in the terrane:

1. Stratabound volcanic-exhalative Au-Ag-As-Sb-W mineralization in intermediate to felsic metavolcanic and metasedimentary rocks of probable late Precambrian age;

2. Disseminated and breccia-zone gold mineralization associated with Cu-Mo$^{\pm}$As$^{\pm}$Sb bearing porphyritic granitic intrusives.

3. Precious metal enriched base-metal volcanogenic massive sulfide deposits of mid Paleozoic age;

4. Epithermal gold quartz vein deposit associated with Jurassic and Cretaceous regional metamorphism and plutonism;

5. Contact metamorphic gold, copper-gold and tungsten-gold skarns associated with Jurassic and Cretaceous granitic intrusives;

6. Tin greisen-gold quartz veins associated with Jurassic and Cretaceous granitic intrusives.

7. Carlin type sediment hosted epigenetic mineralization.

8. Paleoplacer type mineralization hosted in tertiary terrestrial sediments.

Each of the above mineral occurrence type constitutes a major bulk mineable exploration target. The petrology, mineralogy, major and minor elemental chemistry, chronology, fluid inclusion and stable isotope chemistry, and structural control of the mineralization types are discussed as guides to gold exploration in the region.

Relationship Between Gold and Scheelite Mineralization in the Core of the Bohemian Massif, Czechoslovakia

P.Morávek

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Gold-bearing mineralization is one of the principal metallogenic types in the core of the Bohemian Massif. It is of vein, stockwork and stratiform characters and occurs in the both fundamental geological units: in the low-grade metamorphosed Barrandian and in the high-grade metamorphic Moldanubian blocks. The results of recent studies indicate mobilization of gold from Upper Proterozoic volcanosedimentary formations by effects of Variscan granitization and/or regional metamorphism. Spatial association of gold mineralization with scheelite mineralization in the core of the Bohemian Massif is its characteristic feature. Their relationship has been studied both on a regional scale and in detail.

On a regional scale, the Au-metallogenic zone and areas of scheelite anomalies show an analogous course /fig. 1/. At the contact area between Barrandian and Moldanubian blocks, they exhibit a transverse zoning controlled by the metamorphic grade; while gold mineralization is located mainly in the domain of low-grade metamorphism, the area of scheelite anomalies is shifted into that of high-grade metamorphism. In the crystalline Moldanubian complex, zones of gold and scheelite mineralization occur together. The distribution of Au and W in the rocks of both geological units shows their pre-Variscan enrichment - in the Proterozoic and partly the Lower Paleozoic /fig. 2/. This distribution pattern and the spatial relationship between gold and scheelite metallogenic zones indicate a possible pre-Variscan sources of gold and tungsten and a connection of gold and scheelite mineralizations with pre-Variscan structures.

In individual gold districts, scheelite forms either ore bodies or it is present as an accessory mineral in the gold-bearing quartz veins. The spatial distribution of scheelite bodies and their stratiform or lenticular character are controlled by lithology. These bodies are confined to layers of mafic rocks with high Ca-contents /basic tuffs, Ca-Si hornfels, hornblende gneiss/. The orientation of the scheelite bodies is either parallel to the gold mineralization /Kašperské Hory deposit - fig. 3/ or transverse /Čelina deposit - fig. 5/ - in this case gold mineralization cuts across the stratiform scheelite bodies. Scheelite is one of the oldest minerals of the vein-type gold mineralization.

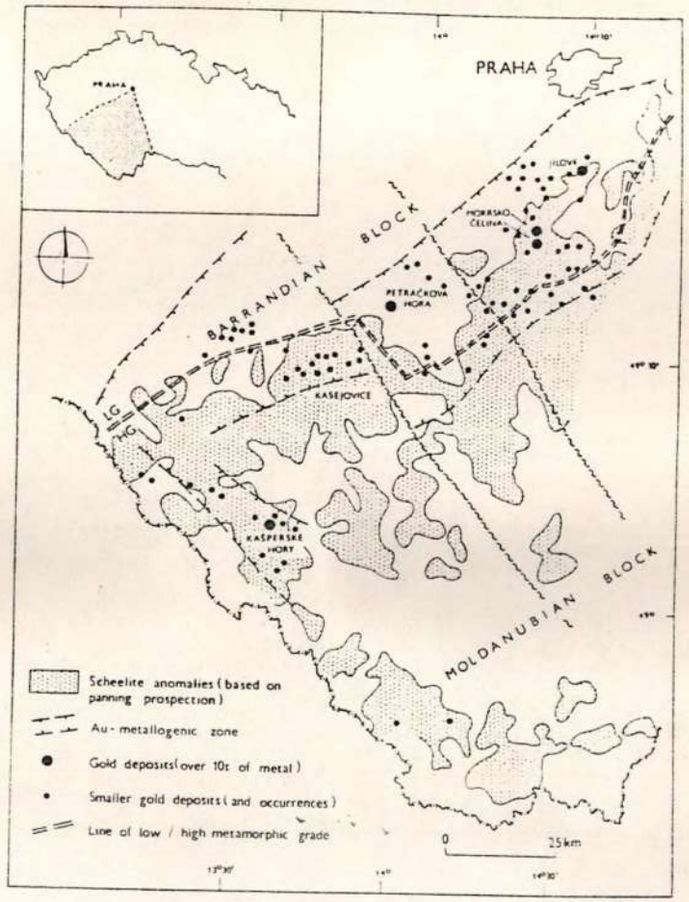


Fig. 1. Distribution of gold mineralization and scheelite anomalies in the central part of the Bohemian Massif.

The distribution of scheelite in gold districts frequently dispays a zonal character. Scheelite prevails in the deeper parts of deposits together with Bi,Te and Mo, whereas in the middle and upper parts, As, and Ag, As, Cu, Pb and Sb respectively, are present /Jílové deposit/. Scheelite occurs predominantly under the gold pay ore /Mokrsko deposit - fig. 6/. Likewise, stratiform scheelite mineralization occurs above all in the footwall of the gold mineralization /Kašperské Hory deposit - fig. 3/.

The results of the study indicate not only a close spatial, but also a genetic association of gold and schee-

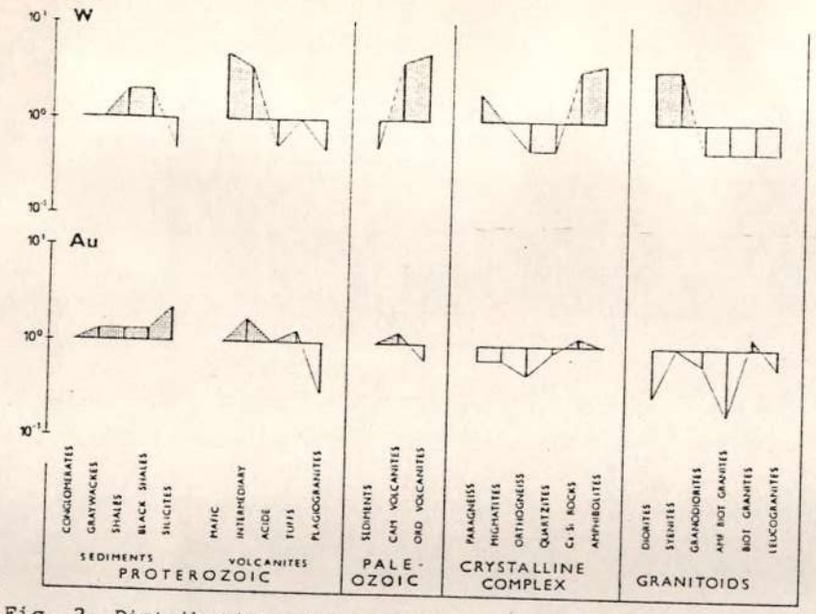


Fig. 2. Distribution of Au and W in the geological units of the Bohemian Massif. Au and W values normalized by median concentration in the Bohemian Massif /W=1 ppm, Au=3 ppb/. Correlation coefficient = 0,63. N = 1986

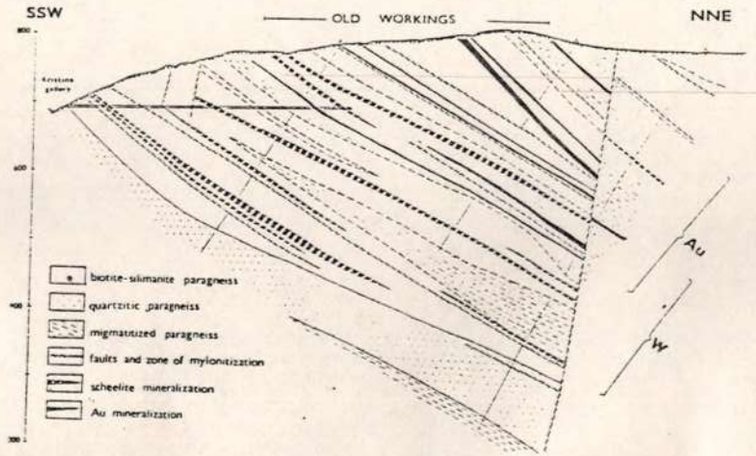


Fig. 3. Kašperské Hory deposit - cross section /after Punčochář 1988/.

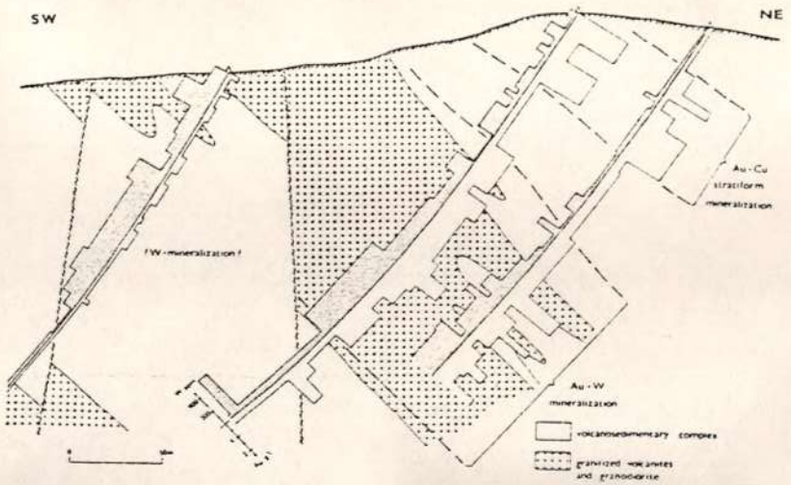


Fig. 4. Petráčkova hora deposit - cross section /after Studničná 1988/

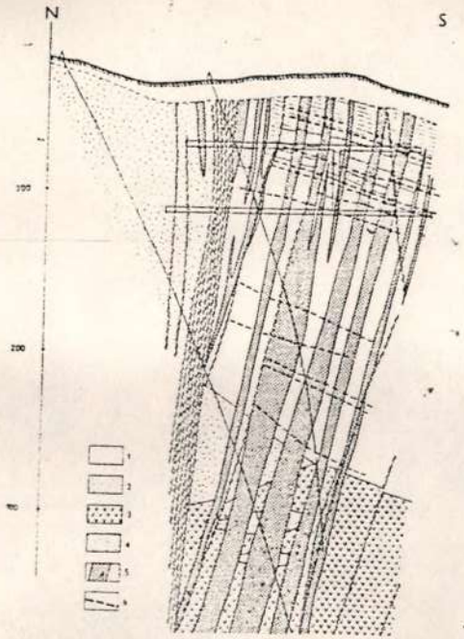


Fig. 5. Čelina deposit cross section
1-intermediate to basic tuffs
2-acid tuffs and lavas
3-plagiogranite
4-basic volcanics
5-Au-bearing quartz stockworks
6-stratiform scheelite mineralization

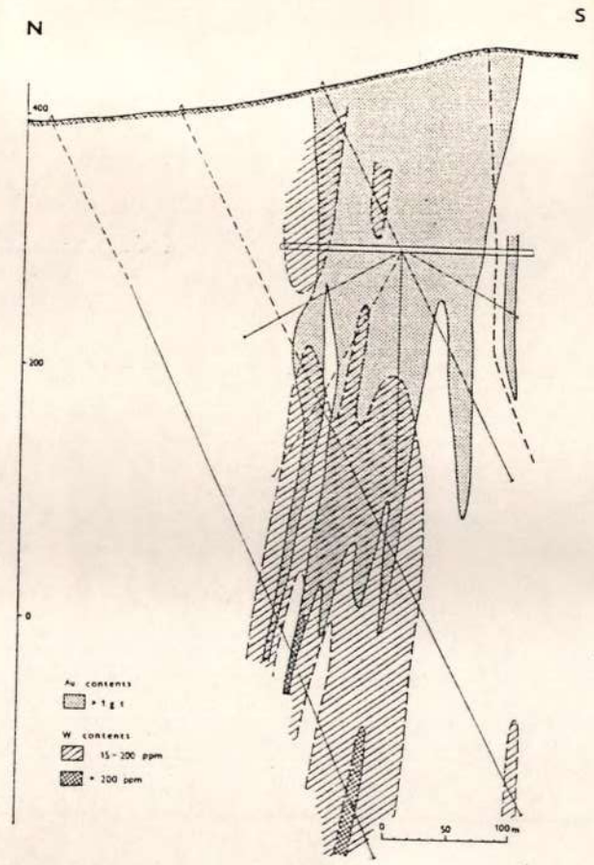


Fig. 6. Mokrsko deposit - cross section.

lite mineralization in the core of the Bohemian Massif. A part of scheelite ore accumulations is assumed to be syngenetic, of hydrothermal-exhalative origin and of pre-Variscan age /mainly Upper Proterozoic/. The greater part of scheelite ore concentrations is most probably epigenetic, of hydrothermal-metamorphic origin, connected with the Variscan granitization and/or metamorphism. Tungsten was probably mobilized together with gold from pre-Variscan source rocks.

TERTIARY GOLD-QUARTZ MINERALIZATIONS OF THE "TAUERNGOLDGANG" TYPE, AUSTRIA

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1. INTRODUCTION

The "Tauerngoldgang" type represents one of the more important types of gold mineralizations of the Alps. It has contributed considerably to the production of gold and silver in Salzburg and Carinthia Provinces of Austria. Mining started as early as Roman times and has continued intermittently up to 1942. The most famous gold mining centres are indicated in Fig.1.

2. GEOLOGICAL SETTING

The deposits are located within the Penninic zone, consisting of Hercynian gneisses (Metamorphosed Carboniferous to (?) Permian granites, granodiorites and tonalites) and overlying Schieferhülle (composed of (?)Precambrian, Paleozoic and Permomesozoic rocks). Geochemically, most of the granites show typical I-type, some of them S-type and others I/S transitional type characteristics (Finger & Steyrer 1988). The gold mineralizations of the Schieferhülle may be hosted by antigoritites (metamorphosed Mesozoic ophiolithes), metavolcanics or Mesozoic metasediments (phyllites, marbles)(Fig.1).

GEOLOGICAL SKETCHMAP OF THE ALPS AND THE PENNINIC ZONE OF THE HOHE TAUERN
(FINGER and STEYRER, 1988 – with friendly permission by the authors)

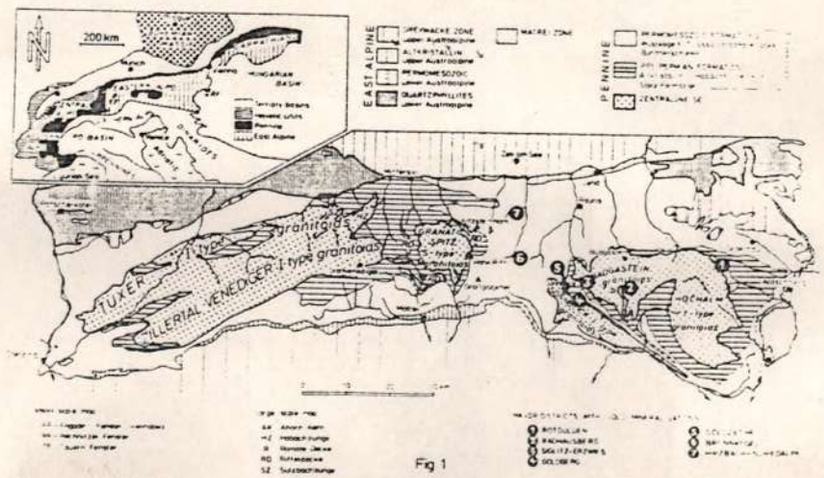


Fig.1

3. CHARACTERISTICS OF MINERALIZATION

The mineralized structures (fault zones, ductile shear zones, veins) generally strike between N and NNE, and dip from almost vertical to about 70° W or E. The major veins resp. shear zones can be traced locally for more than 8 km along strike (Siglitz-Erzwies vein system) and an extension towards depth of at least 1000 m is proven. The mineralization is irregularly distributed both along strike and dip, with high-grade ores (ore shoots) abruptly interchanging with almost completely barren sections. The shape and size of these shoots are strongly variable, the largest having a plunge length exceeding 200m, a breadth around 50m and a width of almost 2m. The steeply plunging shoots (Siglitz-, Goldberg-, Goldzeche- as well as Hirzbach/Schiedalpe Districts) have a pronounced zonation of the Au-and Ag-grades, with the highest in the core (Au 50 ppm; Ag 200 ppm) and less than 10 ppm Au resp. 30 ppm Ag in the outermost zone (Fig.2).

Long section of the DIONYS Vein (Siglitz D., Salzburg P.), showing the distribution of Au (ppm) in several ore-shoots

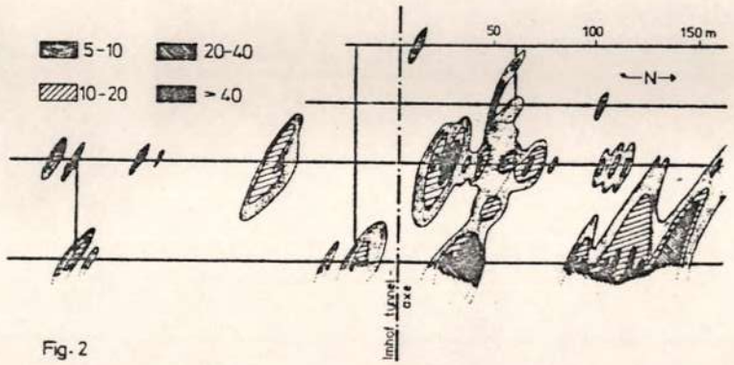


Fig. 2

Sometimes a very distinct (primary) within-deposit zoning can be recognized: an upper zone with Ag-rich galena, chalcopyrite, sphalerite in an ankerite/pistomesite gangue, giving place at depth to a Au-rich pyrite-arsenopyrite-quartz mineralization. Supergene enrichment occurred near surface with formation of relatively coarse grained gold, sometimes embedded in either goethite or scorodite. Almost all of this gold had been mined out long ago.
Wall rock alteration, such as sericitization, silicification, pyritization, carbonatization and (minor) chloritization is typical, but limited to a m-wide zone on both sides of even the thickest veins.

4. MINERALOGY

The ore mineralogy of the "Tauerngoldgänge" is very complex (Paar & Chen 1980,1982). Native gold, which is the only gold mineral of the ores, occurs (1) in wiry, dentritic, mossy, spongy as well as massive forms, (2) as drop-like inclusions (from less than 1 µm up to 80 µm)

in various sulfides/sulfosalts (py, asp, cp, ga), (3)healing fractures in cataclastic py, asp, and (4) as constituent of the py- and asp-lattices. Considering the gneiss-and metavolcanic-hosted mineralizations, native gold is characteristically associated with Bi-Te minerals (tetradymite, tellurobismutite, tsumoite), sulfosalts of the lillianite series (Ag-heyrovskyite, lillianite, gustavite, vikingite), cosalite, aikinite-type phases (gladite, krupkaite, pekoite, friedrichite, bismuthinite), pavonite-type phases, matildite and hessite. A similar mineralogy can be noted in the marble-hosted gold ores, whereas phyllite-hosted mineralizations have a quite simple mineralogy. The gold-quartz veins in the antigoritites carry significant gersdorffite, polydymite, millerite as well as the Cr-mica mariposite The latter is a very good indicator for gold in this type of environment.
The composition of the gold is quite variable and strongly dependent on the chemistry of the host rocks. Generally, a Au/Ag (atomic)ratio from 10:1 to 2.5:1 is typical for the metaplutonite-hosted mineralizations, whereas ratios between 3:1 to 1:1 are predominant in metasediment environments (Fig.3).

Composition of Au (wt %) from vein-type and strata-bound occurrences in Salzburg/Carinthia, Austria.

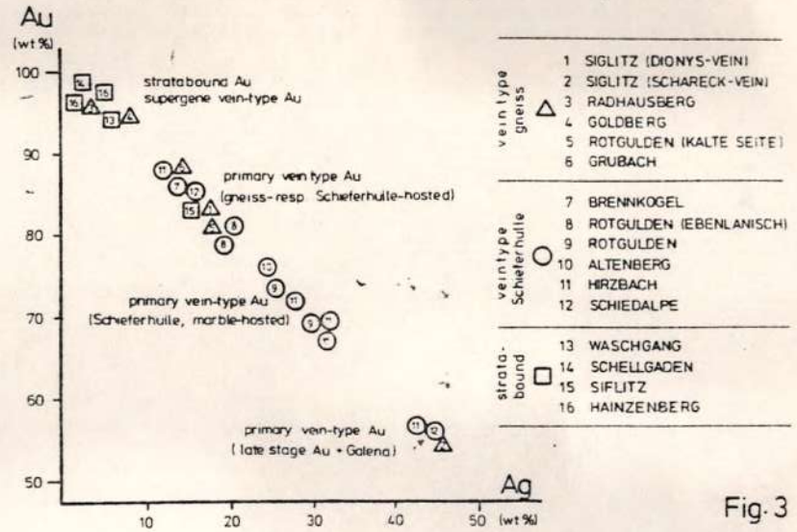


Fig. 3

5. AGE OF MINERALIZATION/CONDITIONS OF FORMATION

In some regions (Siglitz-Erzwies and Rotgülden) the mineralized structures of the gneiss extend into overlying paraautochthonous Mesozoic calcite and dolomite marbles of Triassic/Jurassic age, thus indicative of a Post-Jurassic age of the structures. An Alpidic age of the Tauerngold mineralization is widely accepted among scientists, with deposition of the ores at several stages during a late (Tertiary)

phase of the Alpidic metamorphism.
Preliminary studies of fluid inclusions of vein quartz associated with the gold mineralization indicate temperatures of formation ranging from ~180°C (in some metasediment environments) up to 350°C (but less than 470°C) for gneiss-hosted mineralizations. This estimations are in good accordance with temperatures derived from the arsenopyrite-geothermometer as well as mineral stabilities and critical assemblages (.ieyrovskyite-lillianite-galena).

6.FINAL REMARK

Preliminary calculations of ore reserves only in the Goldberg-Siglitz/Erzwies Districts yield more than 10, t of gold ore averaging 6 ppm Au, 30 ppm Ag, as well as valuable concentrations of Cu,Zn,Pb. A reinvestigation of the"Tauerngoldgang" type is thus highly recommendable.

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Study on The Geochemistry, Lithology and Metallogeny of Zhao-Ye Migmatitic Hydrothermal Gold Deposits Belt

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Zhao-ye gold deposits belt (Z-Y) is the largest gold producing area in China. It located at western Yantai district, Shandong prov.

I. This belt lies E-W covered an area approx. 200x30 Km. Geotectonically, occurred in the western portion of East Shandong shield of North China Platform,it's western boundary is cross cut by N-S Yi-Shu Deep Fauit, and is contiguous to the Pacific Plate on it's east.Archean Jiaodong Group (Arj, Mainly biotite granulite & plagioamphibolite)is the predominate stratum outcropped in this region. Regional tectonic activities went on intermittently since early Pt. (The forming of E-W Qixia anticlinorium basement) up to Mesozoic Yenshan Movement (remobilization of East Shandong Shield). NW & NE-NEE fault systems were formed subsequently during this long period. This is one of the typical example of "remobilized platform area" in China.

II. Gold mineralization only occurred in migmatitic granitoids namely Linlong gneissic biotite granite and Guojialin K-felspar porphyroblastic granodiorite. At least 5 geologic heat events happened in this area that related or affected to the forming of granitoids and gold mineralization. The isotopic data are listed below (in m.y. b.p.):

Arj: 1,900-2,900 (U-Th-Pb), 1,800-3,600 (Rb-Sr), 1,200-1,900 (K-Ar); migmatitic granitoids: 1,200-1,900 (U-Th-Pb), 600-1,000, 1,200 (Pb-Pb), 1,900-2,600 (Rb-Sr), 100-476 (K-Ar); ore: 400, 600-1,000, 1,200 (Pb-Pb), 110 (K-Ar).

The author expounds: 1). The age dated earlier than 2,900 m.y. b.p. was the forming age of Arj - the submarine mafic volcanics, which contained higher contents of Pb, Ag, Bi, Mo, F and Au (av. 22-163ppb); lower abundance of Ni, Sr, As & Hg. Arj is the primary source bed of gold. 2). 1,900 - 2,600 m.y.b.p. were the records of regional metamorphism and the later migmatization. Gold and accompanied metals might be remobilized and released from the source bed by metamorphic and migmatitic hydrothermal solution especially in alkaline alteration of migmatization. 3).The ore bearing solution might migrate to favorable structural sites, where the gold mineralization were formed, and enriched by later heat events. The most remarkable mineralization event was around 110 - 180 m.y.b.p..

III. As a rule, the trace gold contents of Arj are inversely proportional to the intensity of migmatization, and is in positive correlation with late alterations. During early Na/K feldsparization, gold were remobilized from Arj, and became various forms of gold complexes migrated away in hydrothermal solution; then, enriched by late alterations such as silicification, sericitization, pyritization and especially in beresitization. The following data might

lead us to the same conclusion. In fresh, unaltered Arj, the average content of trace Au in rock samples collected in mining district is 163 ppb from 21 samples written as 163/21 (the same below), in various migmatites & relics, down to 75/15, in Linlong & Guojialin migmatitic granitoids, Au decreased violently to 3.4/62 and 4.2/14 respectively; then, under later alterations, Au increased upward to 577/25, among these, 5 samples of beresitized rocks ranged from 1 to 3.5 ppm. The general trend of alteration-mineralization are: enriched in K_2O, SiO_2, H_2O, Pb, Zn, As, Ag, Ni, Mn, Au; and reduced in Na_2O, MgO, Cr, Co, V, Ti, Ba, F, REE. Cu, Pb, Zn, Au, Ag, As, Mn are selected indicators and showing primary halo zonation that can be served in geochemical prospecting.

The REE distribution pattern of Linlong & Guojialin granitoids are similar to early Proterozoic world granites, which gives us another evidence of it's diagenetic ages are much earlier (older) than Mesozoic. Despite of hundreds of K-Ar isotopic ages dated between 110-180 m.y., these data maybe explained as the ending of the last tectonic-heat event occurred in Z-Y region, and youthened the other isotopic data in dating.

IV. Two genetic types of gold mineralization were found in Z-Y belt. In general, the "filling vein" type (gold bearing quartz vein) mainly distributed toward the east, and seated in relative higher elevation. The "altered rock type" deposits (gold mineralization disseminated in altered rocks of fractured zone) occurred largely westward and occupied in lower relief. Two types accompanied together in one gold deposit is not rarely seen. The "filling vein" type deposits were mainly mineralized under filling process, formed in tensional faults that pertaining to brittle deformation; "altered rock" type mineralizations were presented in fractured zones of ductile shearing deformation mainly mineralized under hydrothermal replacement. Various kinds of tectonites were formed due to different geologic environments under brittle or ductile deformation, resulted in different lithologic properties of gold mineralization, these are the mechanism of 2 types of gold mineralization. Frequent tectonic-heat events happened here, made gold mineralization more complicated and often appeared superimposed or transitional types.

V. Study on fluid inclusions showed: 1). The ore-bearing hydrothermal solution is " Ca^{2+} - HCO^- " type. Due to the transportation distance and physical-chemical environment of ore-bearing solution were slightly different between the above mentioned "filling vein" type & "altered rock type"; the mineralization concentration of fluid inclusions of the former were averaged 10%, and 11.56% in the latter; more gaseous phase in filling vein type were found. And the diagenetic hydrothermal solution is "Na-K-Cl" type, i.e. "Chloride" type, it is quite different from the ore-bearing solution.

2). The compositions of fluid inclusions of other gold deposits occurred in Archean metamorphic regions in China are "Ca^{2+} - HCO^-" type, such as Jiapigou gold deposits in Jilin province and other similar ones. It shows, the gold mineralization is not only spacially related to the ancient metamorphic regions, but also closely related to its metallogenic origin, i e. the ore-bearing solution might be inherited and envolved from the ancient metamorphic hydrothermal solution.

3). The temperature of ore forming varies from 400° - 150°C, it

gradually decreases through pre-mineralization period and I-IV stages of mineralization. Stage II & III are the main mineralizing stages, the temperature ranges 320° - 180°C & 320° - 150°C respectively. In "filling vein" type, mainly from 284° - 327°C, and 280° - 340°C in "altered rock" type.

4). The pressure during mineralization were varied, for example, in Jiaojia gold mine - "altered rock" type, the pressure during mineralization were 615-975, 1068, 235 - 239 atm. in no. 1, 2, 3 ore body respectively, all the data showed mineralizations were happened under shallow depths.

VI. The average finess of gold in "filling vein" type is 739.7 ranges from 454 -950, and in "altered rock" type, it's average is 789.7 varies from 635 - 966.

Study on S isotopes shows: The range of average δS^{34} of each deposit in Z-Y belt is rather small, usually less than 3‰, in different deposits, usually less than 5‰. Average δS^{34} are all positively deviated from meteorite value 7 - 12‰. Heavy S are more concentrated in "altered rock" type. for example, average δS^{34} in Linlong gold mine (filling vein type) is +6.7‰, and Jiaojia gold mine, the typical "altered rock" type is +12.4‰.

The features of S isotopic constituents of ore and host rock are alike. They are all controlled by the background value of S isotope in the source bed i.e. the Arj the average δS^{34} of Arj is +7.4‰.

The average value of S in ores varies regularly followed the mineralizing type of ore, such as from quartz-pyrite ore to veinlet disseminated ore to massive pyrite ore, δS^{34} increased and ore grade enriched progressively. The δS^{34} of ore S varies proportional to the intensity of gold mineralization is a common rule existed in Z-Y belt.

Conclusion: We may summarize the metallogeny of these two types of gold deposits in Z-Y belt as below:

	-Late Archean-		-Proterozoic-		-Mesozoic-
g. process	subma. volcanism	reg. metamorphism; migmatization; hydroth. sol.,			filling, alteration,
products	volcanics	Arj mig. granitoids; quartz vein,			quartz veins altered rock
tectonism	deep faulting, S-N	compressing	ductile def:	brittle def.	
results	Yishu deep f.;	E-W anticlinor, NE-NEE faults	ductile shear z.	tension fault	
Au. mineralization	geochemical prov. of Au	primary source bed	Au remobilization migration, enrichment mineralization		

Topic 2D

MESOZOIC-TERTIARY REGIONAL HISTORIES

MINERALIZATION AND HYDROTHERMAL ALTERATION AT THE RAWHIDE GOLD-SILVER DEPOSIT, WEST-CENTRAL NEVADA, U.S.A.

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INTRODUCTION AND GEOLOGIC SETTING

The Rawhide Au-Ag deposit is a Tertiary volcanic-hosted epithermal hot spring deposit located in the Basin and Range province of the western U.S.A. (Fig. 1). Early mining efforts at Rawhide were hampered by the low grade and dispersed nature of mineralization and total historic production from the early 1900's is only approximately 1500 kg Au and 23,000 kg Ag (Vanderburg, 1937). Recent work by Kennecott Exploration (now BP Minerals America) has delineated sizable reserves of bulk-mineable ore containing >31,000 kg Au (>1 million oz.). The BP Gold Company anticipates to commence production before the end of 1988. The deposit is localized along a pronounced NW-trending structural zone which delineates the northern boundary of the Walker Lane with discontinuous, generally NW-trending ranges and right lateral translational faults of the Walker Lane to the south and continuous, NNE-trending ranges more typical of the Basin and Range to the north (Fig. 1A; Locke and others, 1940; Stewart, 1979). This structural zone is also coincident with the northeastern margin of the Miocene Rawhide volcanic center, a 10 x 20km area characterized by a complex sequence of mafic, intermediate, and silicic intrusions, flows, and pyroclastic rocks with minor associated volcaniclastic sedimentary rocks (Ekren and Byers, 1986). Mineralization at Rawhide occurred at 15.5+/-0.5 Ma (Silberman and others, 1975) and is temporally and spatially associated with the intrusion of a rhyolitic diatreme and flow dome complex into this volcanic sequence.

The lowermost unit of the Rawhide volcanic complex that is exposed within the immediate vicinity of the deposit consists of a thick and variable sequence of polymictic, matrix supported, crystal lithic lapilli ash tuffs, ash tuffs, and volcaniclastic sediments. These rocks are collectively referred to as the lithic tuff and can exceed 250m in thickness (Fig. 1). The base of this unit has not been encountered in drilling. The lithic tuff is overlain by a series of andesite flows which are the principal host for much of the bulk mineable mineralization. Both of these units are intruded by a large body of hornblende-biotite rhyolite porphyry which crops out primarily to the northwest of the deposit. A distinctive sequence of stratified tuffaceous sediments and intercalated volcanic breccia overlies the andesite and appears to be restricted to the immediate vicinity of the Rawhide deposit. Finely stratified, siliceous, gray to black, pyritic siltstones within this sequence are interpreted to have formed during subaqueous hydrothermal venting within a shallow lacustrine environment and to be contemporaneous with initial hydrothermal activity at Rawhide. Prior to complete lithification, these sediments were variably tilted and deformed during the emplacement

of a biotite rhyolite intrusive complex and related breccias. Coarse volcanic breccia is interlayered with finely stratified tuffaceous sediments and contains clasts of a wide variety of lithologies including biotite rhyolite. Breccia interlayers generally increase in thickness and abundace upsection and towards the rhyolite intrusion. A steeply dipping, dike-like body of biotite rhyolite, referred to as the Balloon Hill rhyolite, forms the spine of the NW trending ridge which includes Murray and Balloon Hills (Fig. 1). Although this rhyolite is strongly altered, mineralization is largely restricted to structures and permeable wallrocks in the southwest, or hangingwall, of the rhyolite (Fig. 1). A regionally extensive rhyolitic ash flow tuff crops out to the northeast of the deposit and predates the development of the Rawhide volcanic center.

MINERALIZATION

The Rawhide deposit consists of a NW trending series of podlike ore zones within a mineralized area with a total strike length of approximately 2500m and an average width of 400m (Fig. 1). An additional, highly structurally controlled, area of mineralization occurs along the southern flank of Hooligan Hill to the SW of the principal area of mineralization. Individual ore zones are irregular in geometry but typically are elongated to the northwest. Veins, dikes, and structures related to mineralization strike N to NE, an orientation transverse to the overall orebody trend (Fig. 1). Mineralization occurs primarily in wallrocks along the SW or footwall margin of the Balloon Hill rhyolite intrusion and occurs in all lithologies but is most consisently developed in the brittle andesite flow unit.(Fig. 1B,C). Host rock permeability strongly influenced the formation of bulk-mineable ore. Zones of primary permeability in porous lithic tuffs and volcaniclastic sediments host finely disseminated mineralization accompanied by pervasive silicification and adularization with minor or no associated veins. This style of mineralization is characteristic of the Crazy Hill ore zone. Bulk-mineable mineralization in intensely fractured brittle host rocks, such as the andesite flow unit, is characterized by abundant, closely-spaced, sheeted to stockwork quartz-adularia veins. Textural and fluid inclusion evidence indicates that much of the quartz was initially deposited as chalcedony and was subsequently recrystallized to quartz (Sander and Black, 1988).

The deposit is extensively oxidized with the deepest oxidation coincident with areas of most extensive mineralization and extending to depths of 225m or more. Au occurs as electrum in both oxide and sulfide bearing ore. Ag occurs primarily as embolite and lesser cerargyrite in the oxide ore and as silver selenides, sulfides, and sulfosalts in sulfide bearing ore. Pyrite content of unoxidized ore is typically 1-5% but locally exceeds 10%. Other base metal sulfides are rarely present and only identified microscopically. The ratio of Ag/Au averages about 10 within oxidized ore zones and is generally higher, although highly variable, away from mineralization. Minor silver enrichment along the oxide-sulfide interface is locally present.

HYDROTHERMAL ALTERATION

Hydrothermal alteration at Rawhide is widespread and consists of varying degrees of silicification, adularization, and intermediate argillization. Gold-silver mineralization is associated with moderate to strong silicification and K-silicate alteration

characterized by the gangue mineral assemblage quartz-adularia-illite-pyrite. Alteration is zoned outward to extensive areas of variable argillization. Late kaolinite-alunite-opal veins overprint all other alteration and vein types and appear to be related to supergene oxidation of the deposit. Supergene oxidation also resulted in an argillic overprint which obscures original hypogene alteration mineralogy, particularly affecting phylosilicate minerals. Alteration commonly is strongly controlled by hostrock lithology, primarily as a result of differences in hostrock permeability.

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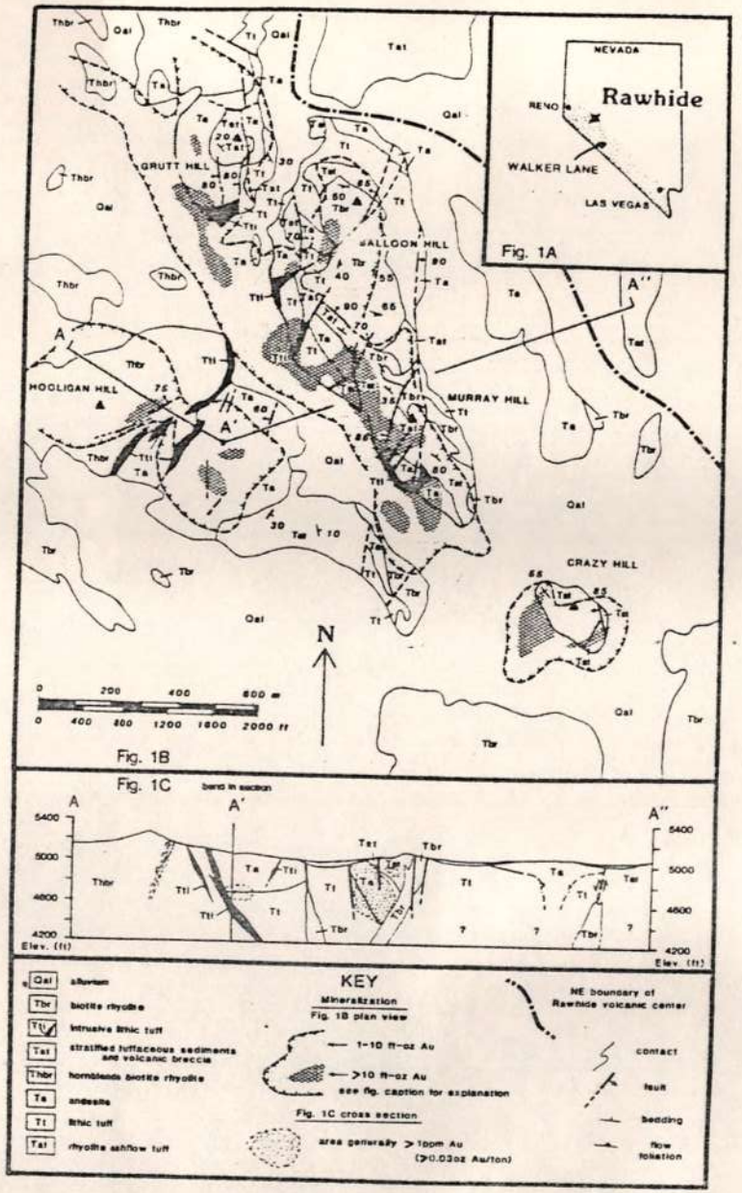
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Figure 1 (see following page). Location and simplified geologic map and cross section of the Rawhide gold-silver deposit. Distribution of mineralization indicated by contouring of total Au ft-oz values for each drill hole. Total Au ft-oz value = Σ (assay value)$_i$ (length of sample interval)$_i$ over the entire length of the drillhole, utilizing an assay value cutoff of 0.01 oz Au/ton. The 1 ft-oz contour outlines mineralized areas and the 10 ft-oz contour crudely approximates the surface projection of ore zones. Modified from work by Kennecott personnel.



LINGLONG GOLD DEPOSIT IN EASTERN SHANDONG PROVINCE

WITH EMPHASIS ON THE NATURE OF LINGLONG FAULT

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Linglong is one of the top gold deposits in eastern Shandong Province which has been mined long since Song Dynasty about 1000 years ago or even still much earlier. It is hosted in Mesozoic Linglong Granite and consists of hundreds of quartz veins filling fractures trending from NE to NEE. Lateral alteration in wall rock on both sides of quartz veins is only 5-10 m in width, being much less than that of the hydrothermal replacement or wall-rock alteration type of gold deposits along fault zones in this region. However, though most of their types of lateral wall-rock alteration represented by feldspathization, sericitization, carbonatization (including sideritization and calcitization), silicification and pyritization are rather similiar to those of the hydrothermal replacement deposits but other types common in some of the hydrothermal replacement deposits like rutilization and fuchsitization are wanting here. In central part of the deposit it's cut by NNE-trending Linglong Fault into two parts, namely the Eastern Hill District and the Western Hill District. The future of this old gold mine depends on the nature of Linglong Fault and the degree of denudation undergone by the two districts on its both sides.

MINERAL SEQUENCE

Hydrothermal mineralization here can be divided into 6 stages, namely 1, anhydrous silicate stage, 2, hydrous silicate stage, 3, sulfide stage, 4, base metal sulfide stage, 5, carbonate stage, 6, native gold stage. Among them, stages 3 and 4 are the principal ore-bearing stages in which Au:Ag ratio is 1-3 in average but in stage 6 fineness of native gold in veinlets is up to 910.

VEINWALL ALTERATION

Veinwall alteration is quite different in both districts. In Eastern Hill District carbonatization is so strong that it can be traced down even below 130 m level and width of sericitization and silicification zone is up to more than 10 m while in Western Hill district the former fades away already at about 190 m level and the latter reaches only about 5 m. Furthermore hydromuscovitization is strongly developed in Eastern Hill District while feldspathization is more intense in Western Hill District.

QUARTZ VEIN

Morphology and spatial distribution of veins in both districts are quite different. Eastern Hill district is full of multiple veins and network of veins with intervening distance about 20-100 m while Western Hill district is full of single veins with intervening distance about 500-1000 m. In quartz veins, width of adularia-quartz vein no more than 3 cm at 120 m level in Eastern Hill District but more than 20 cm at 230 m level in Western Hill District. Fine-grained powder-like pyrite and

smoke-grey quartz are common in eastern Hill district but absent in Western Hill district while massive pyrrhotite is on the contrary. Regarding carbonates, calcite-quartz vein is well-developed in Eastern Hill District with grain size of calcite up to several cm while in Western Hill District there's only siderite veinlets 1 mm in width. Besides, drusy is more strongly developed in Eastern Hill District than in Western Hill District. Data of fluid inclusion thermometry of quartz of stage 3 show that the temperature is 250-300℃ at 206 m level in Eastern Hill District while 310-350℃ at 220 m level in Western Hill District.

CONCLUSION

All the above-mentioned features indicate that Western Hill District is the upthrusted block while Eastern Hill District is the downthrusted block. This is proved true by field evidence indicated by striae on stickensides of Linglong Fault.

Therefore Eastern Hill District is less denuded and more ore is preserved down below in depth. This is also proved true already by further exploration.

SANSHANGDAO GOLD DEPOSIT IN EASTERN SHANDONG PROVINCE WITH EMPHASIS ON EXTENT AND DELINEATION OF HUGE OREBODIES

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Sanshangdao is one of the top gold deposits in eastern Shandong province, belonging to hydrothermal replacement or wall-rock alteration type and hosted in crushed and hydrothermally altered Mesozoic Linglong Granite in contact with Archaean metamorphic complex of Jiaodong Group along an upthrust fault zone trending NE with an extension over 3 km and width from 50 m to 200 m.

WALL ROCK ALTERATION

Types of wall-alteration include rutilization, chloritization, silicification, calcitization, sericitization, muscovitization, Cr-sericitization, sideritization and pyritization. The katamorphic altered rocks from edge to center of the fault zone consist of cataclastic granite, quartz-sericitized cataclastic granite, quartz-sericitized breccia, beresitized breccia and beresitized mylonite. Major deposit lies near the upthrusted side of metamorphics within the enlarged portion of the most beresitized brecciated zone and partly within the beresitized mylonitic zone, displaying distinct horizontal zoning but obscure vertical zoning. Strongly altered zone is rich in pyrite and Cr-sericite and elements of Au, Ag, Fe, Cr, V, Co, Ni, Cu, Pb, Zn, As, Sb, Bi, but poor in Na, Mn.

PYRITE

All pyrites contain As and Ba, being up to 0.75% and 556.6 ppm respectively and belong as a rule to P-type conduction in thermoelectricity. However, pyrites from auriferous and nonauriferous mineralizing stages are quite different in crystal habit, chemical composition, unit cell dimension, physical properties and IRS. The former contains 81.5% of {100}+{hk0}, 15.1% of {100}, 3.4% of {210} but the latter contains 26.0% of {100+hk0}, 65.3% of {100}, 8.0% of {100+111}, others 0.7%. By means of mineralogical mapping based on statistical morphology of pyrite, the ratio $f=(a-(a+o))/(e-(a+e))$ is found to be <2 in orebodies (Au) 2g/t) and >2 in wall rocks(Au $<2-(0.5g/t)$. Therefore f value can be used to delineate the boundary between orebodies and wall rocks. In course of gold deposition, sequence of successive changes in crystal habit of pyrite is a→(a+o)→o in wall rocks and a→(a+e)→e→(e+a)→a→(a+o)→o in orebodies. In pyrites from orebodies to wall rocks there is an increase of Fe/S and Sb and a decrease of Co/Ni, Au/Ag and Bi. Gradients of the above-mentioned variation is not remarkable in vertical zoning (Tab.1), indicating its being a promising huge deposit in comparison with those small to median ones.

SERICITE-MUSCOVITE

Their polymorph are $2M_1$, containing much Mg, Fe, F, H_2O^- and Si(Si^{IV}) as well as Ti, Ni, Cr(Cr-sericite). Grain size of muscovite, sericite and Cr-sericite are up to 2-10 mm, 0.03-0.24 mm and 0.002 mm respectively. Sericite and muscovite occur in wall rocks while Cr-sericite with Cr_2O_3 content up to 0.96% occurs in orebodies. Their chemical typomorphic features are good indicators for grade and extent of gold deposits of this type.

Tab.1 Typomorphic Gradients of Vertical Variation for Pyrites from Sanshangdao Gold Deposit

Typomorphic features		Vertical variation gradient per meter
Crystal habits	(100) (100)+(hk0) (100)+(111)	0.11% 0.10% 0.07%
Sb Bi		0.009 ppm 0.054 ppm
Au/Ag Fe/S Co/Ni		0.006 0.001 0.038
Thermo-conduction	type α	0 +0.096 μV/℃

QUARTZ

Content of SiO, in quartz is inversely proportional to that of Al_2O_3. Quartz from auriferous mineralizing stage contains much Al, K, Na, Cu, Pb, Zn and larger c/a, with di-peak to tri-peak thermoluminescence curve.

FAULT GOUGE

It occurs in NE trending fault zone along the boundary between orebodies and overlying altered wall rocks and is formed after gold mineralization. It contains kaolinite, illite and a little chlorite besides powdered or fragmentary ore and altered wall rock and is divided into several layers with various colour and different grade of gold(up to 2.45 g/t) indicating that post-mineralizing fault activities have taken place for several times along the same fault zone. Its colour, chemical composition, clay mineral constituents and Au content can be used as good indicators for prospecting for gold deposit.

QIXIA GOLD DEPOSIT IN EASTERN SHANDONG PROVINCE

WITH EMPHASIS ON GOLD NUGGETS

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Qixia Gold Mine is famous for occurrence of gold nuggets in eastern Shandong province of eastern China. It belongs to quartz vein type filling fractures in Archaean basic and intermediate metamorphics of Jiaodong Group. They comprise plagioclase amphibolite, biotite leptite and various kinds of gneisses which have been undergone amphibolite-granulite facies of regional metamorphism.

WALL ROCK AND ITS ALTERATION

Average Au content in Jiaodong Group is 24.03 ppb, being five times more than its Clark Value (4 ppb). It implies that Jiaodong Group is the source rock of gold mineralization of this region, in which some amphibotes have abnormal high gold content (53 ppm) suggesting that amphibote is one of the major Au-bearing minerals in Jiaodong Group.

Wall rock alterations are represented by potash feldspathization, tourmalinization, magnetization, epidotitization and crocidolitization in early stage, and chloritization, sericitization, calcitization, ferrocalcitization, silicification and pyritization in later stage. Compositions of altered and unaltered rocks show that Mg, Fe, Ca, Na have been released from wall rock into hydrothermal system while K, H_2O, CO_2 have moved vise versa during hydrothermal alteration(Tab. 1).

Tab. 1. Composition of altered and unaltered rock

	CaO	MgO	FeO	Fe_2O_3	Na_2O	K_2O	H_2O^-	CO_2
Amphibolite	5.78	3.53	3.81	1.83	3.94	1.81	1.44	0.09
Beresite	3.96	1.64	2.55	1.18	2.09	3.73	2.10	5.62

MINERAL SEQUENCE

Sideroplesite, pyrite, ferberite, scheelite in mineralizing stage 1 is particularly typomorphic with respect to composition of the Archaean country rock rich in Mg, Fe and W. Co/Ni ratio of pyrite as well as sulfur and lead isotopes in sulphides of the deposit are also approximately the same as in the country rock.

Later mineral assemblages are represented by quartz, galena, sphalerite, chalcopyrite, pyrite, ankerite and electrum in stage 2, quartz, pyriye, electrum and calcite in stage 3 and native gold in stage 4. Stage 5 is responsible for primary gold nugget which gives rise to secondary gold nugget due to erosion.

TYPOMORPHISM OF MINERALS

Some minerals of this deposit are studied with respect to crystal

morphology, crystal surface microtopography, crystal chemistry, IRS, thermoluminescence, thermoelectricity, fluid inclusion, isotopes, etc. Mineratogical mapping have also been done. Description of predominate minerals are as follows,

Ferbertite and scheelite They are the minerals discovered for the first time in Qixia Gold Mine as well as in Jiaodong Goldfields. It shows that ferbertite is somewhat rich in Nb, Sn, Ti, Sc and Tb, Tm while scheelite is also somewhat rich in Nb (Tab. 2).

Tab. 2. EPA of ferbertite (1) and scheelite(2) (wt%)

	FeO	MnO	MgO	CaO	Nb_2O_5	SnO_2	TiO_2	Sc_2O_3	Tb_2O_3	Tm_2O_3	WO$_3$	Total
1	20.30	2.79	0.09	0.05	0.23	0.09	0.04	0.03	0.05	0.002	75.34	99.37
2	0.06	0.01	0.00	19.58	0.07	0.00	0.00	0.00	0.00	0.00	80.24	99.96

Electrum Its Au/Ag ratio changes systematicaly both in time and space, increasing gradually from 2.86 to 5.89 from earlier to later stages corresponding to decrease in ore grade. It contains Ta, Mo, Bi, W up to 2.56%, 2.27%, 0.77%, 0.35% and Cr, Fe, Mg up to 1.61%, 0.75%, 0.01% respectively.

Pyrite From stage 1 to 3, grain size of pyrite decreases gradually with its habit also changing regularly in the following order, {100}→{210}+{100}→{210}, {210}+{100}, {210}+{100}+{111}+{hkl}→{100}+{210}+{111}→{100}. Pyrites in auriferous stages are fine-grained, complicated in crystal habit, having both positive and negative striations and growth layers on {210} faces and rich in Au, Ag and Cu, Pb, Zn.

Quartz Thermoluminescence of quartz from auriferous vein, pegmatite and felsite are different. High content of CO$_2$ and N$_2$ in fluid inclusions of quartz is typomorphic for high grade ore.

CONCLUSION

From isotherm map of quartz fluid inclusion, isoline map of Au/Ag ratio of electrum, isograde map of gold and isopach map of ore vein, the position of high-grade ore shoot and ascending path of hydrothermal solutions can be located. The above-mentioned maps, wall-rock alterations and mineral compositions are indicators for the unexposed granitoid intrusive down below this deposit.

XIADIAN GOLD DEPOSIT IN EASTERN SHANDONG PROVINCE

WITH EMPHASIS ON OREBODIES EN ECHELON

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Xiadian is a gold deposit of hydrothermal replacement or the so-called wall-rock alteration type, hosted in altered crushed granitoid zone from 40 m to 330 m in width and more than 3 km in length along an upthrust fault trending NE with Archaean metabasics of Jiaodong Group overlying Mesozoic Linglong Granite. Wall-rock alteration consists of microclinization, albitization, sericitization, calcitization, silicification, pyritization and rutilization.

PEGMATOID

Irregularly nodular pegmatoid in altered wall rock is flesh-red in color and consists of coarse microcline up to 5 cm in grain size (40%), albite (30%), quartz(20%) and muscovite (10%), indicating its formation being in a volatile-rich and oxidized environment favourable for gold transportation and concentration. Feldspars in Linglong Granite, altered granite and pegmatoid form a continuous series with respective composition of $Or_{91.7}Ab_{8.3}An_{0.0}$, $Or_{88.4}Ab_{11.6}An_{0.0}$, $Or_{91.3}Ab_{8.7}An_{0.0}$ for microclines and $Or_{11.8}Ab_{88.4}An_{0.8}$, $Or_{8.3}Ab_{90.3}An_{1.4}$, $Or_{8.3}Ab_{90.3}An_{1.4}$ for plagioclases. For microclines Al-Si ordering parameters (δ) are 0.8513, 0.9201, 0.9411 and intensity of thermoluminescence (I) at 260-280℃ are 326.7×10^{-9}lm, 364.0×10^{-9}lm, 663.3×10^{-9}lm. Evolution of feldspars shows that occurrence of pegmatoid is the prelude of later hydrothermal mineralization as in porphyry Cu and W-Sn quartz-vein deposits.

MINERAL SEQUENCE

Hydrothermal mineral sequence of the deposit can be divided into 4 stages, namely pyrite-quartz stage(1), Au-bearing pyrite-quartz stage(2), sulfide-calcite-quartz stage(3) and quartz-calcite stage(4), in which stage 2 is the main stage of Au deposition. Their mineral assemblage is characterized by coarse-grained pyrite (up to 5 cm), quartz (up to 12 cm) and a few hematite, magnetite, rutile, arsenopyrite and graphite for stage 1; quartz, pyrite, eletrum (Au 62.01-68.52%, Ag 30.25-36.39%) and a few rutile, pyrrhotite, sphalerite, chalcopyrite, galena and graphite for stage 2; quartz, calcite anda few rutile, pyrite, sphalerite, chalcopyrite, galena and electrum for stage 3 and fine-grained calcite, quartz and pyrite for stage 4.

QUARTZ

For quartz from stage 2 SiO_2 (99.00%, Al_2O_3) 0.40%, K_2O) 0.15%, Na_2O) 0.15%, Hg) 0.00004% with 4 thermoluminescence peaks while for those from other stages SiO_2) 99.00%, Al_2O_3 (0.40%, K_2O (0.15%, Na_2O (0.15%, Hg (0.00004% with only 1-3 thermoluminescence peaks of much less intensity.

PYRITE

Impurity elements in total in pyrites from stage 2 reach 990.7-4170.1 ppm and 1984.3 ppm in average with the sum of Ag, Cu, Pb, Zn, As, Sb, Te being 490.6-3654.3 ppm while in those from other stages the former reaches only 446.0-1779.6 ppm and 1112.8 ppm in average and the latter reaches only 356.1-1040.4 ppm. Statistics of 314 crystals shows that crystal habits of pyrite from stage 2 are very complex, including {210} (30.10%), {210}+{100} (27.55%), {100} (17.35%), {210}+{100}+{111} (14.80%), {100}+{111} (3.16%), {111} (1.02%), {100}+{310}+{810} (0.51%), {100}+{210}+{321}+{111} (0.51%) while those from other stages are rather simple, including only {100} (4.76-100%), {100}+{310} (0-42.85%), {100}+{210} (0-34.92%), {100}+{111} (0-14.29%), {111} (0-3.18%).

OREBODIES

Strike rose diagram of ore-controlling fractures, isograde map of gold and isopach map of orebodies at different levels indicate that separate lenticular orebodies trending mainly from NNE to NE and only rarely to NW are arranged en echelon vertically and slightly inclined to the major fault zone which is the major ascending path of hydrothermal solution. The model concerning spatial distribution of orebodies has been proved true by later excavation and further laboratory work. Away from the major fault zone typomorphism of pyrite from stage 2 at different levels displays also an arrangement en echelon. From proximal end to distal end pyrites in each of the separate orebodies en echelon show as a rule increase of {210} with decrease of {100}, {210}+{100}, {100}+{210}+{111} and increase of Ba, Ag, As, Sb, Co, Co/Ni with decrease of Fe/S, Ni, Cr, Mo, Bi as well as increase of P-type conduction with decrease of N-type conduction and increae of unit-cell parameter (a_0). For quartz from proximal end to distal end content of Li and Rb decreases while content of Ba and Sr increases. Therefore, it is obvious that the pattern of mineral typomorphism displays also an arrangement en echelon.

CONCLUSION

Mineralogical mapping of pyrite morphology and thermoelectricity shows that the deposit is less eroded and denuded after its formation in comparison with other deposits in this region and therefore there is still much ore of higher grade preserved down below.

THE GEOLOGY AND GENESIS OF A PLACER GOLD DEPOSIT, ULOOLOO GOLDFIELD, SOUTH AUSTRALIA.

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The Ulooloo Goldfield is located 230 kms north of Adelaide, South Australia. It was discovered in 1871 and the alluvial diggings produced £18,000 of gold from 1871-1886, mostly in the form of nuggets and coarse gold. The goldfield was also worked in the Great Depression. Mining leases covering the Ulooloo Goldfield are presently held by Dalebrook Exploration Pty Ltd. A recent detailed study was not able to establish a relationship between distinctive sedimentological features of the Pleistocene alluvium and the distribution pattern of gold. Instead, an understanding of the groundwater chemistry and flow pattern has enabled the distribution of chemically precipitated gold to be identified. The detrital gold has been reconstituted to form nuggets that show surface and internal textures characteristic of redeposition under low-temperature conditions.

The Ulooloo Goldfield occurs in a valley fill overlying late Precambrian (Adelaidean) metasediments of the Adelaide Geosyncline. The alluvium is considered to be Early Pleistocene in age and is correlated with the Hindmarsh Clay of the Adelaide region. It is a particularly well-developed example of a longitudinal fluvial system in a trunk valley confined by tributary alluvial fan deposits that interfinger with the fluvial system. The valley is over 7 kms in length and about 1 km wide. The depth of the placer ranges from 5-10 metres. Relief on the basement is as great as 10 metres.

The gravel-dominated sediments of the longitudinal fluvial system are characterised by 3 facies associations, 2 comprising channel fill and the other represented by laterally extensive sheets of coarse gravel. Channel types 1 and 2 (see below) are characteristically thick (ca 3m), interconnected stringers of gravel with width/depth ratios of about 4:1. They represent composite channel fills that scour into bedrock or debris flow deposits of the alluvial fans. When buried, the low sinuosity channels are encased laterally by sandy-silt levee deposits or debris flow deposits. Vertical aggradation rather than lateral accretion is the dominant sedimentation pattern within the channels. Calcretes are developed away from sites of active deposition. The presence of calcretes and the red colouration of the sediments suggest a semi-arid palaeoclimate.

Type 1 channels are well developed in the proximal reaches of the valley and are commonly 10-20 metres wide. They are infilled by well-rounded, massive or horizontally stratified gravel (facies Gm), often graded with well-defined imbrication (*a*-axis flow transverse, *ab*-axis dipping upstream) and minor planar cross-stratified gravel (facies Gp). Facies Gm is interpreted as the internal structure of shallow high energy flows. Channels ca 3-5m in thickness contain up to 20%

of planar cross-beds (facies Gp) and show lateral transition to horizontally bedded gravel. Facies Gp was formed as lateral modifications of longitudinal bars during falling stage, when flow diverges away from bar axes. This facies is thought to be more prominent because the bar/channel relief is greater resulting from deep flood flows.

Type 2 channels are composed of trough cross-stratified gravels (facies Gt), also well rounded and fining upwards with sand and pebbly sand exhibiting planar and trough cross-bedding and horizontal stratification (facies Sp, St, Sh resp). Minor sets of horizontally stratified gravel are also present. The gravel/sand units are interpreted as deposits of the active fluvial tract with facies Gt generated by gradual filling of a channel with dunes. Continued aggradation in the channel resulted in deposition of facies Gm, St, Sh and Sp. This channel type is found at a lower stratigraphic level than channels of type 1 and is particularly well developed in the distal part of the deposit.

Commonly overlying the channel deposits at the proximal end of the valley are laterally extensive sheet gravels, characterised by the abundance of horizontal stratification (facies Gm). The gravels are commonly imbricate with *a*-axis flow transverse and *ab*-axis dipping upstream. These gravels are interpreted as having been deposited by vertical accretion of longitudinal bars in a narrow and confined high energy proximal braidplain.

Sediments deposited by small alluvial fans that interfinger with the braided fluvial gravels are characterised by coarse angular material, commonly of cobble to boulder size floating in a clay matrix. Other features include poor sorting, reverse grading, disorganized fabric and absence of sedimentary structures. These are interpreted as highly viscous debris flows (facies Gms) that were promoted by short periods of abundant water supply.

The pattern of Early Pleistocene sedimentation is thus characterised by proximal and distal braided fluvial facies, interfingering with debris flows that were deposited by transverse alluvial fans. As the system aggraded, the proximal braided facies prograded over the distal braided facies, possibly in response to rising sea-level or a rise in local base level such as caused by active cross-valley alluvial fans.

The alluvials at the Ulooloo Goldfield are underlain by late Precambrian meta-sediments. Enclosed within an overturned anticline that plunges to the southwest are slates, quartzites, conglomerates and dolomites of the Saddleworth Formation (Burra Group) thought to have been deposited in a shallow shelf-deltaic environment. The Leasingham Quartzite Member of the Saddleworth Formation is composed of brecciated quartzite and marks the unconformable boundary between the Burra Group and the fluvioglacial sediments of the Umberatana Group. The slates of the Wilyerpa Formation host stratabound quartz stockworks and laterally extensive quartz veins ca 0.5-1.0m thick. The unit also hosts sulphide gossans and associated base metal anomalies.

The majority of the mining at Ulooloo has been confined to the Pleistocene alluvium. Some working of quartz veins was reported in the 1920's with grades up to 5 dwt Au/tonne. Recent investigations suggest that silicified breccias of the Leasingham Quartzite Member and quartz

veins found within the Wilyerpa Formation are the potential source for the alluvial gold at Ulooloo. The fluvioglacial sediments of the Umberatana Group host many of the important gold deposits in the Adelaide Geosyncline. Stratabound quartz stockworks in the Appila Tillite (Wilyerpa Fm equivalent) are the host for gold at Mt. Grainger, 60 kms north of Ulooloo whilst 30 kms to the south at Mongolata gold occurs in quartz veins occupying slate and sandstone.

Gold recovered from the Ulooloo Goldfield is coarse and nuggety, with the largest nugget found in 1930 weighing 11 ozs. Selective mining recovered grades of up to 15-30 gms Au/tonne. The support for a chemical origin for the gold involving low temperature precipitation comes from the abundance of nuggets that are often botryoidal and spongy in appearance. Mineralogic observations indicate nuggets of very high fineness (eg Au 96.2%, Ag 3.6%, Cu+Fe 0.2%) that enclose Fe oxide masses and pseudomorphs after pyrite. An important preferential association is the occurrence of gold nuggets and Fe oxide-after-pyrite pseudomorphs both within individual nuggets and the gravel matrix. Throughout the Fe oxide matrix, numerous small particles of gold (1-20 microns) were observed. Smaller-sized particles of gold are also contained in the pyrite pseudomorphs encapsulated within the nuggets. Here the gold is present as blebs and thin discontinuous layers that appear to be arranged parallel to cubic faces of the former pyrite.

The fineness of the gold nuggets is thought to result from migration of gold and the removal of soluble gangue and sulphides. The nuggets show features in common with those found in laterites at Kalgoorlie, Western Australia. It has been shown that in such an environment, gold is complexed with the chloride ion as $AuCl_4^-$ by ferrolysis under conditions of low pH and high Eh. The gold is subsequently deposited with goethite (FeOOH) by reduction with Fe^{2+}. However, the presence of more than one gold complex having operated in the same profile at Ulooloo is possible. It is suggested that nuggets were accreted initially by ferrolysis. Here the gold was complexed with chloride under conditions of pH 3-4 and high Eh and subsequently precipitated by reduction with Fe^{2+}. Gold may have also been complexed with thiosulphate, $[Au(S_2O_3)_2]^{3-}$ at pH <3 with simultaneous formation of diagenetic pyrite formed by reduction of Fe^{2+} in solution or by reduction of nugget FeOOH in part. Photomicrographs show evidence of FeOOH dissolution ("corrosion caverns") adjacent to sites of pyrite growth on goethite. The gold thiosulphate complex was adsorbed on the sulphide surface and reduced to Au by the pyrite. At pH>4, the pyrite is oxidized to FeOOH. Oscillation between pH<3 and pH>4 would produce intergrowths of diagenetic pyrite and gold. The variation in pH is thought to be the result of fluctuations in the ground water table, caused by seasonal or climatic changes. The system is an electrochemical cell where reduction and oxidation occur simultaneously.

THE GEOLOGY AND EXPLORATION OF FADDYS PROSPECT, S.P.L. 1216 - VITI LEVU, FIJI

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The Faddys Prospect is located approximately 15kms south west of Nadi on the main island, Viti Levu, of the Fiji Group at co-ordinates 177° 17'50" E and 17° 51'15" S.

During the depression in the early 1930's, Fiji was extensively prospected by itinerent prospectors and small syndicates. Discovery of gold in the Uciwai Momi-Mistry area occurred in 1935 and the area was reported on by Loftus Hills and M.D. Garretty in 1935. The Mistry Prospect was considered the main discovery, but in 1936, H.S. Faddy applied for Prospecting Licence 342 and in his letter of application he stated that he had uncovered hard gold bearing lodes with good values. There is no further mention of work on this prospect. The Mistry deposit, which occurs 2 kms south of Faddys, was worked at various short intervals in 1936, 1940 and 1957-58, but total gold production has not exceeded 25 kilograms of gold.

In 1985, Hallcroft Pty. Ltd. took up an S.P.L. 1216. Climax Mining Limited entered into a joint venture on SPL 1216 in 1985 and have managed all the exploration on the SPL. The sampling of the gossan outcrop at Faddys indicated gold values and an exploration programme began.

This continuing exploration has been along normal procedures but influenced by seasonal conditions and availability of drilling equipment and airborne geophysics. There have been three programmes of reverse circulation percussion drilling totalling 50 holes varying from 60-150 metres in depth and also three programmes of diamond drilling totalling ten holes in efforts both to check the geological interpretation from the reverse circulation drilling and also to check the values obtained in that type of drilling.

In Fiji diamond drilling is very expensive and most of the reverse circulation drilling is carried out "wet". Only recently has the airborne magnetometer results become available.

The rocks within the SPL 1216 belong to the Wianimala Series, which are folded generally about an east south axis with shallow fold plunges, but with sharp plunge reversals. The rocks are mainly volcanics consisting of both flows and tuffs. The most predominant types are andesitic tuffs and flows which tend to occupy areas of low relief. Associated

with the andesites are basalts.

In the area south of Uciwai there a number of east south east striking trachytic dykes which are usually associated with some brecciation and silicification. In the drilling at Faddys Prospect similar trachytes (dykes) have been intersected.

Acid volcanics, either as rhyolite tuffs or flows, occur and again it would seem that both flows and dykes are present. A large flow occurs in the area of the old Mistry Mine and here it appears to overlie the andesitic/basic tuffs. In the southern part of the area, just to the north of Momi, the rhyolite/quartz feldspar porphyry has a rather graphic texture and may represent an intrusive porphyry.

There is a lot of variation in the sediments, but the most persistent types are finely laminated mudstones and shales which become indurated and cherty near the associated volcanic contacts. These grade into greywackes, marly sediments and lithic tuffs.

The structures within the SPL are fairly complex.

The main folding is about an east south east axis resulting in an open fold situation, however, there are frequent steepening of the limbs with overturning and strike faulting.

There are three main fault directions - North North East (30°), East North East (70°) and East South East (120°) (strike faulting). The East North East direction represents the main structural line of weakness that links the volcanic centres (Caldera) of Kingston, Vatukoula, Raki Raki, Mount Kasi and Faddys.

At Faddys the main ore control appears to be structural where a breccia zone striking 70° and dipping 45° to the north west, extends over a width of approximately 40-50 metres, with a strike in excess of 300 metres. Within the zone of brecciation there is pervasive silicification with quartz showing veining, rim replacement and overgrowth. The mafic minerals have been chloritised and the feldspars 'bleached' and kaolinised. Throughout, pyrite is both disseminated, veined and in places up to 30% of the 2 metres sample interval.

The gold appears to be occurring throughout the lode zone, but may be concentrated in terms of higher values in steeper dipping shears/veins.

At Faddys there is no evidence of any extensive base metal minerals, ie; galena, sphalerite and chalcopyrite and associated gangue mineral barytes such as occurs at the Mistry Mine.

In the oxidised zone the gold values are irregular indicating both leaching and redeposition in association with silica and hematite, resulting in a pseudo gossan.

SUPERPOSITION OF CRETACEOUS Au-Ag EPITHERMAL BRECCIAS ON JURASSIC Pb-Zn-(Cu) MESOTHERMAL SKARNS, SHUIKOUSHAN DISTRICT, HUNAN, CHINA

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Historically, Pb-Zn-(Cu) skarn ores have been continously exploited from the Shuikoushan orefield (Fig. 1) since 1906. However, the discovery of major pyrite-Au-Ag breccia ores has outlined significant gold reserves, currently being developed.

Recent mapping of the Shuikoushan district (Fig. 2) and re-analysis of the structure has revealed that the Au-Ag ores are siliceous hydrothermal breccias associated with an eroded calc-alkaline volcanic complex (Laomengshan-Xinmengshan) of Early Cretaceous age (120 Ma, K/Ar) that intruded the basal units of Cretaceous molasse. Both the volcanic complex and hydrothermal breccias were emplaced along major late Jurassic thrusts, formed during the final stages of the Yanshanian orogeny. In contrast, the non-brecciated Pb-Zn-(Cu) skarn deposits (Yagongtang, Zhongqu and Laoyazao) directly contact the Jurassic Laoyazao granodiorite (143-158 Ma, K/Ar) which was emplaced into overturned Yanshanian fold hinges, prior to late Jurassic thrusting.

Reconstruction of the pre-thrusting Jurassic paleo-surface (Fig. 3) indicates that the Laoyazao granodiorite and associated skarn ores were emplaced at depths exceeding 1.2 km; possibly as deep as 3 km, depending on assumed thicknesses of Jurassic strata eroded during the Cretaceous. Such mesothermal depths are consistent with both skarn mineralogy (diopside, idocrase) and the complex alteration of the Laoyazao granodiorite, which includes: pervasive coarse secondary microcline + muscovite + calcite; and veins and disseminations of microcline + chlorite + calcite.



Fig. 1 Location of Shuikoushan orefield

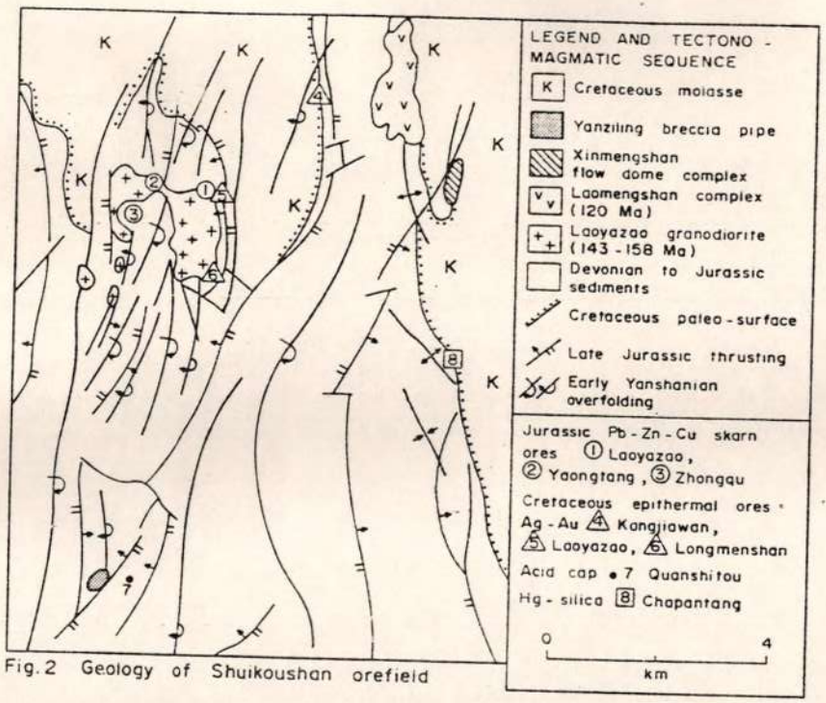


Fig. 2 Geology of Shuikoushan orefield

Depths of emplacement of the early Cretaceous hydrothermal Au-Ag breccias were measured directly from the Cretaceous piedmont paleo-surface (Fig. 3). Depths and mineralogy of individual deposits are comparable with models for epithermal Au-Ag deposits in the North American Cordillera: 700-900m pyrite-Pb-Zn-Ag-Au, Kangjiawan (Ag/Au = 36.1), Laoyazao No. 4 (Ag/Au = 19.1); 250-450m pyrite-Au-Ag, Longwangshan, (Ag/Au = 5.1). In addition, intense kaolin-jarosite-hematite alteration at Quanshuitou and silicified Hg disseminations at Chapantang may represent acid-cap and hot-spring sinter expressions of the Cretaceous epithermal system.

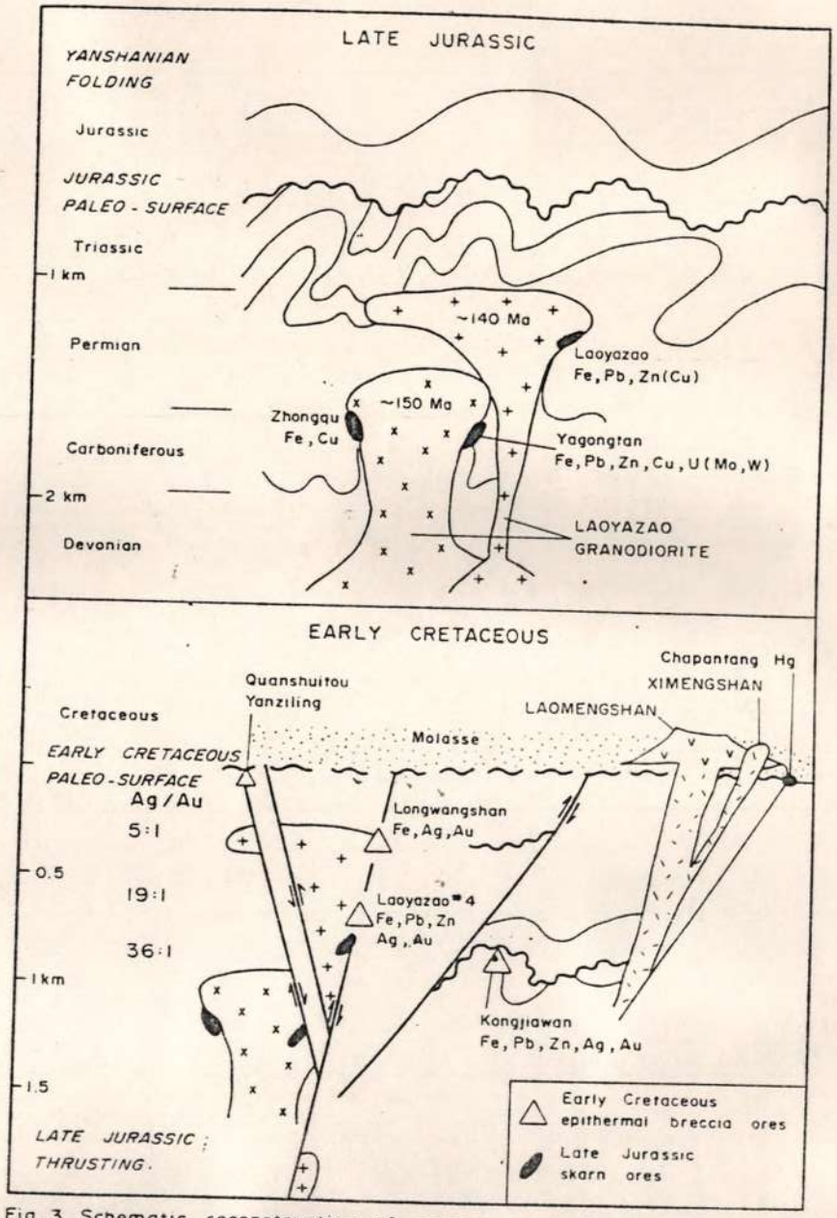


Fig. 3 Schematic reconstruction of tectono-magmatic events and emplacement of ores

The morphology and geochemistry of supergene gold at Hannan South gold mine, Western Australia.

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INTRODUCTION

Gold is mobile under certain conditions in the lateritic weathering profile and may reprecipitate with well defined crystal morphology and high fineness. In contrast, hypogene gold is generally irregular in shape and an amalgam (e.g. Webster and Mann, 1984; Wilson, 1984; Stoffregen, 1986; Freyssinet et al., 1987; Lawrance, 1988). In the semi-arid environment of Western Australia, gold is thought to have been remobilized as a chloride in oxidizing saline groundwaters and reprecipitated by reduction in the supergene environment (Mann, 1984).

A study of the lateritic weathering profile at the Hannan South gold mine shows that supergene processes have produced a wide range of secondary gold crystal forms of high fineness, from a primary gold source associated with sulphides. Many of these secondary gold forms show moderate to severe dissolution features and are intimately associated with perfectly formed crystals, indicating a number of generations of dissolution and precipitation within the supergene environment.

GEOLOGY, GEOMORPHOLOGY AND WEATHERING

The Hannan South gold deposit is situated in the Norseman-Wiluna belt of the Archaean Yilgarn Block 15km SSE of Kalgoorlie (Fig. 1). Lateritic weathering profiles of this region are generally 70-80m thick and, if well preserved, distinct horizons may be recognised. At the base of the profile, parent rock is partially altered to kaolin and smectite to produce the lower saprolite. Above this zone, in the upper saprolite, all primary minerals except quartz, magnetite and ilmenite are altered to clay and iron oxides, but with preservation of the primary rock fabric. The upper saprolite grades into the mottled zone, where primary quartz grains become corroded and pedoturbations and concentration of clay and iron oxides obliterate primary rock fabrics. The uppermost part of the residual profile is capped by an indurated ferricrete (laterite) up to 4m thick, composed predominantly of hematite concretions. At the surface, degradation and reworking of the laterite produces a loose lateritic gravel.

The deposit at Hannan South is hosted by a highly altered basaltic unit, now a granular and semi-massive siliceous epidote-ankerite rock, within a foliated carbonate- and white mica-rich felsic tuff. A pyritic carbonaceous shale, underlain by a tuffaceous sediment, forms the footwall to the west. Andesite porphyry and intrusive dolerite are in sharp contact with the lode to the east. The deposit is situated beneath a playa that forms part of a southern draining ephemeral lake system. The lateritic profile over the deposit, has been partially truncated by the western migration of this system (Jutson, 1950). The profile is complete on the western margin of the lake, where the laterite and mottled zone are exposed in erosion scarps. Extensive sand dunes occur on the eastern lake margin. The weathering profile at Hannan South now consists of lower saprolite (20-75m depth) and upper saprolite (4-20m depth), which becomes highly bleached towards the surface, and is overlain by 3-4m of red gypsiferous lacustrine sediments. The profile is saturated with the highly saline groundwater of the lake system and secondary minerals produced in this environment are very well developed and exhibit abnormally large growths; for example, tubular halloysite occurs up to 20µm in length.

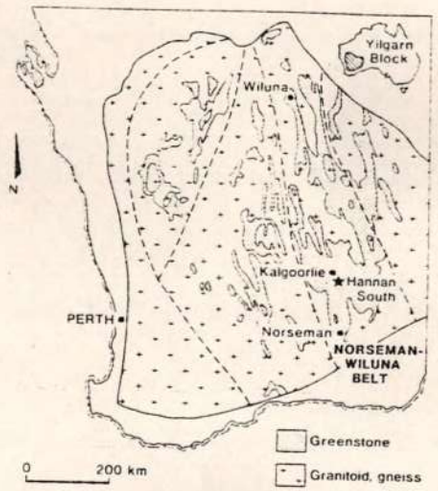
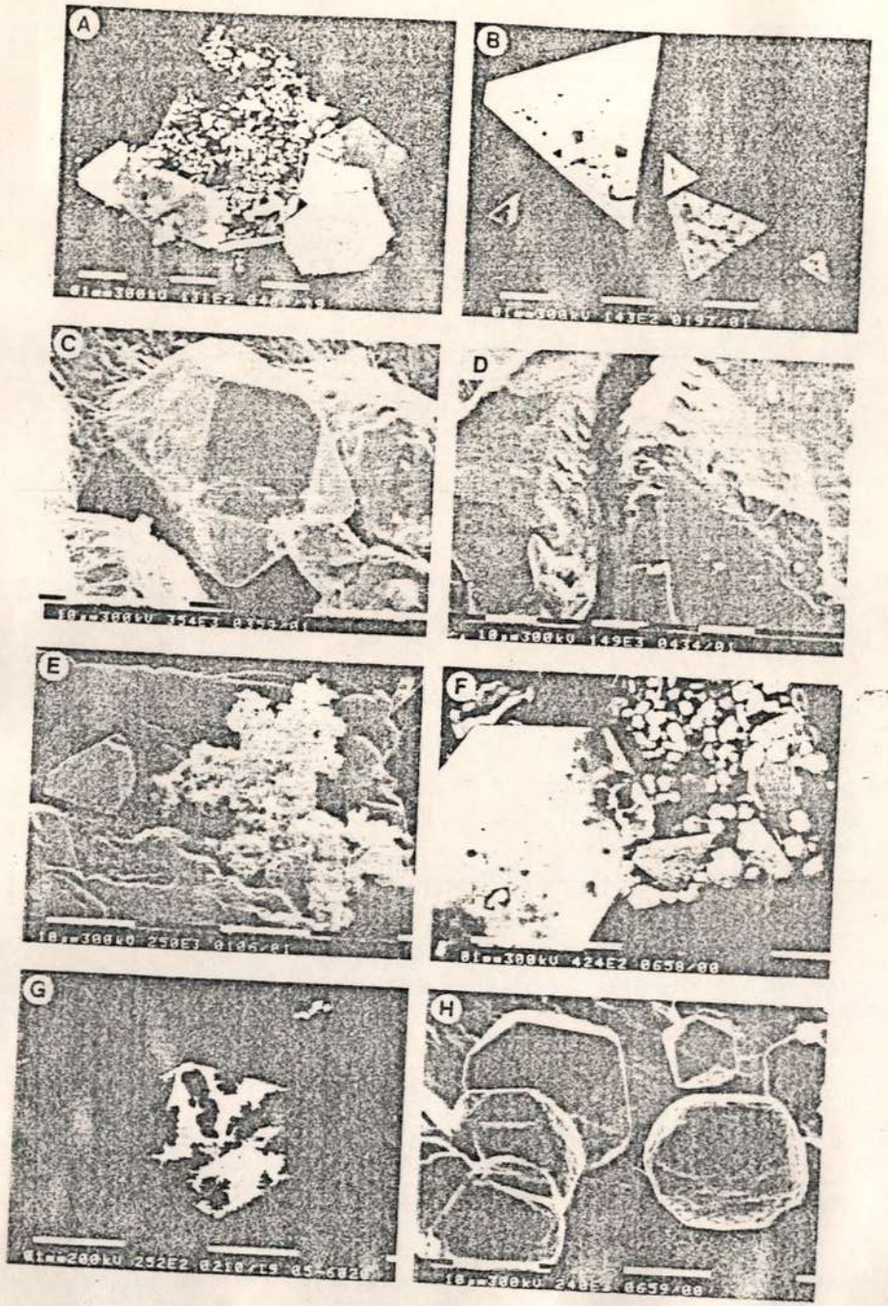


Figure 1: Regional geological map of the Yilgarn Block showing the locality of the Hannan South gold mine.

GOLD DISTRIBUTION WITHIN THE WEATHERING PROFILE

The mineralization at the Hannan South mine has two zones: a lower partially weathered primary ore zone and a upper secondary zone, both within the weathering profile. The primary zone, as defined by a 1ppm Au cut off, is a tabular pod 110m long and 10-15m wide, and has no extension with depth, being faulted out at 55-75m depth: this fault defines the base of the weathering front. It has a NNW-SSE strike, parallel to surrounding lithological units and dips NNE at 70 degrees. In this zone, gold is associated with sulphides and has an average grade of 17ppm Au and may grade up to 58ppm. Pyrite is the most abundant sulphide, occurring as discrete anhedral and subhedral grains and clusters, as patchy granular aggregates with semi-massive fabric and as composite grains with cobaltite. The pyrite measures 0.05-15mm and is commonly porous and finely fractured as a result of weathering, which increases with decreasing depth. Galenobismuthite, bismuthinite and wittichenite blebs occur either within pyrite or as free grains. Hypogene gold is mainly associated with these bismuth-sulphide minerals and rarely as blebby inclusions in pyrite. Within the weathered primary ore zone, supergene gold occurs as isolated grains and clusters, and as fracture fillings in epidote around partially weathered sulphides.

Figure 2: (*See facing page*) SEM photomicrographs showing morphological and dissolution features of supergene gold at Hannan South. A, B, F and G are backscattered-electron images and C, D, E, and H are secondary-electron images. Scale-bar divisions are shown in the lower left corner of each photomicrograph. A Aggregate of crystals showing the diversity of plate types and association of smaller octahedra. B Isolated trigonal plates. C Perfectly formed octrahedron associated with severely corroded forms in a halloysite and halite matrix. D Partial octahedral crystal growth along the edges of a crack in a large rounded octahedron. E Irregular fine semi-crystalline mass of gold next to an octahedral crystal. F Dendritic gold on the surface of a regular hexagonal plate. G Partial dissolution of a hexagonal plate. H Strongly corroded and well formed octahedra adjacent to each other on a gold plate. Note corrosion in preferential crystal lattice directions.



Centered almost directly over the primary zone is a flat lying secondary zone, which is roughly circular with a diameter of about 220m; it has an average grade of 20ppm Au with localised areas at grades of 50-110ppm. This zone has a transitional contact with the underlying weathered primary zone, at 35-45m depth, and extends up to 16-20m depth. Supergene gold occurs as irregular pockets and veinlets over partially weathered sulphide lenses (0.5-2m long) and is associated with ferricrete of palaeo-watertables. Less commonly, gold is found in iron-oxide veins within the lode and adjacent country rocks. However, the supergene gold shows no distinct association with secondary minerals. Above the secondary zone, the upper highly leached saprolite is unmineralized.

SUPERGENE GOLD

Supergene gold in the weathering profile at Hannan South exhibits an unusually wide range of secondary gold forms. All are varieties of the face-centered cubic lattice crystal structure of gold and are of high fineness (Ag < 0.05%).

The largest crystals are those in which crystal growth along the (111) plane of the face-centered cubic lattice has predominated abnormally over growth in any other direction to produce thin (0.5-3µm) hexagonal, trigonal and rare rhombohedral platelets from 15um - 3mm in diameter. These crystals commonly occur on felted iron-oxide surfaces and in iron-rich kaolin, as clusters with other crystal forms (Fig. 2A) and as isolated grains (Fig. 2B). Smaller octahedral crystals, 5-20µm in diameter (Fig. 2C) and exhibiting a modified normal face-centered cubic lattice form, are commonly found on gold plates and disseminated throughout the clay matrix. Large partially rounded and fused octahedra (0.05-0.1mm in diameter) have smaller platelets and octahedra on their surfaces. Partial octahedral crystal growth of 1-15µm size is observed along the edges of cracks in the large rounded octahedra (Fig. 2D). Irregular, fine, semi-crystalline masses of gold (Fig. 2E) up to 40µm are sited adjacent to both gold plates and octahedral crystals. Dendritic, mammillary and wire gold growth is intimately associated with other gold forms (Fig. 2F), but occurs most commonly in iron oxide and carbonate veins and on fracture surfaces of the weathered rock.

About half of the gold platelets show dissolution features (Fig. 2G) and surface pitting. Dissolution generally occurs from the edges toward the centre of the crystal, but in some, it originates at the centre of the plate. About 80 percent of the small octahedra show moderate to severe etching of the complete surface and have an average diameter of 12µm. In contrast, the remaining octahedra are perfectly preserved, showing no evidence for dissolution and have an average diameter of 18µm. Corroded and well formed crystals occur together (Fig. 2H).

DISCUSSION AND CONCLUSIONS

The distribution of gold in the weathering profile and the wide variety of gold crystals at the Hannan South gold mine are a product of a complex weathering history. The mineralized zone is confined to the supergene environment and can be divided into two parts; a partially weathered primary zone and an upper secondary zone. Gold within the lower partially weathered primary ore zone is at lower concentration than that in the upper secondary zone, where the the total amount of gold per volume of weathered rock is much greater. Within the weathered primary zone, gold is predominantly associated with pyrite and bismuth-sulphide minerals. In contrast, in the secondary zone it is associated with iron oxides precipitated at palaeo-watertables and in iron-rich clay of the saprolite, occurring as crystals of high fineness, with well defined shapes. Morphological and geochemical evidence indicates that this gold is supergene, having been remobilized and precipitated during weathering.

The presence of abnormally large secondary clay minerals within the weathered profile is evidence that they have had uninhibited growth in large open pore spaces in a saturated environment (Norrish, 1982). The large, well-formed nature of the secondary gold also suggests that its growth was enhanced by the saturated, highly saline environment. Mann (1984) suggested that chloride complexes are responsible for the mobility of gold in these environments. This conclusion is supported by experimental work by Suito and Uyeda (1953) who produced thin, mainly triangular and hexagonal gold crystals, about eight microns in diameter, by the reduction of a dilute auric chloride solution.

Corrosion features suggest that the gold has been locally remobilized in response to fluctuations in the watertable level within the oxidized zone, precipitating new generations of supergene gold. The fluctuating watertable has occurred as a result of changes in climate and the progression of the migrating lake system over the deposit. Clustering of all forms of crystalline and non-crystalline supergene gold and the association of different generations suggests precipitation in microenvironments within the supergene environment. Rounding and semi-fusion of large octahedral crystals of gold suggest that they were one of the earliest supergene gold forms produced. Smaller, strongly corroded grains adjacent to larger, well formed crystals indicate that the smaller grains may have been a source of gold for the precipitation of a late generation of euhedral crystals. Small octahedra on plates and as partial crystal growth in microenvironments along cracks in larger rounded octahedra, indicate a recent generation of gold precipitation. Irregular semi-crystalline masses of gold show no sign of dissolution and were developed late relative to other crystal forms. Dendritic gold and associated forms have precipitated throughout all periods of supergene gold deposition, where solution chemistry has changed rapidly and prevented crystal growth.

Variations in depositional conditions during the development of the weathering profile at Hannan South, have produced a wide range of secondary gold forms within the supergene environment. Dissolution features suggest that gold has been remobilized locally, with subsequent precipitation of new generations of supergene gold. Lateritization is inferred to have proceded a more arid saline environment and subsequent development of a saturated, highly saline environment beneath a playa lake system.

ACKNOWLEDGEMENTS

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THE GEOLOGICAL CHARACTERISTICS OF LINGLONG GOLD DEPOSITS, CHINA

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ABSTRACT

The Linglong area in Shandong province is one of the largest and most famous gold camps in China. It comprises more than 10 gold mines, which mostly occur in the Linglong migmatitic granites.

The Linglong granites occur in the Eastern Shandong precambrian shield. The wallrocks are Archean biotite granulites, plagioclase hornblendites and amphibolitic granulites which formed a complex NW trending anticlinorium (Fig. 1). The granites are composite bodies consisting of medium-coarse grained granite, gneissose biotite granite, garnet bearing leucogranite and Ksp-porphyroblast-bearing gneissose granodiorite. According to their bulk composition, they belong to monzogranite, granodiorite, and monzodiorite. The granites can be divied into two types: melt granite and replacement granites on the basis of their geological occurrence, structure and texture, their contact with Archean wallrocks, their REE pattern, and their chemical composition. Both are the products of the Archean regional metamorphism.

In addition to the anticlinorium, a shear zones and a fault systems are well developed in the area and controlled the mineralization. The gold-bearing quartz veins occur in these structures and cut the Linglong granites.

There are four mineralization stages (Table 1): milky quartz-pyrite, quartz-pyrite, quartz-base metal sulfides and carbonate. The ore minerals are native gold and pyrite. The stable isotopic data of (Pb, S, O and H) of these stages show that the mineralization was associated with the Linglong granites. Fluid inclusion studies indicate there are two types of inclusions: liquid-rich and CO_2 inclusions, with homogenization temperatures of 400-150°C and medium salinity. The gold mineralization are correlated with the content of CO_2 of fluids. The ore-forming fluids may be from the Linglong granites and mixture with the meteoric water.

The Linglong granites are the melting products of the Archean metamorphic process. During these metamorphic process, metamorphic fluids formed through the fluids and rocks interreaction process. These fluids deposited quartz veins and alteration zones.

Table 1 - Mineralization stages in Linglong gold deposit

Mineralization stages	Main mineral paragenesis	Au/Ag	Pb mode age m.yr.
1. Pyrite, milky quartz	Milky quartz, pyrite chalcopyrite	0.5	846
2. Pyrite quartz	Pyrite, quartz, native gold, chalcopyrite, pyrrhotite, sericite	1.68	770
3. Base-Metal sulfides-quartz	Pyrite, galena, native gold, sphalerite, pyrrhotite, chalcopyrite, quartz, sericite	5.0	710
4. Carbonates	Calcite, quartz, pyrite	Low	657

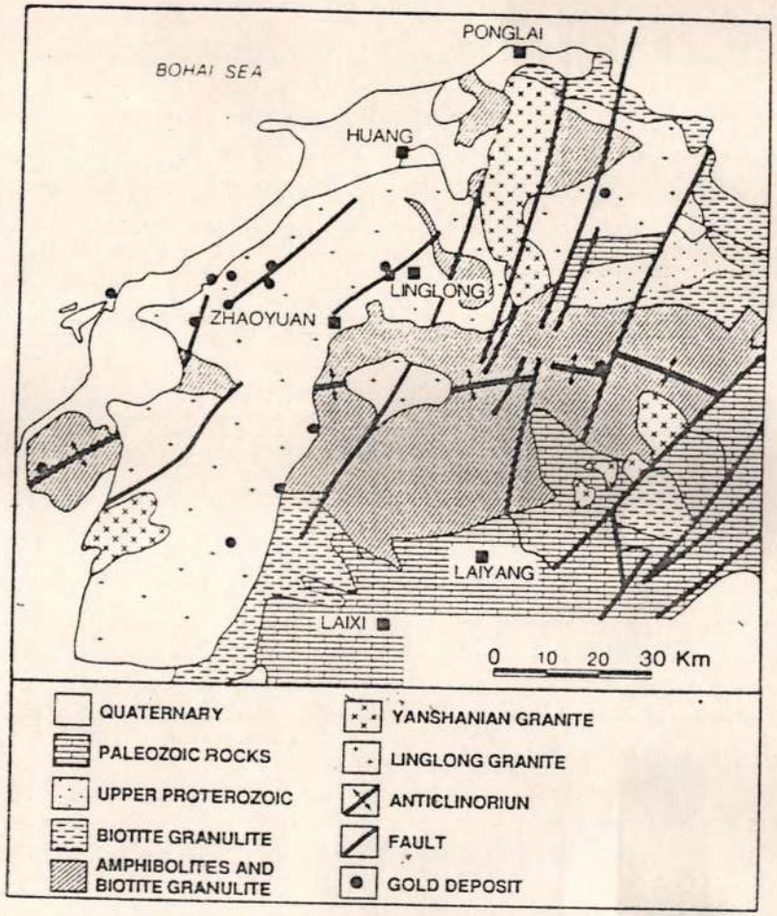


Fig.1 GEOLOGICAL MAP OF LINGLONG AREA

GEOLOGICAL RELATIONSHIPS, K-AR AGES, AND ISOTOPIC DATA FROM THE WILLOW CREEK GOLD MINING DISTRICT, SOUTHERN ALASKA

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The Willow Creek mining district is located in the Peninsular terrane, on the southwestern margin of the Talkeetna Mountains batholith. The district contains exposures of tonalite (74-73 Ma) and adamellite (67-65 Ma) of the batholith and an older unit of schist which has no nearby correlative units. The tonalite and schist both host gold-bearing quartz veins in fractures and shears, whereas the adamellite appears to be barren of gold mineralization. Our data suggest that there is a previously unmapped fault along the contact between the mineralized tonalite and schist. The fault may have provided a conduit for mineralizing fluids, and may represent a potential target for gold exploration.

Geologic relations and K-Ar ages indicate that at least two periods of hydrothermal activity occurred at 66 Ma and at 57-55 Ma. At 66 Ma, gold-bearing quartz veins were emplaced while the intruding adamellite and dikes of pegmatite and aplite provided heat to the host rocks. At 57-55 Ma, the hydrothermal activity coincided with minor volcanism recorded in the overlying sedimentary rocks and with the first movement along a regional strike-slip fault south of the mining district. This second period of hydrothermal activity could have led to a new phase of mineralization or to remobilization of the constituents of the older mineralized veins. Both periods of hydrothermal activity occurred during right-oblique subduction of the Kula plate beneath the Peninsular terrane and mineralizing fluids may have originated in zones of metamorphism and partial melting in the descending Kula plate.

Calculations from our data suggest that the oxygen-isotopic compositions of the mineralizing fluids in the tonalite and schist were similar to the tonalite and unlike the schist. This could have resulted if the fluids equilibrated with the tonalite at temperatures high enough that fractionation approached zero. The measured values of $\delta^{18}O$ from quartz in gold-bearing veins are +13.2 to +15.8, with one low value of +9.2, and the calculated fluid values are +6 to +8. These values occur in the veins with ages of 66 Ma, as well as in undated veins. The Pb-isotopic compositions of sulfides from two veins in the tonalite are nearly identical, but differ from those in the schist. These compositions suggest that the Pb in veins in the tonalite had a common source. In the schist, the gold-bearing fluids may have exchanged Pb with the metasedimentary rocks.

We suggest that at 66 Ma, a fluid equilibrated with the tonalite at high temperature, then mineralized both the tonalite and the schist. However, the fluid exchanged Pb with the schist and developed a more radiogenic Pb-isotopic signature than it had in the tonalite.

TABLE 1.—Potassium-argon ages of metamorphic and plutonic rocks, dikes, and mineralized veins in the Willow Creek district, Alaska

ROCK TYPE	MINERAL	AGE (Ma)
Ages of tonalite (unit Tkt)		
1.	Hornblende	73.1 ± 2.2
2.	Biotite	69.0 ± 2.1
3.	Hornblende	73.3 ± 2.2
	Biotite	72.0 ± 2.2
4.	Hornblende	74.4 ± 2.2
	Biotite	70.4 ± 2.1
	Hornblende	72.2 ± 2.2
Ages of dikes which cut tonalite		
5. Lamprophyre	Hornblende	66.2 ± 2.0
6. Pegmatite (Mineralized)	Muscovite	66.8 ± 2.0
	Alkalf Feldspar	64.7 ± 1.9
Ages of adamellite (unit Tka), biotite granite phase		
7.	Muscovite	67.2 ± 2.0
	Biotite	65.0 ± 2.0
Ages of hydrothermally altered tonalite and quartz vein		
8. Au-quartz vein	Muscovite	66.3 ± 2.0
9. Propylitized tonalite near fault	Plagioclase	54.7 ± 1.6
	Chlorite	56.8 ± 1.7
10. Sericitized tonalite	Hornblende	70.2 ± 2.1
	Muscovite	56.6 ± 1.7
Ages of schist (unit Jps) and serpentinite (unit Jsp)		
11. Schist near fault, Hatcher Pass	Muscovite	54.5 ± 1.6
12. Schist	Chlorite	50.6 ± 2.5
13. Schist	Muscovite	59.0 ± 1.8
14. Schist	Muscovite	65.9 ± 2.0
15. Serpentinite	Muscovite	59.6 ± 1.8
16. Serpentinite	Actinolite	88.9 ± 4.4
	Actinolite	91.0 ± 4.6

TABLE 2.—Values of $\delta^{18}O$ of quartz from mineralized veins, tonalite, and schist, Willow Creek district

SAMPLE	LITHOLOGY	$\delta^{18}O$	TEMPERATURE (°C)	RANGE OF CALCULATED FLUID $\delta^{18}O$
Metamorphic segregation quartz in the schist				
H.	Quartz	+15.7	550-450[1]	
I.	Quartz	+14.7	550-450	13-15
J.	Quartz	+15.7	550-450	12-14
				13-15
Gold-bearing quartz veins in the schist				
K.	Quartz	+15.3	100[2]	8
L.	Quartz	+15.8	100	8
Gold-bearing quartz veins in the tonalite				
M.	Quartz	+15.7	100[2]	8
N.	Quartz	+14.4	100	7
O.	Quartz	+15.4	100	8
P.	Quartz	+13.7	100	6
Q.	Quartz	+15.7	100-160	6-8
R.	Quartz	+15.4	100	8
S.	Quartz	+13.2	100-170	6-8
	Quartz (pegmatite)	+9.2	550-700[3]	7-8
Whole rock samples				
T.	Schist	+14.4		
U.	Schist	+12.0		
V.	Tonalite	+6.9		
W.	Tonalite	+7.3		

[1]Temperatures estimated from mineral assemblages in the enclosing schist.
[2]Temperatures estimated from fluid inclusion measurements by Burleigh (written communication, 1986).
[3]Temperatures estimated from minimum melting curves of pegmatite.

FIGURE 1. Location of Figure 2, Southern Alaska. (right)

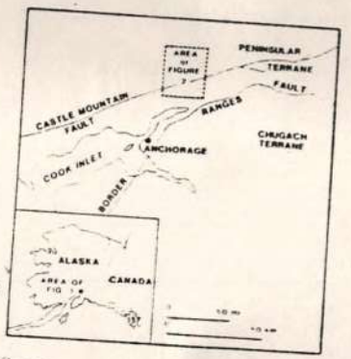
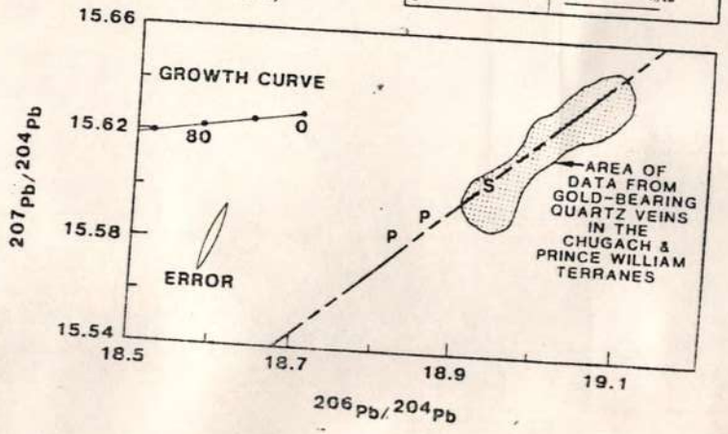


FIGURE 3. Lead-isotope diagram showing data from gold-bearing quartz veins in tonalite (P), and schist (S).(below)



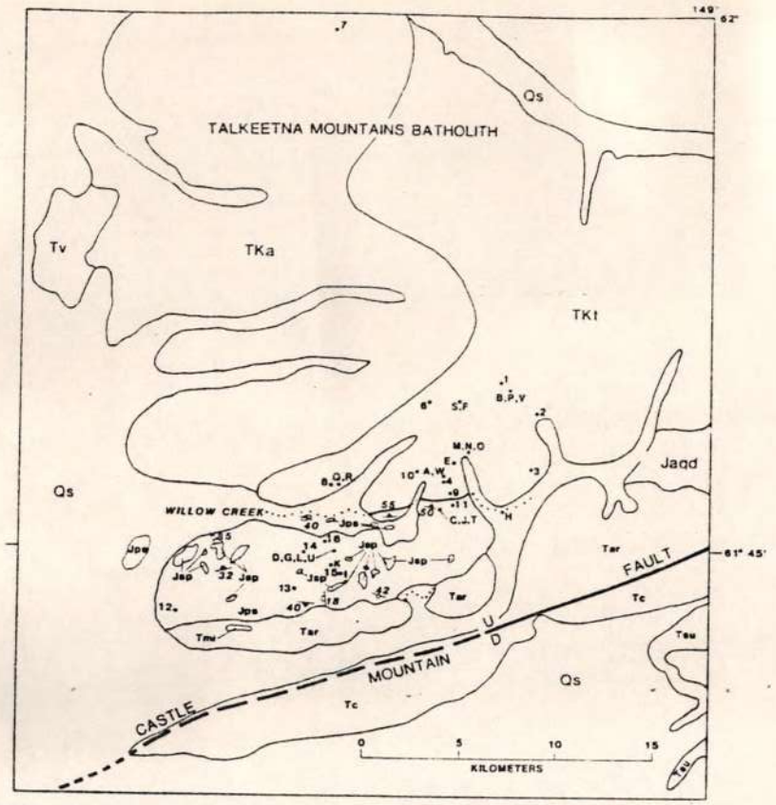


FIGURE 2. Geologic sketch map. Map-unit symbols: Qs, Quaternary surficial deposits; Tc, Tertiary Chickaloon Formation; Tar, Tertiary Arkose Ridge Formation; Tsu, Tertiary sedimentary rocks,undivided; TKa, Tertiary or Cretaceous adamellite; TKt, Tertiary and Cretaceous tonalite; Jsp, Jurassic(?) serpentinite; Jps, Jurassic(?) pelitic schist; Jaqd, Jurassic amphibolite and quartz diorite.

TABLE 3—Pb-isotope data from sulfides of the Willow Creek district. cp—chalcopyrite, ga—galena, lm—limonite, py—pyrite, tt—tetrahedrite. Analyses by M. H. Delevaux, U. S. Geological Survey

SAMPLE	MINE AND MINERALOGY	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
Mines in the tonalite				
E.	Independence gn. cp (1000ppm Pb)	18.827	15.590	38.499
F.	Holland cp, tt (200ppm Pb)	18.867	15.593	38.523
Prospect in the schist				
G.	Wheeler py, lm (150ppm Pb)	18.948	15.607	38.630

TABLE 4—Measured and calculated ($^{87}Sr/^{86}Sr$) for the tonalite and schist, Willow Creek gold-mining district; m—measured; c—calculated for 72 Ma.

SAMPLE	LITHOLOGY	Sr	Rb	Rb/Sr	$^{87}Sr/^{86}Sr$ m	$^{87}Sr/^{86}Sr$ c
A.	Tonalite	488	73	0.150	0.7042	0.7038
B.	Tonalite	682	51	0.075	0.7039	0.7037
C.	Schist	178	83	0.466	0.7079	0.7065
D.	Schist	195	119	0.610	0.7074	0.7056

TIMING OF MINERALIZATION AND ALTERATION AT SILBAK PREMIER SILVER-GOLD DEPOSIT, BRITISH COLUMBIA

DEAN McDONALD
UNIVERSITY OF WESTERN ONTARIO

GENERAL STATEMENT

Between 1918 and 1953, Silbak Premier Mine in northern British Columbia produced 4.3 million metric tons at 13.2g Au and 275g Ag per ton from sulphide-bearing sheeted and stockwork veins and breccia zones. Vein stock works and breccia zones are marginal to and crosscut irregular to tabular plugs and dykes of Jurassic age potassium-feldspar porphyritic dacite. The dacite intrudes or is conformable with massive and fragmental andesite of Late Triassic to Early Jurassic age. Breccia zones typically are 1 to 20 meters wide and are en echelon for over 1000 meters snd have a down-dip extent of more than 500 meters. En echelon quartz-chlorite veins cut mineralized veins and breccias.

DESCRIPTION AND TEMPORAL RELATIONSHIPS

The oldest breccia is within massive andesite peripheral to potassium-feldspar porphyritic dacite. It is a crackle or "in situ" breccia of siliceous rounded to angular fragments that vary in diameter from 1 to 15 centimeters. The proportion of fragments vary from less than 25 percent up to 90 percent. Where the proportion of fragments is large, fragments are angular and have little or no rotation. Matrix to the fragments is pervasive carbonate minerals and pyrite with irregular patches of decussate chlorite and sericite.

The oldest veins have intergrown or banded quartz and chlorite mosiacs locally rimmed by pyrite. They crosscut the crackle breccia, and are themselves cut by stockwork veins. Quartz-chlorite veins are 0.5 to 3 centimeters wide, tabular, and have narrow envelopes of decussate chlorite and carbonate minerals. These "sheeted" veins are observed in the lower part of the deposit and form parallel, en echelon series.

Stockwork veins are irregular zones of banded or featureless veins that are coincident with or extentions of sulphide-bearing breccia zones. Veins vary in thickness from 0.5 to 4 centimeters and have relatively planar orientations. Matrix to the breccia is normally chalcedonic and contains patches of metallic minerals.

In general, the oldest stockwork veins are quartz-rich with calcite and minor albite, jasper and rhodochrosite. These veins and coincident breccia matrix contain patches of pyrite, sphalerite, chalcopyrite, pyrrhotite, tetrahedrite, native silver and electrum. Quartz, sericite, potassium-feldspar and carbonate minerals pseudomorph primary quartz, plagioclase and hornblende assemblages in host dacite and andesite. These textures extend out no more than four times the vein width and decline in intensity from the vein. Further from the vein margins chlorite and carbonate pseudomorph the plagioclase and hornblende assemblage. Quartz-rich margins to the breccia zones extend less than a meter and form a symmetrical distribution

patterns. Replacement by sericite and carbonate minerals is more intense and has greater distribution in the hanging wall. Secondary chlorite replacement is patchy in distribution but normally more prominent in footwall areas.

Stockwork veins and breccia matrix with as much as 45 percent pyrite, galena, sphalerite, chalcopyrite, pyrrhotite, tetrahedrite, native silver and electrum cut the more quartz-rich stockwork veins. Quartz, chalcedony, calcite, barite, and albite are intergrown with the sulphides and locally form crude bands. Quartz, sericite, and potassium-feldspar pseudomorph primary quartz, plagioclase and hornblende marginal to the vein and are exceeded in distribution by chlorite, carbonate and pyrite pseudomorphs.

Base metals, tetrahedrite, electrum, and native silver are observed in both vein types, however, polybasite, pyrargyrite, and argentite are confined to quartz-carbonate veins. Quartz-carbonate stockwork veins are more prominent at the topographic top of the deposit and base metal rich veins more prevalent in the lower parts.

Coarse grained quartz-chlorite veins occupy vertical and horizontal fractures and cut stockwork veins in en echelon pattern. A weak, discontinuous carbonate-pyrite alteration envelopes these veins.

INTERPRETATION

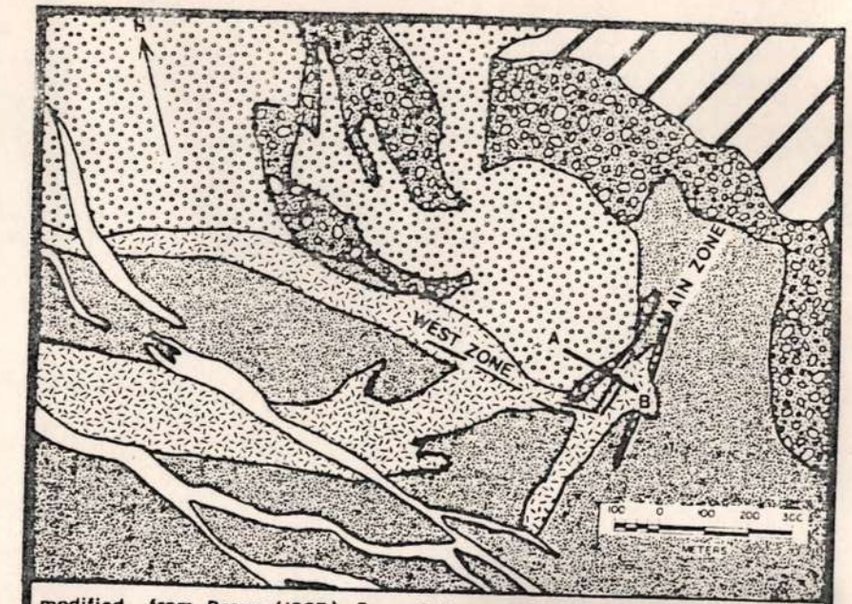
Metallic minerals in veins and matrix to breccia indicate a paragnetic sequence from sulphide rich minerals to sulphosalts and native minerals. Vertical distribution shows changes from sulphosalt assemblages in the topographic top of the deposit to more base metal rich assemblages at the bottom. Alteration assemblages related to veins and breccias show a temporal trend from chlorite-carbonate to sericite-potassium feldspar-carbonate assemblages.

Intrusion of the porphyritic dacite into andesite sequence initiated faulting. Metal-bearing fluid followed emplacement of the porphyritic dacite, initially into diffuse areas of crackle breccia then subsequent faults and fractures during sealing and breakage. Deposition of early precious metal rich veins is followed by more base metal rich veins. Vertical changes in the metallic mineral assemblage and mineral alteration along vein margins can be attributed to changing abundances of CO_2 and H_2S with declining temperature.

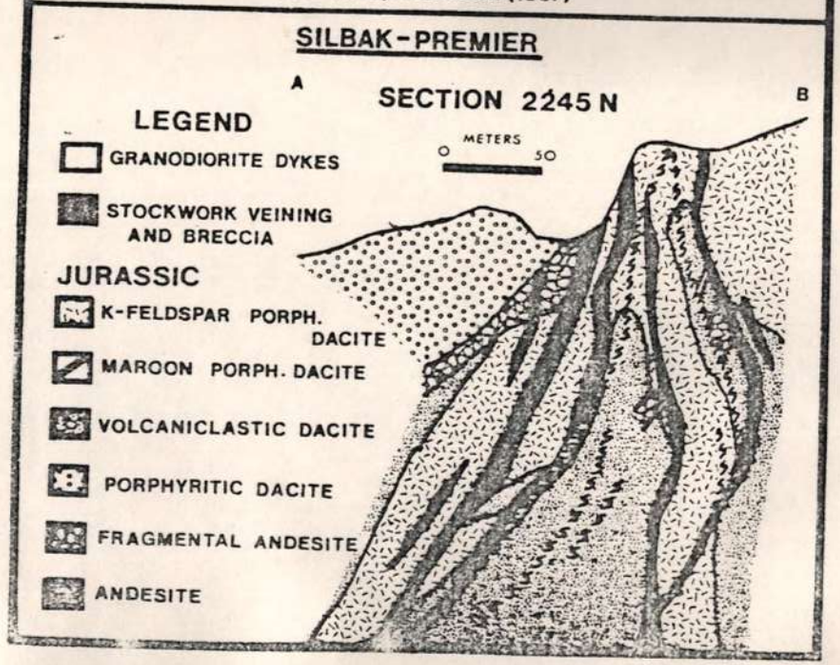
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modified from Brown (1987), Payne & Sisson (1987)



ORE CONTROLS OF THE ALASKA JUNEAU MINE, SOUTHEAST ALASKA

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The Alaska Juneau (AJ) Mine (which includes the Ebner and Perseverance mines) was one of the largest, lowest grade operations in the world between 1915 and 1940 and yielded 132.7 mm g Au, 75.6 mm g Ag, and 20.5 Mkg Pb from 91 Mmt of ore. Proven reserves consist of 26.4 Mmt at 1.37 g/t Au and there are 91 Mmt of inferred reserves. The orebodies have been mined over a horizontal distance of 4 km and to a depth of 850 m. The U.S. Bureau of Mines examined the AJ Mine as part of its Juneau Mining District study and developed a new ore-control model in which orebodies occur above and below the hinge of a major, SE-plunging, synclinal fold. Echo Bay Mines is currently evaluating the deposit.

ROCK UNITS - Rocks in the AJ Mine area consist of NW-striking and NE-dipping, regionally metamorphosed argillaceous sedimentary and mafic volcanic rocks of Triassic age. Metamorphic grade increases from prehnite-pumpellyite on the west to amphibolite on the east.

The mine area is underlain by the black Perseverance phyllite and the Ground Hog greenschist which lie above the massive Gastineau volcanics. The Perseverance phyllite includes quartzose felsic phyllite and has been intruded by numerous gabbro sills.

STRUCTURE - Three phases of folding have occurred in the mine area. Most notable are mesoscopic to megascopic isoclinal F2 folds which have wavelengths up to 600m and are overturned to the west. Fold axes plunge 30° to 50° SE. Large folds display polyharmonic folding in the hinge area.

There are two orientations of faults in the AJ Mine area: 1) faults subparallel to foliation, and 2) faults that crosscut rock units and orebodies. Many of the faults have had displacement both before and after mineralization. The foliation-parallel faults strike NW and dip steeply NE. Fault planes tend to be undulatory with both horizontal and vertical slickensides. Many of these faults are brittle - ductile shears and are subparallel to the axis of the AJ syncline. The most notable of these faults is the Nugget Gulch fault which can be traced from the Ebner to the Perseverance mines, a distance of 4 km.

Crosscutting faults strike ENE and dip steeply N or S. The Silver Bow fault, most notable of the crosscutting structures, has had oblique-slip left-lateral normal offset of about 550m. Most of the offset was post-mineral but initial movement occurred during mineralization.

ALTERATION - Quartz veining in the mine area was accompanied by intense hydrothermal alteration. The alteration assemblage consists of brown biotite and ankerite/ferroan dolomite with

widespread chrome mica. Reactive gabbro and greenschist exhibit the most conspicuous alteration but the black phyllite may also be altered. Where the quartz veins are hosted by the Ground Hog greenschist, that unit has been altered very similarly to the gabbros. Most alteration is confined to areas with quartz vein swarms but the contact between the Ground Hog greenschist and the Perseverance phyllite displays biotite/carbonate alteration well away from the main orebodies.

ORE CONTROLS - Mineralization at the AJ Mine was emplaced near the end of regional metamorphism under mesothermal conditions at a depth of about 5 to 8 km. The U.S. Geological Survey dated the peak of the metamorphic event at 57 to 60 m.y. ago and has given an age of mineral deposition, based on K-Ar from muscovite in quartz veins, of 55 m.y. to 57 m.y. Geothermometry of sulfide minerals by the Survey indicates that temperatures were 300-375° C in the veins, and in excess of 375° C in the wallrocks. Sphalerite geobarometry and fluid inclusion studies by the Survey indicate vein formation pressures of about 2.5 Kb.

Five quartz vein sets have been delineated in the AJ Mine area. Three vein sets contain only pyrrhotite but two contain economic mineralization. Mineralized vein sets strike NW, but one set dips moderately to steeply NE while the other dips steeply SW. Dips are 40° - 45° apart. Generally, the NE-dipping veins occur in the black phyllite while SW-dipping veins occur in cross-fractures in gabbro bodies. The two sets are synchronous based upon cross-cutting relations.

Quartz veins average 0.6 m thick, with a maximum of 6 m, and rarely extend more than 70 m. Boudinage is common in the irregularly shaped, phyllite-hosted veins. Veins hosted by the gabbro tend to be straight-walled and massive.

A large gabbro body in the fold hinge that plunges SE from the North Orebody has been strongly mineralized along both its upper and lower contacts. The lower contact hosts the Ebner and Deep North orebodies while the upper contact controls the Upper North, South, and Icy Gulch orebodies. In the Perseverance Mine, ore is concentrated underneath a fold hinge of felsic phyllite.

The richest orebodies occur at the bottom of the hinge. In the Deep North Orebody, below the hinge, the ore averaged over 2.4 g/t Au while ore in the South and Upper North orebodies, above the hinge, averaged about 1.37 g/t. Perseverance ore, from below felsic schist in the hinge, ran 3.4 g/t Au.

The lower contact of the fold hinge has been mined over a distance of about 600 m while the upper contact has been mined for 1,500 m. The Perseverance orebody below the felsic phyllite in the hinge has been mined for 600 m down plunge.

The ore zones are controlled by the superposition of the NW striking faults on the hinge region of the main fold. Pre-mineralization penetrative cleavage, due to near horizontal compression, imparted a strong anisotropy which controlled the geometry of the veins. Kinematic indicators (S-C fabric, rotated porphyroblasts, etc.) support a NE over SW sense of movement.

Fracturing was facilitated by increased fluid pressure and/or uplift resulting in a local tensional environment favorable for vein emplacement. The strong anisotropy combined with near vertical compression resulted in shear veins forming subparallel to foliation. Tensional veins (indicated by calcite fibers) formed 40°-45° from the foliation and the shear veins. The highest vein densities occur along the contact of the gabbro and phyllite due to the high competency contrast.

After mineralization, the horizontal compressional regime resumed. Axes of quartz vein boudins show that the X-Y plane of the stress ellipsoid was subparallel to the shear veins and the foliation at this time.

MINERALIZATION - Mineralized veins in the AJ deposit contain pyrrhotite, sphalerite, galena, pyrite, chalcopyrite, and arsenopyrite. Microprobe studies by the Bureau of Mines have also noted native bismuth, bismuthinite, joseite (Bi_4TeS_3).

Metallic assays of selectively collected mineral samples, in which the +100 mesh and -100 mesh fractions were analyzed separately, showed that coarser gold is concentrated in and near sphalerite. Six sphalerite samples contained an average of 380 g/t Au (65% of which was in the +100 mesh portion). For comparison, 4 galena samples averaged 72 g/t Au, and 5 pyrrhotite samples taken averaged 87 g/t Au.

There is no obvious mineral zonation within the veins, but there is a change in sulfide assemblages and Au/Ag ratios both along and across the ore zone. A longitudinal zonation has been recognized from the NW to the SE. Pyrrhotite occurs throughout the system, sphalerite occurs in the North Ore Body and is common in the South Ore Body and eventually decreases to the south. Galena is first found in the southern part of the North Ore Body and is most abundant in the South Ore Body and the Perseverance. Arsenopyrite is rare in the South Ore Body and increases to the south.

The North Orebody also displays a concentric lateral zonation. Pyrrhotite, sphalerite, and galena all occur at the footwall adjacent to the Nugget Gulch fault. Galena is concentrated near the fault while sphalerite is more extensive. Pyrrhotite extends well into the hangingwall beyond the orebody.

The ratio of Au to Ag is highest at the NW end of the system in the Ebner Mine where a 7:1 ratio has been reported. The ratio decreases steadily to the SE with 2.4:1 in the North Orebody, 1.5:1 in the South Orebody, and 1:1 in the Perseverance Mine. At the Ascension and Glacier/Silver Queen mines, 1.5 km to the SE, the Au/Ag ratio drops radically to 1:200.

CONCLUSIONS - In the AJ Mine, orebody location is controlled by the interaction of a ductile-brittle shear zone and the hinge area of isoclinally folded gabbros and phyllites. Both upper and lower contacts of the hinge have been mined extensively but mineralization continues beyond historically-worked areas with no diminution. Additional ore should exist deeper along the plunge of the hinge.

Mokrsko Gold Deposit - A New Type of Gold Mineralization in the Bohemian Massif, Czechoslovakia

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Gold deposits in the Bohemian Massif are connected with bimodal Upper Proterozoic volcanosedimentary complexes. The Jílové Belt in Central Bohemia represents the most important structure of this rock type. Regional geochemical prospecting in the Belt detected new gold districts; subsequent drilling and mining operations localized unknow gold deposits.

The Mokrsko Deposit, the largest and most important one in the Bohemian Massif with reserves over 100 t of gold is quite unique due to its specific structure. Gold mineralization is filling up a tectonic zone of dilation character, seated both within Proterozoic volcanics and granodiorite of the Central Bohemian pluton, which is of Variscan age. The thickness of the ore zone varies from less than 100 m in tuffaceous complex to over 200 m in granodiorite. Low-grade gold mineralization /2 g/t in average/ is formed by steep parallel quartz veins and veinlets which exhibit a frequency of up to 100/1m, with extremely low variation of gold contents /variation coefficient less than 70 %/. The vein system simplifies downwards together with a decrease in thickness and gold contents as well. The gold is extremely fine and of high fineness /over 950/. It is accompanied above all by arsenopyrite; pyrrhotite, pyrite, molybdenite, scheelite and Bi-Te minerals are less frequent.

A geochemical study of trace elements distribution resulted in their division into three groups, i.e. elements related to gold mineralization /Au, As, Bi, Mo, W/, to lithology /Co, Cu, Ni, partly Zn, Pb, W/ and to subsequent younger tectonics /Ag, Sb, Ba, Pb, Zn/. Gold pathfinders exhibit a vertical zoning; while As is concentrated predominantly in the upper parts of the deposit, W /scheelite/ concentrates downwards close to the pay gold ore line.

Gold mineralization is interpreted as hydrothermal-metamorphic, connected with granitization of the Upper Proterozoic volcanics. Ore deposition probably took place in the conditions of contact metamorphism on the range of upper epidote-ampfibolite and lower amphibolite facies. This interpretation is supported by the lack of any lower temperature hydrothermal wall rock alteration and by the presence of mafic silicates /biotite, amphibol/ of the same composition both in gold bearing quartz veins and in

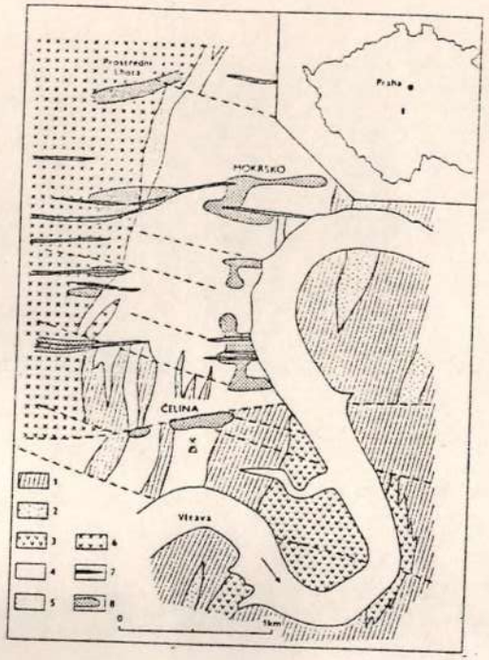


Fig. 1. Geological map of the Čelina-Mokrsko gold district

1-mafic volcanics
2-intermediary volcanics
3-plagiogranites
4-tuffs
5-shales
6-granodiorite
7-dyke rocks
8-gold mineralization

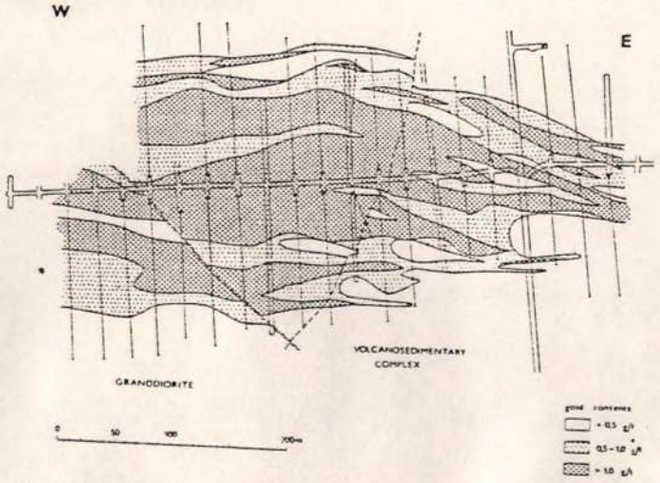


Fig. 2. Distrinution of gold in the Mokrsko deposit Gallery level

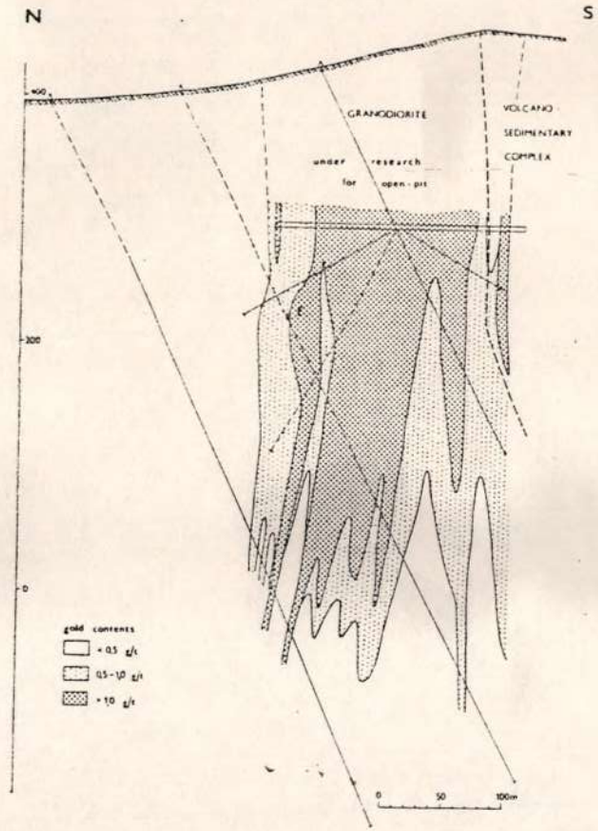


Fig. 3. Distribution of gold in the Mokrsko deposit. Cross section

adjacent rocks as well. A rather high thermal gradient connected with the granodiorite intrusion is probably responsible for the vertical zoning marked by the distribution of pathfinders and for the decrease in concentration coefficient of gold downwards.

HIDDEN VALLEY GOLD-SILVER DEPOSIT
DISCOVERY AND EXPLORATION
PAPUA NEW GUINEA

R.W. Nelson - Principal Geologist, M.H.D. Christie - Geologist
CRA Exploration Pty. Ltd. - Madang PNG

INTRODUCTION

The Hidden Valley gold-silver deposit is situated at lat. 7° 30' S long. 146° 25'E and lies approximately 15 kilometres SSW of Wau in the Morobe Province of Papua New Guinea. (Wau SB55-14 1:250 000 Map Sheet).

The deposit sits on the drainage divide between the Upper Watut and Bulolo Rivers, at an altitude of 2400m a.s.l. Access to the prospect is by helicopter from Wau or on foot by the old Bulldog Track that passes to the east of the prospect.

Alluvial gold was first discovered in Hidden Valley by W.H. Chapman in early 1928. (Lowenstein, 1982).

The discovery of Hidden Valley by CRA Exploration resulted from the follow-up of a 8.4 g/t Au -80 mesh stream sample with 12.6 g/t Au in the corresponding pan concentrate collected previously in a regional geochemical exploration programme. Base metal values were also anomalous. Stream traversing revealed a zone of altered granodiorite that gave an interval of approximately 100m @ 3 g/t Au, 45 g/t Ag in rock chip sampling along Hidden Valley Creek in the vicinity of a large landslip. Early drill testing followed in December 1985.

By December 1987, 67 diamond drill holes totalling 18790m had been completed.

The geological resource is estimated to be in the range of 35 to 40 million tonnes at a grade of approximately 2 g/t Au and 30 g/t Ag based on a cut off grade of 1 g/t Au.

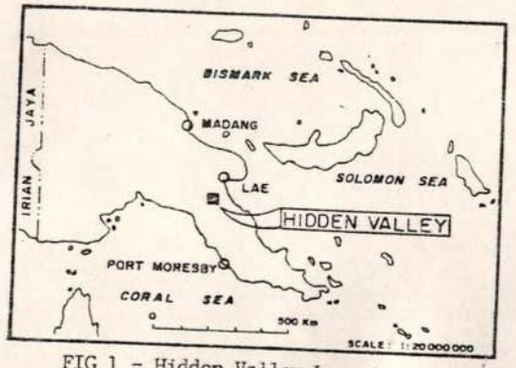


FIG 1 - Hidden Valley Location

REGIONAL GEOLOGY

The basement rocks in the Wau area are slates and chloritoid schists of the Kaindi Metamorphics (local name) which forms part of the Jurassic/Cretaceous Owen Stanley Metamorphic Belt. This basement was intruded by batholiths of Morobe Granodiorite during the mid Miocene period. A further period of volcanic activity occured in the Pliocene when andesite and dacite porphyry dykes (Edie Porphyry) and stocks were intruded into the basement and granodiorite.

LOCAL GEOLOGY AND STRUCTURE

At Hidden Valley the Morobe Granodiorite intrudes a sequence of fine grained metasediments (Owen Stanley Metamorphics). Porphyry dykes are intrusive into both granodiorite and metasediments.

The gold mineralisation is structurally controlled by a moderately dipping fault, the basal tectonic breccia zone, and the shallowly dipping granodiorite/metasediment contact.

The metasediments, consisting of indurated intercalated silts and sandstone and black phyllites form a caprock above the Hidden Valley deposit.

The Morobe Granodiorite is the dominant host to the gold mineralisation. It is generally a coarse crystalline rock with large porphyritic phenocrysts of K-feldspar enclosing plagioclase hornblende and biotite in a quartz matrix.

A series of NW-SE trending faults dominant the structure at Hidden Valley. The most important being the "basal tectonic breccia" which forms a planar base to the mineralisation.

The breccia strikes NW-SE and dips 30-35° to the NE.

It is seen in the drill core on a zone of brecciated granodiorite 2-30cm thick. It crops out in the Hidden Valley Creek for about 300m.

ALTERATION AND MINERALISATION

Alteration of the host rocks at Hidden Valley varies from mininal to intense, with a general association between intensity and mineral assemblage. Where alteration is slight chloritisation of the mafics predominates. In moderate to strongly altered rocks plagioclase is altered to illite, and in intensely altered rocks K-feldspar, plagioclase and mafics are all partially or totally altered to illite. This is considered to be a transition from weak propylitic to strong phyllic alteration.

Argillic alteration is restricted to localised clay breccia zones.

There appear to be 7-8 mineralogical vein suites present at Hidden Valley, each is probably multigenerational but a general sequence is apparent from cross cut relations. The predominant veins appear to be;

1) pyrite + chlorite + epidote + quartz.
2) chlorite-hematite + carbonate ± pyrite.
3) manganiferous carbonate
   i) quartz-adularia
   ii) adularia-mixed sulphides-Au (sphalerite, galena, ± tetrahedrite)
   iii) kutnahorite-Au

Early quartz and chlorite veins suites do not normally contain gold values.

The presence of coarse adularia, colloform banding, pitted sulphides and local brecciation suggest deposition by boiling.

The adularia from the veins has been dated by K-Ar at 4.1-4.2 million years.

Free gold extracted from oxidized veins has a fineness of approximately 725.

DRILLING

Drilling commenced in December 1985 and by December 1987, 67 diamond drill holes totalling 18790m had been completed. The first four holes were drilled in the region of the slip.

The holes in numerical order returned gold and silver values (in g/t) over intersection of 26m from 0m at 2.1/32, 68m from 0m at 2.1/32, 114m from 61m at 3.0/52 and 137m from 184m at 2.7/28.

The geological resource is estimated to be in the range of 35 to 40 million tonnes at a grade of approximately 2 g/t Au and 30 g/t Ag based on a cut off grade of 1 g/t Au.

A VIEW THROUGH AN EPITHERMAL-MESOTHERMAL PRECIOUS METAL SYSTEM IN THE NORTHERN BLACK HILLS, SOUTH DAKOTA, U.S.A.: A MAGMATIC ORIGIN FOR THE ORE-FORMING FLUIDS

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GOLD IN THE BLACK HILLS

The Black Hills of South Dakota consist of a central core of late Archaean to early Proterozoic schists unconformably overlain by Palaeozoic and Mesozoic sedimentary rocks. Almost 1.25 million kg (40 million oz.) of gold and 250,000 kg of silver have been produced from the Black Hills; most of this production was from the early Proterozoic iron formation-hosted Homestake gold deposit. In the Precambrian section, there are U-Au paleoplacers in quartz-pebble conglomerates (e.g. Nemo), stratabound Au associated with iron formation (e.g. Homestake), Au-quartz veins in metagreywacke, amphibolite, and shear zones. Hosted by Phanerozoic rocks are basal Cambrian Au paleoplacers (e.g. Lead area), Tertiary epithermal intrusion-hosted Au (e.g. Gilt Edge) and breccia-hosted Au deposits (e.g. Richmond Hill), and Tertiary epithermal sediment-hosted Au-Ag-(Pb)-(W) vein and replacement deposits (e.g. Annie Creek). The Homestake mine continues to operate, and most activity by other companies is focussed on the Tertiary epithermal deposits.

TERTIARY EPITHERMAL-MESOTHERMAL DEPOSITS

The Tertiary hydrothermal deposits are spatially and temporally associated with an alkalic igneous province along an east-west zone from Devils Tower (Wyoming) to Bear Butte (South Dakota). Lithologies include quartz monzonites, latites, rhyolites, trachytes and phonolites. Most of the rocks are porphyritic, and form dikes and stocks in the Precambrian schist, and sills, laccoliths, dikes and stocks in the Phanerozoic section. DeWitt et al (1986) concluded that the Tertiary mineralization was younger than, or similar in age to, trachytic and rhyolitic sills emplaced in the Deadwood Formation (Cambrian), and older than phonolitic intrusions.

Because of structural relief, and underground exposure to a depth of 3000 metres in the Homestake mine, a 4 km vertical section is exposed through the Tertiary hydrothermal systems (Fig. 1). By reconstructing the pre-Tertiary stratigraphy, it has been established that the exposed mineralization formed at depths of 1 to 4.5 km.

In spite of local variations related to igneous intrusions, the general character of mineralization varies with depth. Gold-silver mineralization occurs in quartz-pyrite ± galena ± fluorite ± annydrite ± biotite ± molybdenite ± cosalite veins in Precambrian schist at depth, quartz-pyrite-fluorite veinlets and disseminated pyrite in igneous stocks and breccias, and silicified arsenian pyrite-marcasite replacement mantos adjacent to vertical fractures in Lower Palaeozoic sedimentary rocks (calcareous and dolomitic sandstones, limestones).

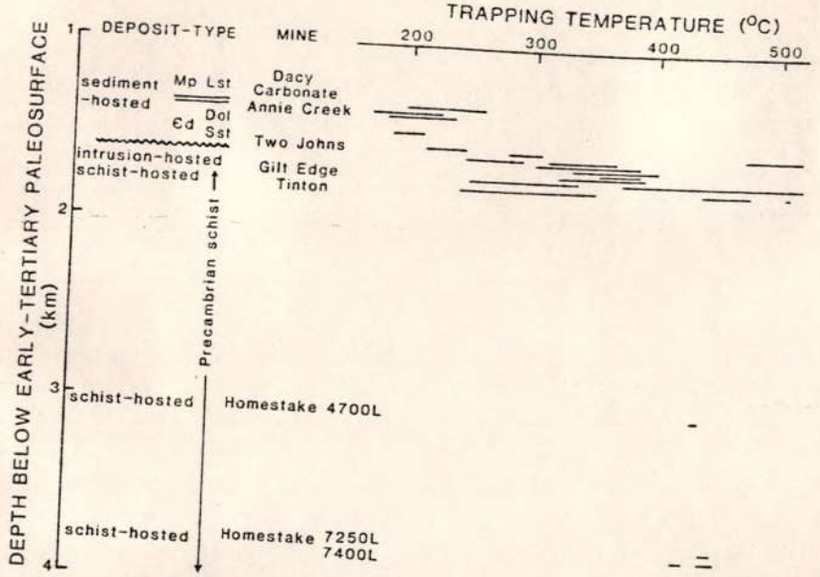


FIGURE 1: Summary of the stratigraphy, location of deposits, and variation in trapping temperatures with depth in the Tertiary hydrothermal systems. Not all mines are listed. Єd = Deadwood Formation, Mp = Pahasapa Limestone.

Lisenbee (1985) noted a general metal zoning in the northern Black Hills from Mo-W in the center to Pb-Ag on the periphery of the intrusive complexes.

ORE-FORMING FLUIDS

Fluid inclusions in quartz and fluorite from veinlets in these deposits are diverse (Fig. 2). Most fluids have low salinity (<10 wt%), but saline fluids (15-63 wt% equivalent NaCl) occur deeper in the system and in the intrusion-hosted deposits. Daughter minerals of halite and sylvite have been identified. The gradation in fluids from high-temperature, high-salinity to moderate-temperature, low-salinity (Fig. 2) suggests a mixing of fluids. Although there are considerable temperature ranges within single deposits (especially intrusion-hosted), trapping temperatures are consistently high (450-500°C) deep in the system, but decrease abruptly over a short vertical distance in the vicinity of the unconformity (Fig. 1). Trapping temperatures in the sediment-hosted deposits above the unconformity are in the range 170-260°C.

Quartz $\delta^{18}O$ values in Tertiary veins range from 11.7 to 16.9 per mil. Fluid $\delta^{18}O$ values range from 6.2 to 11.6 per mil; the lowest value is from a sample in the vicinity of the unconformity, and higher values represent fluids in conduits deeper in the schist. δD values of -53 to -75 per mil have been determined for the hydrothermal

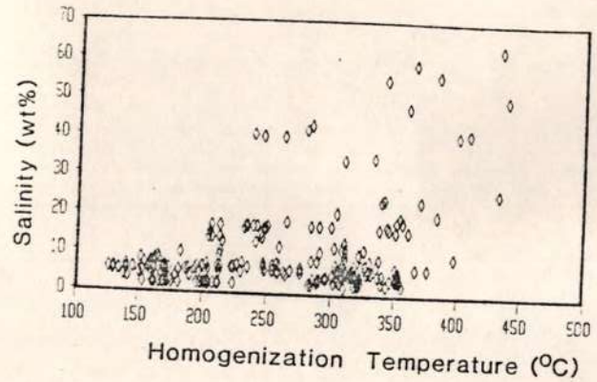


FIGURE 2: Salinity versus homogenization temperature for epithermal and mesothermal deposits in the northern Black Hills. A Na/K fluid ratio of about 2 exists in some halite-sylvite bearing inclusions.

fluids (Rye and Rye, 1974).

Rye and Rye (1974) stated that although their isotopic data were typical of magmatic waters, they could not exclude the possibility that meteoric waters were also involved. The isotopic and fluid inclusion data presented here also suggest that magmatic water was an important component of the ore-forming fluids. The gradation in salinities, the marked decrease in temperature above the unconformity, and the presence of lower $\delta^{18}O$ values at shallower levels (about 1 km depth) are consistent with a model whereby auriferous magmatic fluids, generated by the crystallizing igneous intrusions, mixed with meteoric waters in the aquifers in the basal Palaeozoic sequence. This fluid mixing, resulting in cooling and dilution of the ore fluid, was a likely cause of gold deposition in the sediment-hosted deposits. The alkalic magmas are inferred as the gold source; assimilation of anomalously-auriferous Precambrian crust in the Black Hills region may have enhanced the gold contents of the magmas.

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CHARACTERISTICS OF BONANZA EPITHERMAL GOLD MINERALIZATION AT THE SLEEPER DEPOSIT, NEVADA, USA

by

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The Sleeper deposit, 45 km northwest of Winnemucca, Nevada, represents one of the few bonanza epithermal precious metal systems recognized in the Basin and Range Province of the United States. The deposit was discovered in 1982 along an iron-stained fault zone on the northwest flank of the Slumbering Hills by John D. Wood of AMAX Exploration, Inc. The deposit lies beneath the pediment of the Slumbering Hills and is covered by approximately 30 m of alluvial sand and gravel intermixed with lacustrine silt and clay. Production started in February of 1986. Mining from two open pits results in a combined yearly production of approximately 200,000 tr oz (6.2 t) Au and a similar amount of Ag. Published reserves are 62 t Au including mill grade and leachable ore.

The Sleeper deposit is hosted by rhyolitic ash-flow tuffs that may have been erupted (at about 15 Ma) from the McDermitt caldera complex 50 km to the north. Three general ore types have been recognized to date, including high-grade banded quartz veins, stockworks, and silicified hydrothermal breccias. The disseminated stockwork and breccia ores constitute most of the mineable reserves, but the bulk of the gold produced to date has come from the high-grade veins. For example, mining from the first four 20-ft (6.1 m) benches produced 411,000 t of mill grade ore (5 g/t) from which 275,000 tr oz (8.55 t) Au were recovered. Of this total, 71.3% of the recovered Au came from 9680 t (2.35% of total tonnage) of high-grade vein material averaging 650 g/t Au. The remainder had an average grade of 6.3 g/t.

At least two major bonanza veins have been recognized to date. The largest, called the Sleeper Main vein, is exposed in the northernmost (Sleeper) pit (Figure 1) and is approximately 1-3 m in width, is steeply dipping, and has a minimum strike length of 115 m. The grade averages approximately 680 g/t Au, but many intercepts are in the 1000-6000 g/t range. A smaller vein of similar undiluted grade, 0.3-0.8 m thick, is also exposed in the Sleeper pit and apparently represents a hanging wall splay of the Main vein. Limited deep drilling indicates that bonanza grade ore extends to at least a depth of 100 m below the pre-mining surface, and that the vein continues to greater depths but with lower grades. Two high-grade veins are present in the southernmost (Wood) pit; correlation with the veins in the Sleeper pit is problematic. The East vein is the larger of the two and has a strike length of at least 275 m, and is 0.6-4.5 m thick with Au content ranging from 10 to 170 g/t. In addition, another bonanza vein outside of the current pit boundaries of largely undertermined extent has been discovered by reconnaissance drilling. Both stockwork and breccia ore appear to crosscut the veins, as do several stages of faults. The youngest faults, which are high angle

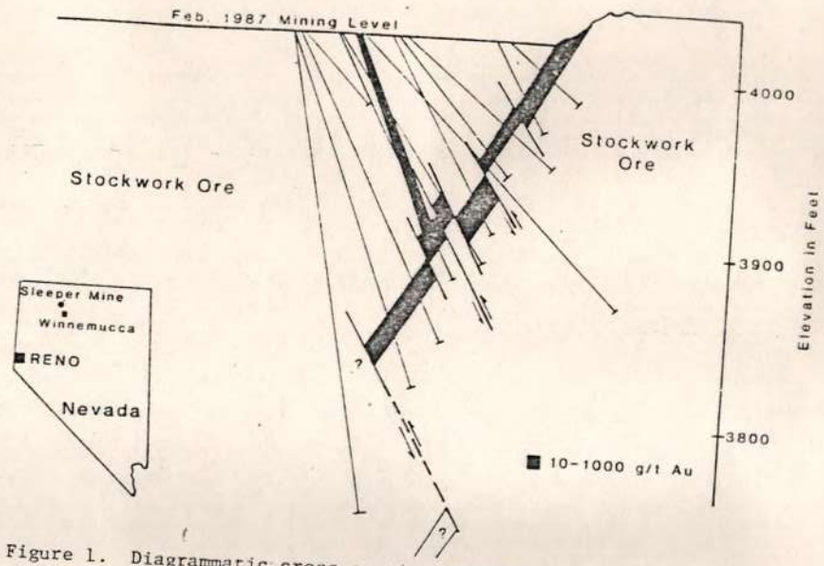


Figure 1. Diagrammatic cross section showing the relative position of the bonanza veins to stockwork ore in the Sleeper pit.

north-south trending Basin and Range structures, are responsible for segmentation of at least one of the principal veins.

Evidence for a minimum of four stages of mineralization in the Sleeper pit is present in the bonanza vein structures: (1) spectacular early Stage 1 colloform-banded electrum and chalcedony, with significant amounts of fine-grained argentite, mirargyrite, pyrite, rutile, and barite, and traces of adularia, tetrahedrite, silver telluride and selenide; (2) brecciated Stage 1 banded ore cemented by silica with minor electrum; (3) dark-colored siliceous veinlets less than a few centimeters in width that exhibit a strong Ag-Se geochemical signature and contain fine-grained framboidal pyrite and sphalerite; and (4) late-stage, barren quartz-stibnite veinlets. In addition, veinlets and vugs containing cerargyrite and alunite are present, but are probably supergene in origin. Stage 1 banded bulk ore contains the majority of the gold, with a gold:silver ratio of approximately 1.6:1. Disseminated ore typically has a gold:silver ratio of less than 1:10, resulting in an approximate deposit average of 1:3.

Electron microprobe analysis of electrum from the bonanza veins indicates that electrum deposited during early mineralization was more gold-rich (68 to 71 wt% gold; mean fineness = 687±8) than later stages of vein mineralization (62.5 to 66 wt% gold; mean fineness = 641±9). Primary electrum, typically 69 wt% Au and 31 wt% Ag, is commonly rimmed by halos of cerargyrite (AgCl) and intergrown with gold-rich electrum (86 wt% Au, 14 wt% Ag) and cerargyrite. We suggest that the development of the cerargyrite is supergene, and that the

silver was leached from the primary electrum by chloride-bearing groundwater. This is consistent with the presence of cerargyrite in post-ore vugs, present-day chloride contents of up to 280 mg/l in the groundwater, and an apparent enrichment in silver of the foot-wall rocks with respect to the hanging wall rocks of the high grade veins.

The colloform textures in the Stage 1 banded ore indicate that silica was precipitated from an amorphous gel that was probably diagenetically altered to the present-day finely-crystalline quartz that exhibits "jig-saw" pattern grain boundaries. Individual silica (precious metal-poor) bands are generally less than a few millimeters in width, and they alternate with bands up to 1 mm in width containing roughly equal amounts of electrum and silica. In some hand samples, more than 30 of these electrum-silica bands, alternating with barren or weakly mineralized silica bands, have been observed. Locally, silica has replaced up to 1 cm wide bands of euhedral calcite, the outside of which are encrusted by electrum. In addition, a few bands contain euhedral quartz crystals up to 1 cm in width.

Silica gels typically precipitate from solutions supersaturated with respect to dissolved silica. In shallow hydrothermal systems, this can be accomplished by boiling and/or rapid cooling of the solutions. Banding in epithermal veins, such as described here, is commonly cited as evidence of boiling. Each band (or pair of bands) precipitates when pressure decrease produced by the hydrofracturing of a silica "cap" on the hydrothermal system induces boiling. Due to the unbrecciated nature of the Stage 1 silica bands, explosive boiling probably did not occur at the structural position of precious metal deposition in the bonanza veins. The repetitive deposition of colloform-textured silica and precious minerals occurred in a laminar flow regime, possibly as a result of non-explosive boiling. However, there is ample evidence that the later stockwork and breccia mineralization formed from an explosively boiling, shallow hydrothermal ("hot spring") system. Although the genetic relationship between the early veins and the later stockwork and breccia ore is largely undetermined at this time, it appears that the veins may have formed at a deeper structural elevation. If so, then the stockwork and breccia ores could represent the last stages of a long-lived hydrothermal system or the superposition of a distinctly younger system on the earlier vein system.

GOLD-COPPER MINERALISATION AT CHINKWASHIH, NORTH EAST TAIWAN.

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ABSTRACT

Gold-copper mineralisation at Chinkwashih in north east Taiwan is associated with Pleistocene dacite intrusives emplaced in folded Miocene sandstones and shales. Since 1894 the district has produced in excess of 200 tonnes of gold and 100,000 tonnes of copper metal.

Mineralisation at Chinkwashih including the Chuifen and Wutankeng mines occurs in numerous orebodies comprised of large veins, breccia pipes, vein networks and replacement bodies in porous and chemically reactive sediments.

A distinct lateral and vertical mineral zoning exists over a surface area of several square kilometres and to depths of one kilometre. The central Penshan, Tsushihsan and Changen orebodies are enargite-gold zones displaying increasing copper with depth, while the peripheral Chuifen and Wutanshan veins are mainly gold-bearing.

The mineralised dacite orebodies exhibit broad alteration patterns adjacent to mineralisation passing from fresh rock into a chlorite-carbonate zone and sericite-silica near mineralisation. An acid-sulphate assemblage composed of alunite-dickite-minor native sulphur is present in the upper portions of the larger orebodies.

Gold mineralisation occurs as minute inclusions in enargite and pyrite and as uncommon but spectacular free gold bonanzas. The principal gangue minerals are pyrite, quartz, baryte, alunite and clays.

Limited fluid inclusion data indicate homogenisation temperatures ranging from 160°C to 300°C with two peaks at 200° and 250°C. The enargite-dominant mineralisation is considered to be an early high temperature phase possibly related to an underlying porphyry-copper type intrusive.

The peripheral gold-bearing quartz-baryte veins could be a contemporaneous zone related to the enargite mineralisation or part of a later epithermal event. Several mineralised dacite intrusives have been identified by underground development and geophysical studies. Copper in soil geochemistry has successfully located several copper-gold orebodies. The style of mineralisation at Chinkwashih is very similar to the gold-enargite occurrences at El Indio in Chile and Lepanto in the Philippines.

GOLD PLACER MINERALIZATION AND GOLD WEATHERING DENALI MINE, VALDEZ CREEK DISTRICT, ALASKA

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The Denali Mine, the largest open pit placer mine in North America, is located on Valdez Creek in the Clearwater Mountains, approximately 240 kilometers north of Anchorage, Alaska. From discovery in 1903 until production ended during World War II, an estimated 840 kg of gold were produced by underground and hydraulic mining methods. Open pit operations commencing in 1984 have produced approximately 2800 kg more. We describe the geology of this unique paleoplacer deposit and present new results concerning the weathering of placer gold as seen in this deposit.

GEOLOGY

The auriferous gravel lies in deeply incised bedrock paleochannels buried beneath thick glacial and glaciofluvial sediments. Four discrete pay channels have been identified, each with unique cross-sectional profile, course, and relative depth of downcutting. Upstream, within the confines of the valley of Valdez Creek, the paleochannels occupy a broad common channel. Commercial production has been achieved on three paleochannels - the Tammany, A, and B channels.

The pay gravel is part of a basal fluvial sequence composed of poorly bedded, moderately sorted alluvium containing sub-rounded, sand- to boulder-sized clasts of black argillite and subordinate intermediate volcanic and intrusive rocks from nearby sources. The fluvial gravel averages eight meters thick; most of the gold occurs in a basal pay streak up to five meters thick. Perched pay gravels occurring higher in the section are attributed to influx of gold from adjacent bench deposits or channels. Historic production grade of the pay gravel is 2,133 mg/m^3.

Overlying the fluvial gravel is glacially derived sediment 15 to 90 meters thick. Throughout much of the deposit lacustrine silt and fine sand lies immediately above the fluvial gravel. Within the lacustrine section, interbeds of silt and sand 1 to 4 cms thick suggest deposition by debris flows, traction currents, and possibly turbidity currents in a rapidly sedimenting, near-glacial

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[1] Funded by the U.S. Bureau of Mines, Anchorage, Alaska, USA.

environment. The lacustrine section is overlain by several types of till, braided stream, and outwash deposits. Granitic rocks, schist, and gneiss predominate in the glacial and glaciofluvial units reflecting a more distal provenance.

The bedrock geology consists of argillite and phyllite belonging to the Maclaren terrane of probable Mesozoic age. This flysch sequence records the effects of a steep prograde metamorphic gradient with greenschist facies developed in the mine area grading to sillimanite gneiss approximately six kilometers to the north. Stocks and small plugs of intermediate composition occur locally.

Lode deposits in the district consist of structurally controlled veins and stockworks with virtually all showings localized within an east-west trending fault system extending sub-parallel to, and 1 to 2 km to the south of Valdez Creek. The lode prospects are spatially, and possibly genetically, related to intrusive bodies. Quartz-carbonate-sulfide±gold veins are typical. No significant lode production has been recorded in the district.

Valdez Creek was repeatedly glaciated during the Pleistocene. The Valdez Creek Glacier was a smaller tributary to the Susitna Glacier, a major glacier which extended from the Alaska Range past the Clearwater Mountains into the Copper River Basin to the south. We theorize that during deglaciation the Susitna lateral moraine dammed the Valdez Creek valley causing the deep sedimentary fill. During each subsequent interglacial or interstadial period, the dam was breached and a discrete channel was incised into bedrock. Placer deposits were formed by the fluvial working and reworking of gold-bearing glacial detritus derived from Maclaren terrane rocks south of Valdez Creek. The four different paleochannels indicate that the channel-filling and downcutting sequence was repeated during at least four successive glacial cycles.

THE WEATHERING OF PLACER GOLD

An in depth study of the +20 to -4 mesh (U.S. Standard) sized gold at Valdez Creek has focused on physical parameters such as shape and weight and on evidence concerning the weathering history of the gold in this drainage.

The placer gold grains in Valdez Creek range from irregular and oblong in the upper parts of the drainage (mean Corey Shape Factor (CSF) of 0.5 at Lucky Gulch) to smooth and flat in the Denali Mine area (mean CSF of 0.3). The Corey Shape Factor of grains collected near the head of the drainage and at intervals through the length of the mine is lognormally distributed with lower values (less spherical grains) downstream. The weight of these gold grains is highly variable in any part of the stream, therefore analysis of variance shows no significant difference in mean weight of gold grains in different segments of the drainage. This evidence suggests that 1) hydraulic sorting of the coarser size fraction is primarily a function of grain shape (sphericity) rather than grain weight, 2) that insignificant sorting has occurred and the gold grains are being mechanically flattened with increasing distance of transport, or 3)

the observed pattern is an artifact of the sampling technique. The gold grains from the Denali mine are from reverse circulation drill cuttings - the other grains are from similar sized grab samples. These results may indicate that samples recovered from reverse circulation drilling are biased toward flat gold grains. These possibilities are being investigated.

Past research into the behavior of gold in the supergene environment has focused on the high-fineness (purity) rim found on placer gold grains by many investigators. Some workers believe this rim has a higher relative gold content because the impurities commonly found in placer gold are more readily leached. Theoretical and experimental work in the last 25 years has shown that gold is soluble in surface waters if complexed with anions such as Cl^- or CN^-. Recently, based on the solubility of gold as a complex anion, other researchers have suggested that the high-fineness rim is the result of precipitation of gold onto the grain from aqueous solution.

We have attempted to evaluate the hypotheses of 1) differential leaching or 2) Au precipitation from solution using gold from Valdez Creek. We are not able to demonstrate the existence of high fineness rims on the gold from Valdez Creek using reflected light (optimized at 452 nm) or the SEM in backscatter electron mode. Our results suggest a third alternative. Placer gold at Valdez Creek is weathering via the formation of etch pits. SEM secondary electron imaging of gold grains from Valdez Creek show pitted surfaces. Over the bulk of the surfaces these pits are numerous and may coalesce with adjacent pits. Surface areas that have been exposed to aqueous solutions for a shorter time, such as scratches or areas where inclusions (quartz grains, etc.) have been removed, show pits that are smaller and more regular in outline. Gold has a cubic lattice, therefore triangular etch pits should be expected; these are clearly visible. Weathering via dissolution at etch pits is consistent with recent research by other authors on feldspars and amphiboles. These results suggest that at Valdez Creek the water is undersaturated relative to gold complex anions and that the aqueous chemistry is such that gold dissolution occurs. They also suggest that elements may be dissolved from placer gold grains in approximate stoichiometric balance rather than via preferential leaching of some elements. These pits are direct evidence that gold is soluble in natural waters at surface temperatures and pressures.

CONCLUSIONS

The unique paleochannel deposit at Valdez Creek indicates the potential for as yet undiscovered placer deposits in glacial environments and in other areas of deep cover. The presence of etch pits in the placer gold from Valdez Creek is direct evidence that gold is soluble in near-surface water. The fact that gold is soluble in some chemical environments implies that in some other chemical environments it will precipitate. Therefore placer gold with high-fineness rims of precipitated gold would be expected in some streams. Other important implications are 1) gold dissolved in one part of the stream may be precipitated in an enriched zone downstream and 2) gold may be redistributed in the supergene zone of lode deposits.

Topic 1

GENERAL REGIONAL STUDIES

REGIONAL LOCATION OF GOLD MINERALIZATION IN WEST SIBERIA

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The history of gold mining in West Siberia numbers 150 years since the first large-scale gold deposit was discovered on the Berikul river in 1838. By now, volcanogenic-sedimentary, hydrothermal, hydrothermal-metasomatic gold deposits are known in the West Siberian metallogenic province. They are located in the Baikalian (PR-$\mathcal{E}_2$), Caledonian ($\mathcal{E}_1$-S), Hercynian (D-P) orogenic structures which frame the Siberian Platform zonally in the direction from ancient to young.

Volcanogenic-sedimentary gold-bearing pyrite-polymetallic deposits of the femic (siderophile) geochemical type (Co, Ni, Cu, Zn, Au, Ag) are represented by the layer- and lens-wise massive and streaky-impregnated ores with the pyrite-chalcopyrite and pyrite-sphalerite-galenite mineral composition. The gold is of fine-disperse nature and forms microinclusions in the sulphide minerals. Quartz and quartz-carbonate veins are quite rare in this type of deposits. Host rocks are formed by basalt and andesite-basalt porphirites, rhyolitic, felsitic porphyries, porphirite and porphyry tuffs. Volcanic rocks alternate with the sedimentary variegated mudrocks, coaly-siliceous-clay shales, limestones, dolomites. Ore bodies are located among the volcanic rocks of successive and contrasted differentiation and associate, as a rule, with dikes, sills, plugs, stocks of gabbro, gabbro-diabases, diabases, diabasic and dioritic porphyrites, rhyolitic porphyries, plagiogranites. Increased Fe and Ca contents are typical of volcanic and intrusive rocks, Na being sharply predominant over K (Na_2O - 3.60-4.20%, K_2O - 0.20-1.0%). In petrology and geochemistry, volcanic and intrusive rocks are comag-

matic. They are derivatives of tholeiitic basalt magma and form the oceanic crust of island arcs. The location of volcanic, intrusive rocks and the related gold-bearing pyrite-polymetallic deposits is controlled by the abyssal fractures; hence they have lineal (belt) character.

Proper hydrothermal gold deposits of the sialic-femic (chalcophile) geochemical type (Au, Cu, Zn, Pb, As, Bi) are represented by the quartz, quartz-carbonate veins, vein systems and streaky-impregnated mineralization zones. Despite the location of deposits in volcanic, intrusive and sedimentary rocks varying in petrographic and lithological composition, all of them have persistent mineral composition. The ore bodies are formed by pyrite, chalcopyrite, sphalerite, galena and gold; scheelite, molybdenite, tetrahedrite, gold-, silver- and bismuth tellurides being more rare. As for nonmetalliferrous minerals, quartz, carbonate and sericite are the most frequent. Endogeneous zonality is manifested from the indegeneous zones of the ore fields through the pivotal to frontal (peripheral) zones: Au, W, Mo → Au, Cu, Zn, Pb → Au, As, Sb. In the same manner, the Cr, Ni, Co impurity contents are decreased in the pyrites of ore bodies, those of Zn, Pb, Ag are increased; the $\delta^{34}S$ isotope fractioning being increased from +0.3÷+2.6‰ to +4.2÷+6.8‰.

Along with the gold-sulphide-quartz vein deposits, the hydrothermal-metasomatic gold deposits in magnesial spinel-forsterite, in calcic garnet-pyroxene-magnetite and garnet-pyroxene-wollastonite scarns are widespread in the West Siberian metallogenic province. Mineralization in scarns and gold-sulphide-quartz veins has similar composition which stresses their genetic relationship. Gold-sulphide-quartz and gold-scarn deposits appear to have spatial, temporal and genetic relations with granitoid plutons of diorite-granodiorite composition. Increased contents of Fe, Mg, Ca and the predominance of Na over K (Na_2O - 3.60-4.40%, K_2O - 2.0-3.40%) are typical of such pluton rocks. They are derivatives of the alkaline-earth

magma and participate in the composition of the Earth's crust of mature island arcs, and we consider them to be I-granites. Granitoid plutons and the associated gold-sulphide-quartz and gold-scarn deposits are located parallel to gold-polymetallic deposits. They are shifted with respect to the latters towards the continent and form an independent gold belt. Deposits in this belt have linear-nodal location character.

Gold-silver and gold-rare-metal hydrothermal deposits of the sialic (lithophile) geochemical type (Au, Ag, Mo, W, Sb, Sn) occur in the volcanic belts juxtaposed over the preceding orogenic structures. Quartz and quartz-carbonate veins and streaky-impregnated ore bodies are composed of Fe-, Cu-, Pb-, Bi-, Mo-sulphides, Fe- and Co-arsenides, sulphosalts of As, Pb, Bi as well as scheelite, gold, silver, electrum. They are related to the gabbro-granite and comagmatic basalt-trachyandesite-trachyrhyolite assemblages. Gold-silver and gold-rare metal deposits are formed under conditions of the continental type Earth's crust and have nodal location character.

Streaky-impregnated and vein hydrothermal gold mineralization of the contrast femic-sialic (siderophile-lithophile) geochemical type (Au, Ag, Co, Ni, W, Sn) is known to appear in the West Siberian metallogenic province. This mineralization is related to the Mesozoic activation of the Earth's crust of the continental type by substructural processes. It is manifested along abyssal fractures, reveals a remote relationship with the basaltoid magmatism of increased alkalinity, and has lineal and, at the same time, nodal location character.

The temporal and spatial analysis of gold mineralization in West Siberia shows the Baikalian, Caledonian and Hercynian metallogenic epochs to be the most productive, the earlier orogenic paleotectonic structures of the island arc development stage in each of the above epochs being the utmost productive. In the above features, the gold mineralization in West Siberia is similar to that of the gold deposits in Australia.

GOLD, A NEGLECTED ELEMENT IN SARDINIAN METALLOGENY

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Sardinia's mineral wealth is well known since a few centuries B.C..

Metals such a Pb, Zn, Ag and, much less important, Cu and Fe have been actively exploited up to present, and industrial minerals such as barite, fluorite, kaolin, bentonite, talc also gave, and are still giving, important outputs; more recent discoveries concern feldspar and bauxite (PRETTI et alii, 1988).

A so wide set of mineral products is related to several metallogenic phases that occurred from Lower Cambrian up to Recent Tertiary times and involves a variety of metallogenic phenomena.

In this fascinating framework, which includes also several minor elements, gold is almost absent. In the main Pb-Zn occurrences the gold content has been always considered too low to deserve further attention, while few other reported higher gold values (TESTA & SARTORI, 1918) occur within bodies of minor size, often not exploitable at all.

To-day, however, the metallogenic investigations show that ore occurrences, other than those explored in the past, are worth of attention; they are low-grade occurrences of different metals, especially Sn, Cu and REE, whose gold content looks to be not negligible. Also some mining companies are devoting more attention to this metal.

Among the before mentioned new investigations, some, perhaps the earlier ones, belong to us, and are related to our researches on greisen-type occurrences around leucogranitic bodies and on sulphide occurrences in Tertiary volcanics; the first results we got stimulated us to begin the study of gold metallogeny in Sardinia.

In the older sardinian terrains, of Lower-Middle Palaeozoic age, the gold content looks to be negligible. In a pyrite-sphalerite lens of Lower Cambrian age we found 50 ppb Au on a hand-enriched pyrite sample.

At the contact between Cambrian and Ordovician, where the older Cu-bearing sulphides occur, values around 0.1 ppm Au, related to 3-4% Cu contents, were detected.

In Silurian terrains, noteworthy are some Sb-W lens-shaped orebodies, whose gold content, possibly related to stibnite, is fairly high (TESTA & SARTORI, cit.). A few samples collected by us showed that gold content is lower in Sb-rich ore (some 0.1 ppm Au on pure Sb_2S_3) and fairly high in W-rich ore (some 3 ppm on pure $CaWO_4$).

For the other mixed-sulphides lenses, scattered throughout the terrains from Ordovician to Carboniferous, the possible gold content

might be related to Hercynian thermometamorphism, that affected all of them. In fact, as we observed recently (FIORI et alii, 1987) the greisen-like facies in the aureoles of Hercynian leucogranites carry often up to 1 ppm Au, together with other metals (Sn, Mo, REE etc.), while the above-mentioned mixed-sulphides bodies containing gold are commonly affected by hydrothermal phenomena; for instance, a small Cu-Zn occurrence in highly metamorphic terrains of north-eastern Sardinia, where we collected a hand specimen containing 0.33 ppm Au, is clearly related to a fault zone.

The most promising field of gold prospecting, though, appears to be that of Fe-Cu sulphides associated to Tertiary volcanics.

These rocks, which crop out along an almost continuous N-S belt in the western half of Sardinia, belong to a typical calcalkaline suite, evolving from andesitic basalts to rhyolites and comendites. Where subvolcanic facies reach the present surface, Fe-Cu(Pb-Zn)sulphides occur as disseminated crystals, in stockworks and sometimes in small veins.

In all these occurrences, gold has been detected associated with sulphides. The first record appears in a report of the geologic office of a mining company, some twenty years ago, on sulphide samples from Bosa (central western Sardinia): there, a few tens of ppm Au were found in enriched pyrite-chalcopyrite ore.

At present, we are performing an extensive study on these occurrences, mainly for Cu occurrence (GRILLO et alii, 1986). Analyses on sulphide concentrates gave the following figures, calculated on pure pyrite:

Osilo (northern Sardinia), disseminated pyrite: 2 ppm
Serrenti (central southern Sardinia), sulphide bearing quartz veins: 8 ppm.
Siliqua (south-western Sardinia), disseminated pyrite-chalcopyrite-bornite: 2 ppm

Finally, as regards alluvial gold occurrences, some sardinian streams (Tirso river in central Sardinia; Rio Ollastu in south-eastern Sardinia) are said to contain gold in their sands.

But the only documented finds of alluvial gold concern a general geochemical survey, including a mineralogical survey in granitic areas, performed by BRGM for account of Ente Minerario Sardo (MARCELLO et alii, 1978): in a few heavy concentrates, rare gold grains were detected. As no heavy minerals samples were collected in Tertiary volcanics areas, no data are available on alluvial gold deriving from those rocks: our further studies will probably include also this interesting theme.

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GEOCHEMICAL CHARACTERISTICS OF GOLD-BEARING FORMATION AND ITS METALLOGENIC IMPLICATION

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The known lode gold deposits in Southchina occur mostly in the strata of the Proterozoic and the Palaeozoic. The multi-epoch gold-bearing formations have been recongnized in the strata. They are a set of sedimentary formation system composed by several gold-bearing beds often containing volcanic materials, there syngenetic preliminary concentration of gold occurred. The gold-bearing formations, specially the volcanic-terrigenous clastic sedimentary formations of the Proterozoic related to eugeosyncline, control the distribution of nearly all of the important gold deposits directly or indirectly. According to the feature of sedimentary composition, tectonic activity, tectonic-sedimentary cycle and their geological ages, three main gold-bearing formations could be divided, namely:

I. the Proterozoic gold-bearing formation of volcanic-terrigenous clastic sedimentation,
II. the Sinian-Cambrian gold-bearing formation of terrigenous-volcanic clastic sedimentation, and
III. the post-Caledonian gold-bearing formation of terrigenous clastic sedimentation.

The Proterozoic gold-bearing formations are distributed in the low-grade sedimetamorphic rocks with calc-alkaline volcanics of Dong'anian Cycle (middle Proterozoic) and Xuefengian Cycle (late Proterozoic), characterised by volcanic-turbidites sediments having intenser eugeosynclinal volcanic activity (spilite-keratophyre). This thick sequence, up to more than 20,000 m, occupies whole Jiangnan Geoanticlinal Belt between the Southchina plate and the Yangzi continental plate, stretching for more than 1,000 km with a width of 100 km or so. They are the oldest basement of Southchina. In this belt the known Proterozoic gold-bearing formations have the distribution of the mostly known gold deposits and the mineralizations under control, and conditioned the inherited later gold-bearing formations for their development, and so the Proterozoic gold-bearing formations have the most significance in the genesis of the gold deposits of Southchina continent.

The Sinian-Cambrian gold-bearing formations are mostly inherited derivates of above mentioned older gold-bearing formations by resedimentation, and distributed mainly in Jiangnan Geoanticlinal Belt and on its both sides, as well as in the post-Caledonian uplifts, specially in Wuyi-Yunkai Post-Caledonian Uplift. As compared with the Proterozoic

The Sinian-Cambrian gold-bearing formations show a variety of sedimentary context. The four kinds of rock assemblage as follow may constitute the gold-bearing formation or bed:

i. flysch or flyschoid formation containing calc-alkaline volcanic materials, and with spilite-keratophyre locally,
ii. molassoid sediment and drift sheet (only in the Sinian),
iii. iron and/or anganese-bearing beds, and
iv. black shale formation or stone coal rich in C, P, V, Mo, Ni, U, Cu, Cd, Ag, Se, some time also Pt and Pd.

Of them the i. has the closest relationship with the gold deposits and others are usually related to minor, but rather widespread, gold mineralization.

The post-Caledonian gold-bearing formations were formed from the Devonian to the Quaternary, and are localized in the younger despressions and margins nearby or above the uplifted basement gold-bearing formations either exposed or blind. Relative small scale, isolated distribution, more various sedimentary type and obvious dependence on the older gold-bearing formations, specially on the Proterozoic, feature the post-Caledonian gold-bearing formations. The gold concentration in part of them could show an epigenetic origin related to brine or ground water.

The original distribution of gold in the gold-bearing formation could be characterised by higher content, heterogeneity in vertical and horizontal, and double populations --the parts of background and the high value. The gold-bearing beds usually localize in the botten of a tectonic-sedimentary cycle or above a plane of reginal discordance. The highest average content reaches to tens ppb in the Proterozoic mafic volcano-sedimentary gold-bearing formation in the northern Zhejiang. However, in the area there extensive tectonic shearing, reginal metamorphism, migmatization, and granitic magmatism occurred, and surprisedly, nearby some important gold deposits, gold in the gold-bearing formation decresses obviously, only about 1-2 ppb, even to 0.n ppb. It is probable that the gold was mostly mobilized and only remained background population.

The paragenesis of trace elements in the gold-bearing formation depends majorly on the sedimentary type and the composition of source area. The concentrated elements in the gold-bearing formations are siderophile, chalcophile, and W, As, C, S, P and B. Together with the enrichment of Fe, Cu, W, Ag or Sb, gold is usually concentrated in a sedimentary formation rich in the multi-element. The comparisons between the older and the younger gold-bearing formations and between them and the related gold deposits in the distribution of trace elements including REE and Au/Ag have revealed an inherited genetic relationship. Nearly all of the important gold deposits in Southchina are similar to the host gold-bearing formation in the paragenesis of ore-forming element unless the formation suffered extensive

migmatization or granitic intrusion.

The evidences from presen study show that the gold-bearing formations, specially those of the Proterozoic, might reserve a major ore-forming material source for the gold mineralizations of Southchina continent, and the later upper crust uplifting, tectonic shearing, metamorphism, migmatization, and geothermal and magmatic activity by plate collision should finally provide the ore-forming energy source for gold mobilization and further enrichment to form the deposits.

On the basis of the gold-bearing formation and according to the form of expression of later ore-forming energy and the geological-geochemical envieroment there gold deposit occurs, gold deposits in Southchina could be divided into five categories. They are related to granitoid, volcanic-subvolcanic rocks, metamorphism, hypergene processes, and groung water or brine, respectively. Their difference in geological age, Au/Ag, Host rock and holded place, ore-forming energy and solution source, feature of element paragenesis, and relationship with gold-bearing formation has been given by present paper.

Present paper consideres that the researches for gold-bearing formation may be useful to the reconnaissance for gold, and the studies on the intensity and the form of the ore-forming energy on the basis of gold-bearing formation could be applicable to the exploration and estimation of the potential type of gold deposit.

THE GOLD DEPOSITS OF BOLIVIA – A GENETIC CLASSIFICATION AND ECONOMIC CONSIDERATIONS

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Introduction

The Bolivian mining history began in precolonial times with the production of gold mainly from placer deposits. During the Spanish colonization the "*conquistadores*" began with hard rock mining in the Andes and on the Brazilian shield. The demand for tin on the world market caused a decline of gold mining in Bolivia and a specialization on tin. The crisis of the international tin council in 1985 produced a serious crisis in the tin based economy of Bolivia . In order to diversify the mining production, the Bolivian government encouraged by the high demand for gold on the international market is now resuming the precious metal mining.

The many gold deposits of Bolivia can be classified according to their regional distribution or genetical aspects.

Regional distribution of gold mining districts

The main Bolivian gold mining districts occur in the Brazilian shield, the Andean Cordillera, and in the Lowlands of Beni and Chaco. These are listed below and shown in Fig. 1 according to HEUSCHMIDT (1986).

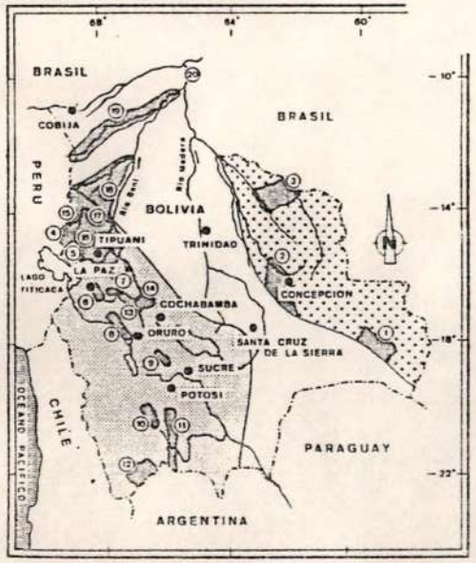


Fig. 1: The gold mining districts of Bolivia

a) Brazilian shield: *Sunsas-Santiago* (1), *Nuflo de Chavez* (2), and *San Simon* (3).

b) Andean Cordillera: *Apolobamba* (4), *Yani* (5), *La Paz* (6), *Lambate* (7), *Central northern Altiplano* (8), *Amayapampa* (9), *Pulacayo* (10), *Chichas* (11), *Lipez* (12), *Inquisivi-Ayopaya* (13), and *Cocapata* (14).

c) Lowlands of Beni and Chaco: *Mojos* (15), *Tipuani* (16), *Alto Beni* (17), *Madidi* (18), *Madre de Dios* (19), and *Madera* (20).

It should be pointed out that some important gold mines such as *Rosario de Araca, Antofagasta,* and *San José de Berque* (Esmoraca) are found well outside the limits of the mining districts given above.

Genetic classification

The Bolivian gold deposits are impressive for their genetic diversity and compositional complexity. A first review of the Bolivian gold deposits was given by AHLFELD (1937). Recent studies on various gold deposits in the Andean Cordillera were conducted by TISTL (1985) and are in progress by the authors.

The gold deposits of Bolivia can be grouped in following genetic types:

1. Sediment hosted deposits

These deposits are found in unmetamorphosed or very low grade regional metamorphic terranes far from coevel volcanic or intrusive activity.

a) Gold-antimonite quartz veins in clastic sedimentary sequences

This antimonite dominated type of vein deposit is typically found in the Eastern Cordilleran area within lower Paleozoic arenitic-pelitic series. The mineralization is typically bound to tectonic structures like shear zones and/or saddle reefs. Subordinate manto-type veins occur. The main deposits of this type are *Amayapampa, Antofagasta, Candelaria-San Juan, San Jorge, Sucre, Cebadillas, Santa Rosa de Capasirca,* and *Jirapalca.*

b) Auriferous nickel-selenide veins in clastic sediments

This rare type of gold mineralization was recently discovered and is characterized by a very complex mineral association consisting mainly of blockite, klockmannite, umangite,clausthalite, penroseite, chalcopyrite and native gold. The only important occurence from the economic point of view is the deposit of *El Dragon* near Potosi.

2. Polymetallic quartz veins and stockworks centered on intermediate batholits

Within or near to the granodioritic Tertiary Andean intrusions, the mineralization shows a classic zonation with increasing distance from high temperature Sn-W-As to low temperature Sb association. Gold is bound to quartz, arsenopyrite, pyrite and complex Sb-Bi sulfosalts. Famous mines of this type are *Rosario de Araca and Atoroma-Mallachuma* in the Cordillera Quimsa Cruz and *Olla de Oro* and *Emma* at the slope of the Illimani massif.

3. Subvolcanic andesite and dacite hosted polymetallic deposits

This type of gold mineralization is bound to the Tertiary intermediate volcanism. Many of the most famous tin-silver mines of Bolivia belong to this type, too, e.g. *Cerro Rico de Potosi.* and *Oruro.*

a) Gold bearing porphyry type stockwork mineralizations

In the northern Altiplano altered and partly brecciated rhyodacite and dacite stocks are impregnated mostly by pyrite. From the low

gold content of the bulk ores this type of deposit is without economic importance. Typical bodies are *La Joya* and *Laurani*.

b) Gold bearing polymetallic veins within and around subvolcanoes

Within and around the porphyry type deposits (2a) discrete veins of very complex mineral associations, mainly Bi-Cu-Pb sulfosalts, Cu-sulphides, pyrite, arsenopyrite and native gold are known. Gold tellurides occur in minor amounts. At the present time the oxidized cap of such veins is mined with success in the *Cerro Chuquina / La Joya* mine.

4. Detrital deposits

In Bolivia 4 types of placer gold deposits can be distinguished:

a) Paleoplacers

In the mountainous region of *Sunsas-Santiago* deformed and slightly metamorphic Mesoproterozoic conglomerates are known to bear gold.

b) Eluvial placers

Eluvial pacers are found in the vicinity of the primary deposits mainly in the *High Cordillera* and the region of *San Simon* on the Brazilian shield.

c) Alluvial placers

The most famous area for its alluvial placers is that of *Tipuani* where gold is mined with interruptions since Incaic times. Recently placer gold production in the areas of *Alto Beni, Madre de Dios, Cachuela Riberon and Araras* on the *Madera* river gets increasing importance.

d) Glacial deposits

Enrichment of gold in moraine material is found in the Cordillera of *Apolobamba* and in the district of *Yani* in many places.

Economy

The official gold production of Bolivia was in 1984 1.1 tons. According to preliminary data in 1987 the production was 17 tons reflecting the strong increase in gold production during the last years (5 tons COMIBOL, the state owned mining company, and 12 tons from small mining, organized mostly as private co-operatives). Reliable data on the gold production are very difficult to get. Credible sources estimate, for example that in 1983 official gold sales were 0.5 million US-dollars, but about 280 million US-dollars worth of gold was illegally produced, exported and sold. For a comparison in the same year the official export of the whole Bolivian mining industry was about 347 million US-dollars. The number of co-operatives dealing with gold mining and producing most of the Bolivian gold was estimated for 1985 to be 266 most of them working in the hardly controlable jungle areas of the upper Amazon basin.

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MODELS SHOWING ENVIRONMENT OF EMPLACEMENT OF GOLD-SILVER MINERALIZATION IN VOLCANIC BELTS

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The formation of the provinces of gold-silver mineralization ranges widely from volcanic belts of island arcs (on the crust of oceanic, continental and transitional types) to epicratonic volcanic areas (on thick continental crust).

Ore regions correspond to segments (blocks) of volcanic belts limited by transverse faults and to the areas of distribution of ore-bearing volcanic (basaltoid, andesitoid and rhyolitoid) formations. These segments are superimposed on heterogeneous geotectonic basement structures; the most promising segments are developed on median masses and their fringes, as well as on anticlinorial uplifts of the folded basement. Gold-bearing areas are confined to blocks where developed are rocks of contrastly, successively and weakly differentiated volcanic formations which are products of multi-stage volcanic activity. They are characterized by a wide variation of composition (from basalts to rhyolites) which includes sub-alkaline varieties, as well as by completeness of the section of the volcanic sequence and the presence of ore formations of the propylite series. Segments of this kind, as compared to those in the adjacent areas are characterized by an increased heterogeneity resulting from long-term development of the magma- and ore-controlling structures with periodical reactivation of the deep ore-magmatic sources.

Ore clusters are equivalent to volcanic structures - paleovolcanoes of the central type, stratovolcanoes, intrusive-dome and volcano-dome uplifts, volcano-tectonic depressions.

Magmatic formations in volcanic areas are most vividly manifested in paleovolcanoes of the central type (stratovolcanoes) originated at the intersection of buried basement faults with one another and with the deep magma- and ore-controlling ones. The criteria of their ore potential are as follows: 1) combination of several volcano-plutonic formations of various age within one volcanic structure; 2) a high degree of differentiation of volcanic products from basalts to dacites and rhyolites; 3) a wide distribution of subvolcanic and extrusive formations; 4) abundance of arc and radial faults; 5) the increase

silica, potassium, gold, silver, manganese and barium content towards the final products of differentiation.

Gold-silver mineralization is localized at different levels of paleovolcanoes: from their folded basement to the upper near-crater part of the volcanic structure on the vertical interval of up to 1.5-2.0 km, showing en echelon pattern of 300-500 and even 700-1,000 m in different paleovolcanoes. Owing to this an important factor in forecasting, exploration and estimating the gold-silver mineralization at depth which are associated with volcanic structures is the degree of erosion of ore-bearing paleovolcanoes.

Typical environments of the ore fields (deposits) are as follows:

- elements of the inner structure of paleovolcanoes (pipes, sector blocks on the slopes, limited by a system of radial and arc faults bodies of subvolcanoes, extrusive domes, calderas, dome uplifts);
- systems of steeply dipping faults limiting volcano-tectonic depressions and grabens, systems of thrusts, gently dipping zones of crushing, which complicate the superimposed depressions and domes;
- belts and clusters of dykes of andesite-basalts, diorite-porphyrites, diabases, quartz porphyry, etc.;
- fragments of major faults and feathering systems of fissures, zones of increased jointing.

The main elements of the model showing emplacement of the ore body and column are as follows: intense pre-ore tectonic activity in the ore-bearing faults, considerable amount of displacement along them, bodies of magmatic and hydrothermal breccias, bends and branching of ore bodies, points of their intersection and conjugation with faults, dykes, combination of mineral associations, contacts of rocks with contrasting physical and chemical properties which are favourable for replacement.

MAJOR GEOLOGICAL CHARACTERISTICS AND ORIGIN OF GOLD DEPOSITS IN CHINA

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I. Types of Gold Deposits

In terms of host rocks, gold deposits in China can be classified into remelting granite type, metasomatic remelting granite type, volcanic-subvolcanic rock type, sedimentary rock (turbidite, carbonate) -slightly metamorphosed rock type, low-grade metamorphic rock type, medium-high grade metamorphic rock type, conglomerate type and placer type.

Gold deposits of remelting granite type are mostly distributed in North China, with Precambrian and Lower Paleozoic strata as immediate country rocks. The igneous rocks are granite-granodiorites of Caledonian, Hercynian and Yenshanian ages, occurring as well-differentiated composite stocks composed of multiple episodes of intrusion. Gold mineralizations, represented by gold-bearing veins of disseminated veinlets or any combination of them, are developed in country rocks marginal to the intrusives or in early intrusive phases. Isotopic constitutions of lead are identical between the ore, the granite intrusive and the strata, indicating that the granite was derived from the remelting of the ancient gold-bearing strata.

Gold deposits of the metasomatic remelting granite type are found in Archeozoic medium-high grade metamorphic rocks in Zhaoyuan and Muping areas in North China. The intrusive rocks occur as batholith composed of granite-granodiorites. The top parts of the rockbody are gneissic-textured, showing metasomatic gradational contact with the strata and the lower portion is of massive texture, demonstrating abrupt "cold" contact with country rocks. Gold deposits consist of gold-bearing quartz veins and disseminated veinlet in brocken zones. Sometimes, the quartz veins are graded to disseminated veinlets with depth. The ores and granite and the strata exhibit significant similarities in S and Pb isotopic compositions, suggesting that the granite is a metasomatic remelting product of the Archeozoic metamorphic rocks. Metallogenic epoch of these deposits is Yenshanian.

The volcanic-subvolcanic rock type deposits are distributed in East China, as a part of the circum-Pacific metallogenic belt. The volcanic rocks are intermediate to acid in composition and were formed in continental environment. Generally, volcanic rocks are earlier than subvolcanic rocks. The volcanic activities have been dated as Jurassic-Cretaceous for continental China and Tertiary for offshore islands. Gold mineralizations occur as quartz veins and disseminated veinlets. As shown by lead isotopes, the volcanic-subvolcanic rocks may have been generated through remelting from, at least partially, the gold-bearing strata in the basement.

Gold deposits of sedimentary-slightly metamorphosed sedimentary rock type is mostly found in South and Northwest China. Their country rocks include turbidite and carbonate rocks ranging in age from Pro-

terozoic to Mesozoic. Proterozoic rocks have in most cases undergone slight metamorphism and changed to slate and metamorphosed sandstones. In general, intrusive magmatism is poorly developed in the mining area. Gold mineralizations are known from Caledonian to Yenshanian and are represented by replacement of filling quartz veins, quartz-carbonate veins or silicification zones along or transecting the bedding planes in host strata. The deposits in sedimentary rocks in west Guizhou are composed of finely disseminated gold in association with hydromica and sulphides. This type of deposits is generally considered to be analogs of the Carlin type in the United States.

Low-grade metamorphic rock type is reported from Proterozoic and Paleozoic systems in Northeast and North China. Their country rocks, belonging to greenschist facies or related transitional facies, include sericite quartz schist and carbonaceous slate. The former is sandwiched in between granulites, and the latter usually grades downwards to schist and granulite. The original rocks are volcano-sedimentary rocks and sedimentary rocks containing volcanic material. Ore bodies, all conformable with the bedding planes, can be divided into three types: quartz vein type, disseminated veinlet type and disseminated type. Genetically they can be divided into metamorphosed type and metamorphic hydrothermal type. Metallogenic ages include Proterozoic, Caledonian and Hercynian.

The medium-high grade metamorphic rock type deposits are exposed in North and Northeast China. The country rocks are composed of Archeozoic and early to middle Proterozoic granulite, gneiss and plagioclase amphibilites, which are assigned to amphibolite and locally granulite facies. Originally they are volcanic rocks, volcano-sedimentary rocks and sedimentary rocks. The deposits, mostly Yenshanian and Hercynian, are composed mainly of quartz veins and sometimes silicification replacements. Late magmatism is often noticed within the mining district. Sulfur and lead isotopes and REE data indicate that ore-forming material of the gold deposits are originated from ancient gold-bearing strata.

Conglomerate type gold deposits are restricted in Jurassic basins in North China. No occurrence of lower Proterozoic Au-U coglomerate deposits is yet known in China.

Placer type deposits, including alluvial, diluvial, eluvial, moraine and karst subtypes, are widely distributed throughout China.

Among the above described types, the metasomatic remelting granite type, medium-high grade metamorphic rock type, sedimentary-slightly metamorphosed sedimentary rock type and placer type are widespread and are of primary significance in China.

II. Geotectonic Settings of Gold Deposits in China

Geotectonically, gold deposits in China are localized in North China Platform, South China Platform, Hegang central massif and Jilin-Nei Mongol-Altai Caledonian-Hercynian Folding Zone, Qinling Caledonian-Hercynian Folding Zone, South China Caledonian Folding Zone, Southeast Coastal Hercynian Folding Zine, Garze Indosinian-Yenshanian Folding Zone and Taiwan Himalayan Folding Zone. In general, those in platforms are of greater importance.

With a few exceptions where no apparent correlation can be noticed between gold mineralization and late tectonic activity, most gold deposits are associated with activation zones marginal to platforms or folding zones or with the second-order fault system adjacent to

deep fault that transects the platforms of folding zones. For example, the Jiapigou gold deposits lie in the secorn-order NW trending faults at the intersection of Huifahe NE-striking deep fault and Helong-Chifeng EW-striking fault at the north margin of North China Platform, and the Zhaoyuan gold field is situated in a branching fault parallel to the Tancheng-Lujiang deep fault in North China Platform. As a general rule, however, the deep faults themselves are barren of gold.

III. Metallogenic Ages of Gold Deposits in China

Metallogenic ages of gold deposits in China include the Proterozoic, Caledonian, Hercynian, Yenshanian (Indosinian-Yenshanian) and Himalayan, with the Yenshanian and Hercynian being of prime importance. Gold deposits of Archeozoic, early Proterozoic and Tertiary ages which are common in other places in the world are of little significance in China.

The deposits in the north margin of North China Platform were mostly formed during the Hercynian and Yenshanian, while those in the south margin and within the platform are of Yenshanian ages. Most deposits in the South China Platform are Caledonian in age and those in Hegang massif indicate Proterozoic and Yenshanian mineralizations. Various metallogenic ages are obtained for gold deposits in folding zones: Caledonian (Qinling Folding Zone), Hercynian (Jilin-Nei Mongol-Altai Folding Zone), Yenshanian (South China Folding Zone, Southeast Coast Folding Zone and Garze Folding Zone) and Himalayan (Taiwan Folding Zone). The ages of all these deposits, with exception of metamorphosed and metamorphic hydrothermal types, are consistent with the time of tectonic activation in each of the district.

IV. Formation Mechanisms of Gold Deposits in China

(1) Genetic Types

Gold deposits in China are formed through magmatic hydrothermal action (responsible for the remelting granite type and metasomatic remelting granite type) volcanic hydrothermal action (volcanic-subvolcanic rock type) reworking process (sedimentary-slightly metamorphosed rock type and medium-high grade metamorphic rock type), metamorphism (low-grade metamorphic rock type which can be subdivided into metamorphosed and metamorphic hydrothermal types) and sedimentation (conglomerate and placer type).

(2) Principle Factors of Ore Genesis

Source Bed (Rock) Studies show that a source bed (rock) is essential to the formation of various types of deposits. The source beds (rocks), which can be divided into original and converted ones, responsible for gold deposits in China include volcanic rocks, volcano-sedimentary rocks, sedimentary rocks, intrusive rocks and their metamorphic equivalents, ranging in age from Archeozoic to Cenozoic. The most important source beds in North China are those of Archeozoic ages and those of upper Proterozoic and Paleozoic ages are of first importance in South China. One of the characteristics of the source beds (rocks) is the presence in some places of magmatic materials, among which basic-ultra basic components seem to be more favorable than intermediate and acid compositionsfor mineralization, probably because of their slightly higher Au abundance and that the gold is in a state to be more readily leached. In addition, hydrothermal sediments or organic matters and sulphides are also recognized in considerable amounts in some localities of the source beds. As another feature,

some source beds show gold abundance higher than its Clark value but it is equally true that gold abundances below the Clark value are known in quite a few cases such as Jinchangyu and Xiao Qinling, which may be accounted by the depletion of Au during mineralization.

Activation Intensive tectonic-magmatisms were extensively developed in some late geological times on the platform and consolidated folding zones in east China, probably due to their unique geotectonic positions. The pressure drop caused by tectonics at high temperatures appears to facilitate diffusion of solution into the source bed favoring the leaching of gold. On the other hand, a pressure decrease at low temperatures would expedite the deposition of gold, resulting in various kinds of reworked deposits. Activation is also responsible for the generation of metasomatic remelting and remelting magmas in the formation of a variety of granite type and volcanic-subvolcanic rock type deposits or may have served as a heat source for other types of deposits. The gold deposits in China are for the most part associated with activation which took place generally in Yenshanian and Hercynian periods in north China and in Caledonian and Yenshanian times in south China. A considerably long time interval can be generally recognized between the age of source bed and that of mineralization.

Ore-forming Solutions Ore-forming solutions for gold deposits in China are composed of magmatic water, meteoric water, formation water and metamorphic water. Deposits of hydrothermal affiliation are generally resulted from solutions composed of waters of different origins.

As shown on Na-K-(Ca+Mg) diagram, the remelting magmatic water is relatively rich in Ca+Mg, metasomatic remelting magmatic water is rich in K and Ca+Mg, intermediate temperature formation water has moderate concentrations of Na, K and Ca+Mg, metamorphic and heated meteoric waters have moderate Na and Ca+Mg, and high temperature formation water is rich in Na.

On Cl-F-HCO_3-SO_4 plotting, except the remelting magmatic water which is relatively rich in F, all the other waters are characterized by high concentrations of HCO_3 and SO_4 and moderate Cl.

Liquid CO_2 and considerable high gas-to-liquid ratios are recognized in inclusions in deposits formed from metasomatic remelting magmatic hydrothermal solutions and high temperature formation waters which are characterized by high temperature and pressure and salinity. Moderate temperature, pressure and salinities and rare, or no, liquid CO_2 and intermediate gas to liquid ratios are characteristic of deposits related to hydrothermal solutions of remelting magmatic or metamorphic origins or to medium-high temperature formation waters. Deposits of meteoric water affiliation are usually formed at low temperatures, pressures and salinities, showing no liquid CO_2 and intermediate gas to liquid ratios in their inclusions (Table 1). Some daughter minerals may be found if the solinity is high.

Physicochemical Conditions Among the principle factors controlling the precipitation of gold from ore-forming solutions in gold deposits of China include the depression of temperature and pressure, variations in pH and Eh, the incorporation of wall-rock components and the mixing of different solutions.

(3) Geological Characteristics of China and the Origin and Evolution of Gold Deposits

TABLE 1 COMPARISON OF HYDROTHERMAL SOLUTIONS RESPONSIBLE FOR VARIOUS TYPES OF GOLD DEPOSITS

	Remelting magmatic hydrothermal solution	Metasomatic remelting magmatic hydrothermal solution	High-temperature formation water hydrothermal solution	Medium-temperature formation water hydrothermal solution	Metamorphic hydrothermal solution	Meteoric water hydrothermal solution
Initial temperature of the solution(°C)	> 400	>500	>500	>400	>400	>500
Homogenezation temperature of fluid inclusion(°C)	280-380	180-470	130-480	120-400	150-415	100-300
Pressure(atm)		1327	550-433	326	423	230-250
Salinity or total concentration(%)	4.9	< 10-40	5.8-48	3-11.7	3.1-7.7	2.7
Liquid CO_2 inclusion	absent	abundant	abundant	rare	rare	absent
Gas/liquid ratio in fluid inclusion(%)	5-20	5-20	5-40	5-10	5-15	5-40

The origin and evolution of gold deposits in China are closely related to the geological characteristics of China Continent. As in the other parts of the world, the Archeozoic is the most important period for the development of gold-rich volcanic rocks, volcano-sedimentary rocks and intrusive rocks. However, because the Archeozoic System in China has undergone high-grade metamorphism, generally reaching to amphibolite or even granulite facies, providing an unfavorable environment for the formation of metamorphic hydrothermal gold deposits. On the other hand, some intermediate-high grade metamorphic rock type deposits are well developed in Archeozoic-Proterozoic strata in responst to the intensive tecto-magmatic activities during Paleozoic and Mesozoic times in China Continent. In other words, major gold deposits in China are those of reformed deposits and metasomatic remelting granite and remelting granite deposits formed in Paleozoic and Mesozoic times after metamorphism and migmatization.

At the end stage of Archeozoic time, there was not a stable weathering environment in China to provide abundent ore material and at the same time no large accumulation site was available as a result of slow depression, which account for the rare accurrence of ancient Au-U conglomerate type deposits in China. Moreover, because China Continent is situated in the outer ring of the circum Pacific belt, the volcanic-subvolcanic rock type deposits in China are of Jurassic-Cretaceous age which is different from the observation that areas of inner Pacific ring are characterized by Cenozoic volcanic-subvolcanic rock type deposits.

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