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EXTENDED ABSTRACTS:

RESEARCH TRENDS IN GOLD EXPLORATION

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Contents

Chlorite chemistry and gold deposition

J.L. Walshe (Australian National University)

The six-component solid-solution model of chlorite allows calculation of temperature and redox conditions of chlorite formation together with ratios $aFe^{2+}/(aH^{+})^{2}$, $aMg^{2+}/(aH^{+})^{2}$, $aAl^{3+}/(aH^{+})^{3}$ from a probe analysis, providing pressure is known or assumed and the chlorite grew in equilibrium with quartz. Work currently in progress is providing useful information about the model's performance as well as providing insights into the processes leading to base and precious-metal deposition.

Low-grade gold mineralisation at Gunung Pani, North Sulawesi, is centred on a porphyritic rhyodacite dome which intruded comagmatic pyroclastic units of probable Pliocene-Pleistocene age. The rocks are weakly altered and the alteration assemblage includes quartz, adularia, chlorite, sericite, carbonate and anatase. Pyrite is the common sulphide but minor sphalerite, galena and chalcopyrite are associated with the native gold (Kavalieris, 1984).

An overall increase in the Mg number of chlorites vertically through the mineralised zone reflects an increase in oxidation conditions towards the surface. At any level a wide range of temperatures (140-260°C) have been recorded. Values of H_2S concentration in the fluid, calculated assuming chlorite-pyrite equilibrium, decrease with increasing oxidation. The calculated initial H_2S content of the fluid is 0.003 molal or 90ppm. Maximum gold solubility is approximately 3ppb assuming gold bisulphide complexing at neutral pH. Gold precipitation was probably controlled by the reaction

$$\tfrac{1}{2}H_2O_{(1)} + H^{+} + Au(HS)_2^{-} \rightleftharpoons Au_{(C)} + 2H_2S + \tfrac{1}{4}O_{2(g)}$$

and would have been promoted by the decrease in H_2S but inhibited by the increase in fO_2. On balance, the maximum decrease of H_2S activity of half an order of magnitude and the maximum increase fO_2 of two orders of magnitude would favour gold precipitation at near constant or decreasing pH. A pH increase of more than 0.5 units would lead to gold dissolution

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and this is a distinct possibility as the assemblages suggest boiling of the fluids. The limiting factor on gold tenor may have been the deposition mechanism rather than an inability of the fluid to transport gold. Textural evidence suggests that gold deposition occurred during periods of pyrite undersaturation and this would have buffered the pH by the reaction

$$FeS_2 + H_2O_{(l)} + 3.5O_{2(g)} \rightleftharpoons 2SO_4^{=} + Fe^{2+} + 2H^+$$

At the Hunt Shoot, Kambalda (Western Australia) gold is associated with pyrite in altered margins to quartz veins beneath the massive nickel sulphides. Temperatures calculated from probe analyses of chlorite (Neall & Phillips, pers. comm., 1984) indicate maximum temperatures of greater than 350°C adjacent to the quartz veins declining to 250-300°C away from the veins. Calculated temperatures are consistent with the presence of biotite in the alteration assemblages. Calculated redox conditions decline away from the veins but much of this shift appears to reflect an overestimate of fO_2 at high temperatures (greater than approximately 320° C). Difficulties with the redox calculations prevent calculation of H_2S concentrations in the fluid but the coexistence of pyrite with chlorite, together with declining temperatures, suggest a significant H_2S gradient away from the veins. Gold deposition resulted from a combination of declining temperatures (about 50-75°C), declining H_2S concentrations in the fluid, and possibly declining redox state of the fluids away from the veins.

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Gold geochemistry

J. Angus (Gold Fields Exploration)

Knowledge of the geochemical behaviour of gold can be applied at various stages of an exploration program - from sampling, through genetic modelling, to resource assessment.

In sampling, and assaying, weathered rock it may be necessary to allow for possible depletion, or local enrichment, arising from weathering processes. The probability of such effects is related to primary mineralogy, the composition of the primary gold, and the general weathering regime.

During genetic modelling it is recognised that the composition of the primary gold, and the minerals and elements with which it is associated, may reflect the physico-chemical conditions under which it was transported or deposited. Hence gold deposited at high temperature ($>450^{\circ}C$), (or gold mineralisation which has been metamorphosed at such temperatures), may be of low silver content and be associated with anomalous levels of bismuth and tellurium. Similarly, within a discrete volcano-plutonic province different styles of mineralisation may be characterised by specific patterns of abundance in associated "indicator" elements. Unless these characteristic associations and patterns are destroyed by secondary processes, it can be possible to rank soil or sediment anomalies according to the associations or patterns expected of the target mineralisation.

The most powerful application of genetic modelling can be the prediction of controls on ore deposition. However, the complex geochemistry of gold, and its varied associations, suggests a wide range of feasible precipitation mechanisms, including oxidation, reduction, neutralisation and boiling of the transporting fluid. As a result, once a prospective system has been identified, the explorer is free to target his sampling according to his particular prejudices - e.g. on an intersection of a proposed "feeder" with either "red-bed" or carbonaceous lithologies; a palaeo-boiling zone; or a ferruginous horizon.

With the present emphasis on exploitation of oxidised (open-pittable) resources, a sound understanding of the supergene re-distribution of gold is of value at the resource assessment stage. In particular, the recognition of secondary "domains" within the weathered profile can improve the accuracy with which local recoverable reserves may be estimated.

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Biogeochemistry of gold

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Micro-organisms have a great influence on physico-chemical conditions in natural environments. Therefore, since gold transport and precipitation depend on pH, Eh and availability of complexing ligands, micro-organisms may play important roles in the cycling of this metal in the weathering zone, and it is possible that microbial processes could be used to recover gold from low-grade deosits.

Soluble complexes with chloride, thiosulphate, organic acids, or cyanide are considered most important in migration of gold in near-surface environments. Chloride complex ($Au\ Cl_4^-$) formation occurs under acid oxidising conditions and could be facilitated by the actions of *Thiobacillus ferroxidans*, the common bacterium active in oxidising metal sulphide deposits. In auriferous carbonate-hosted sulphide deposits, the production of thiosulphate by *Thiobacillus sp*. and the neutral to alkaline conditions should be particularly favourable for gold migration as $Au(S_2O_3)_2^{3-}$. Gold complexes with organic acids and cyanide could form in micro-organism-rich environments.

Limited experimental data indicate that gold is concentrated up to several ppm under favourable conditions in solutions containing various micro-organisms. Furthermore, *Bacillus sp*. appear to catalyse gold precipitation under conditions that are not yet well-defined, and this could be important in the formation of some nuggets.

Heterotrophic bacteria (dependent on organic nutrients) are abundant in ores and waters of goldfields. The spore-forming soil bacterium *Bacillus cereus* is relatively abundant for up to several kilometres from buried gold deposits. The abundance of *B. cereus* in metalliferous environments may be a function of its ability to resist antibiotics produced by metal-tolerant fungi. *B. cereus* assays may prove useful in gold exploration where conventional geochemical analyses are ineffective, e.g. in areas of transported overburden; the test is inexpensive and rapid (50-60 samples per day).

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N O T E S

Stable isotopes in gold exploration

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While stable isotopes studies have been used to give insights into processes of ore genesis for the last 20-30 years, the use of stable isotopes in exploration is still largely a research concept. Genetic studies involving stable isoopes have been used to trace the movement and origin of ore fluids, to define sources of sulphur and to indicate mechanisms of ore deposition.

Based on genetic studies it can be predicted that many types of gold deposits will be associated with an isotope halo. For example, hydrothermal fluids derived from meteoric waters played a dominant role in the genesis of most epithermal ore deposits and in particular gold deposits in volcanic terrain. In many deposits it has been demonstrated that the fluids were heated and convection currents established by intrusion of high-level stocks into permeable rocks. Flow of meteoric waters through and interaction with wall rocks results in large volumes of oxygen and hydrogen depletion of the light isotope. Isotope contour maps have been used to outline areas prospective for gold mineralisation.

Sulphur isotope values measured in ore deposits reflect the source of sulphur and the depositional mechanism of the sulphur species. In ores and host rocks of stratiform deposits the presence of two types of sulphides is recognised from crystal habit, trace-element composition and sulphur isotope values. In many deposits it has been demonstrated that one type formed by low-temperature biogenic reduction of sea-water sulphate while the other most likely was introduced by hydrothermal fluids. A halo formed by superposition of hydrothermal sulphides on biogenic pyrite may extend well beyond the limits of other commonly used mineralogical and geochemical haloes.

The effects of superposition of deep weathering on zones of hydrothermal alteration may be difficult to recognise. Stable isotope values readily distinguish clays and sulphate minerals formed in the supergene zone from similar minerals of the primary alteration envelope.

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Geochemistry of gold during regional metamorphism

V.J. Wall (Monash University)

A significant proportion of the World's economic gold deposits was formed during metamorphism from metamorphic fluids. This paper discusses the mobilisation, transport and deposition of gold, and related processes in metamorphic systems. Examples are drawn from Archaean greenstone-hosted and Palaeozoic slate-belt associations, two of the environments most productive of gold.

The overpressured ($P_F \sim P_{TOTAL}$) nature of metamorphic systems requires the derivation of metamorphic fluids from largely within the metamorphic pile, by devolatilisation reactions. Hence metamorphic fluids are typically of low salinity, contain some CO_2, and are relatively reduced in character (commonly around Mt-Po-Py). Fluids interacted with graphitic metasediments may contain appreciable CH_4 ($+CO_2$), whereas fluids in metasediment sequences containing evaporites are highly saline, and have a high-oxidised sulphur $(SO_4^{2-} + SO_2)/H_2S$. The major element cation ratios and acidity ($\Sigma H^+ + HCl$) of metamorphic fluids are commonly rock buffered, as a consequence of rapid fluid-mineral interaction at metamorphic temperatures, hence the composition of metamorphic fluids reflects the nature of the metamorphic pile and the metamorphic conditions. The metal-scavenging ability of metamorphic fluids reflects the composition of the fluids and their path history. For example, amphibolite facies (400-650°C) fluids exhibit high solubilities of ore-forming components (e.g. Au), higher H_2S contents and higher acidities than comparable salinity greenschist facies fluids in the environment where most metamorphic gold deposits form. In general typical low salinity metamorphic fluids will have a relatively low base-metal content and an excess of H_2S over base metals. Fluids moving toward lower-pressure, lower-temperature environments will tend to base-leach but can remain markedly undersaturated in gold and base metals until relatively low temperatures, unless encountering specialised chemical environments. Considering the very large volumes of fluids involved in metamorphic systems it is more likely that specific metal-enriched source rocks are not as important as the path history of the fluids - and this is essentially structurally controlled (e.g. Etheridge, this volume).

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Unlike in many upper-crustal ore-forming environments, temperature and pressure gradients are relatively low in regional metamorphic settings on the ore-deposit scale and are unlikely to be the major cause of Au deposition of ore concentrations. The most effective ore-forming mechanisms involve changes in redox state, pH and ligand concentrations. These changes are brought about mainly by fluid-mixing and fluid-rock interaction.

N O T E S

Structural controls on gold mineralisation

M.A. Etheridge (BMR) & S.F. Cox (Australian National University)

There are two main aspects of the structural control of hydrothermal mineral deposits:

- the formation of dilatency (openings) for the deposition of veins, breccia matrix, etc; and
- local enhancement of permeability to enable the focusing of fluid flow to a potential site for metal precipitation.

These two aspects are interdependent, because deformation-induced dilatency is a key mechanism of permeability enhancement.

The principles of structural control will be established by considering a number of specific styles of structural control.

1. Mineralisation associated with fault zones - Simple planar fault zones may contain significant widths of brecciated rock which provides high-permeability pathways, space for metal precipitation, and access to reactive lithologies. However, certain less-regular fault geometries lead to particularly high dilatency, which may be prospective. Synthetic steps or jogs in faults have an inherent dilatency, and may lead to large vein masses, extensive breccias or fault/vein/breccia arrays. Examples from the central Victorian goldfields and the Kalgoorlie area are described.

2. Mineralisation in ductile shear zones - Highly foliated, ductile shear zones may also be mineralised, even though they lack the obvious brittle, dilatent structures. First, ductile shear zones are commonly the locus of very large fluid throughput, presumably due to enhanced micro-scale dilatency. Second, small-scale veining is common within shear zones. The direction and sense of displacement of shear zones are readily determined, and are generally systematically related to the geometry and distribution of veins. Type examples occur within Archean greenstone belts.

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3. Veins and breccias associated with igneous processes - Veining and brecciation in the high-level igneous environment are controlled by the high fluid pressures developed in and around intrusive bodies. The geometry of the fracture system produced depends primarily on depth, the gross structure of the igneous body and its country rock, and on the interaction between the rates of fluid production and dissipation. Large vein systems will tend to develop at greater depths, and where fluid production dissipation is slower and more closely balanced. In contrast, breccia bodies are more likely to result from rapid fluid loss, which may be restricted to shallower levels.

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Gold in granitic magmas

D. Wyborn (BMR)

The genetic association between a particular granitic body and any gold mineralisation is not easily proven except in cases where the pluton has acted as a heat source for the driving of fluid circulation cells in favourable country-rocks. But what of the actual gold content of the magma itself! Are there any particular kinds of granitic magmas that are likely to form gold mineralisation during crystallisation? It has been recognised for example, that porphyry-copper deposits associated with the more potassic magmas contain high gold and low molybdenum, but this association is founded on statistical correlation and not scientific principles.

The Braidwood Granodiorite of the Bega Batholith, NSW, is a clear example of where the gold mineralisation is entirely derived from the granitic host. Some 30 tonnes of gold have been won from the granodiorite, mostly from alluvial workings. The gold is derived from minor sulphide veinlets and alteration zones within the granodiorite. The pluton is a mafic I-type granite with a colour index of 15-20 and covers 590 km^2. It is quite potassic (average 3.0% K_2O at 64.8% SiO_2) and highly magnetic (average susceptibility = 30000 micro S.I. units) indicating high oxygen fugacities prevailed in the original magma. An attempt was made to measure the gold content of magnetites from a wide variety of rock types from the pluton. Magnetite was analysed (using non-destructive neutron-activation analysis with a detection limit of 10 ppb.) because it is known to concentrate gold up to 20 times that of the whole rock in granites. All analysed samples contained less than 10ppb Au, implying very low gold abundances in the granodiorite. It therefore appears that the gold was strongly partitioned into the fluid phase during solidification.

A major factor determining the partitioning of gold between granite and fluid is suggested to be the oxygen fugacity. At low $f(O_2)$ sulphur has a low solubility in the silicate liquid and is partitioned into pyrrhotite crystals. Gold is retained in the rock dissolved in the pyrrhotite. At high $f(O_2)$, near hematite-magnetite buffer, sulphur occurs in granitic magmas as (i) separate immiscible blebs, (ii) S dissolved in the silicate

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liquid at much higher abundances that at low $f(O_2)$ and (iii) sulphate in crystalline apatite and anhydrite. The sulphur in (i) and (ii) is nearly all partitioned into the fluid phase upon solidification of the granite and gold is transported along with the S, possibly as HS^- thus effectively removing the gold from unaltered rock.

The original gold content of granitic magmas is mainly dependent on the magmas' source rocks. It is suggested that potassic granites with high Sr contents, like the Braidwood Granodiorite, are most prospective for gold mineralisation because (i) they tend to be highly oxidised and (ii) they are probably derived from high K shoshonitic to boninitic source rocks which are high in gold.

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Sulphide immiscibility in silicate melts: implications for gold mineralisation

R.R. Keays (University of Melbourne)

Sulphide immiscibility of silicate magmas exerts an important role on the genesis of hydrothermal gold deposits by firstly controlling the absolute gold contents of possible source rocks and secondly by controlling the availability of gold from these rocks.

The only gold that is available for ore formation in source rocks is that which is associated with the highly reactive sulphide droplets in these rocks. Gold locked up in silicate or oxide phases is unavailable to ore forming fluids and does not participate in the ore-forming process. Only high-temperature, high-magnesium magmas that did not attain sulphur saturation until a late stage form rocks that contain abundant available gold.

The majority of mafic rocks appear to have been formed from sulphur-saturated magmas that had lost an appreciable proportion of their ore-forming chalcophile metals (gold, platinum group elements, copper, etc.). The high partition coefficients (D = ppm metal in sulphide melt/ppm metal in silicate melt) of these metals (e.g. D_{Pd}=2000) means that they were very efficiently scavenged by immiscible sulphide droplets that either stayed behind in the upper mantle source regions of the magmas or lagged behind the ascending magmas during transport to the Earth's surface.

Evidence that most mafic magmas are sulphur-saturated is provided by (1) the linear relationship between the FEO and S contents of MORB glasses, (2) the presence of sulphide-lined vesicles in MORB glasses, (3) the presence of sulphide droplets with extremely high PGE contents in spinel lherzolite nodules of upper mantle derivation, and an oceanic ultramafics that represent the refractory residence of previously extracted partial melts and (4) considerations of core-mantle relationships. As a consequence of sulphur saturation, both MORB and their low potassium tholeiite counterparts in Archaean greenstone belts have low gold and PGE contents.

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The only mafic rocks tht have high PGE (and presumed initial high gold) contents are high-magnesium rocks or rocks that evolved from high-magnesium magmas. The rocks include komatiites, basaltic komatiites, picrites and boninites, all of which were erupted into rifted (high temperature) environments. Their high PGE contents are attributed to the sulphur-undersaturated nature and high temperature of their parental magmas: the sulphur capacity of basaltic magmas increases by a factor of 5 to 7 per 100 degrees Celsius increase in temperature. They are readily identified by quench and/or variolitic textures which are a product of the high temperatures of their parental magmas.

It is proposed that the formation of many gold deposits is initiated upon the extrusion of these favourable high temperature magmas on to the sea floor. In come cases, much of the available gold (i.e. that associated with magmatic-sulphide droplets in lavas) may be leached due to vigorous interaction with sea water as the lavas cool. The leached gold may be dispersed on to the sea floor or it may be fixed within chemical sediments that accumulate during lulls in volcanism. Later deformation and metamorphism may upgrade the gold in chemical sediments to economic-grade concentrations or may remobilise the gold from the chemical sediments (or from the high-magnesium rocks that had not lost their available gold at the sea-floor alteration stage) and re-deposit it to form epigenetic mineralisation.

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Gold in high-level igneous settings

G. Morrison (James Cook University)

This abstract will be provided separately

Gold in high level igneous settings

Gregg Morrison (James Cook University)

The current boom in exploration for bulk tonnage low grade gold deposits has seen a major revival in interest in epithermal styles of mineralisation, particularly in the western United States. Detailed research in active geothermal systems particularly in New Zealand has provided sophisticated models of system morphology alteration zoning fluid evolution and metal transport that are excellent analogues for the upper parts of many epithermal deposits. The modelled environment is typified by a resurgent caldera in which rhyolite domes are responsible for the heating and circulation of meteoric water and the development of epithermal/geothermal mineralising systems.

Another important type of mineralised geothermal system is that associated with andesitic stratovolcanoes in island arc environments such as those of the south west Pacific. Although these systems have generally been lumped in the general geothermal/epithermal class there are a number of important differences between the rhyolite and andesite systems that should be recognised in exploring ancient analogues.

In the rhyolite systems a dome or plug of rhyolite buried as much as 5 km is responsible for a thermal plume that entrains groundwater and discharges it along deepseated structures such as graben faults or caldera ring fractures. The intrusion itself is generally unmineralised and at shallow levels at least there seems to be little if any contribution of fluid or metals from the magma. This suggests that the country rocks are the source of solutes and the circulating groundwater the majority transporting medium. In the andesite systems a dioritic to dacitic porphyry plug or stock emplaced possibly one or two kilometres beneath the stratovolcano cone is responsible for the hydrothermal system. The intrusion itself may be mineralised in the porphyry Cu-Au style and could be a major source of metals in the overlying geothermal system.

In typical rhyolite geothermal systems the dominant fluid appears to be circulating groundwater at temperatures less than 300°C for 2 km depth near neutral pH and salinity less than 1%NaCl. At depths generally less than 1 km the fluid boils to produce a more saline higher pH residual liquid and a CO_2, H_2S charged acid gas that discharges at surface or condenses or mixes with other fluids near surface. In some andesite systems fluids are 300°C at depths closer to 1 km with pH less than 4 and salinity a few percent or more (e.g. Matsukawa, Japan). These fluids may coexist with near neutral pH, low salinity fluids at depths of 1 km as at Hatchobaru, Japan (Ellis et al., 1979). This probably reflects the input of acid gases especially SO_2 at depth in these systems.

In the rhyolite systems potassic alteration is characterised by quartz± adularia±albite; there is a prominent propylitic-argillic zone with semctite, interlayered clays zeolites and carbonate and only local illite-sericite at higher temperatures; and an advanced argillitic zone with kaolinite, alunite±silica±gypsum±iron oxides. In the andesite systems higher temperatures and generally more mafic wall rocks result in biotite and magnetite±epidote, chlorite with K feldspar in the potassic zone; a more discrete propylitic zone with epidote and chlorite; a higher proportion of illite and chlorite din the argillic zone and a distinctive advanced argillic zone with pyrophyllite, diaspore, dickite and locally andalusite or corundum and a separate often cross-cutting zone of quartz-alunite.

Mineralisation in the rhyolite systems is best developed in the boiling zone and generally localised in quartz-felspar veins or zones of silicification beneath a barren advanced argillic cap or in surface precipitates (sinters) from the low salinity fluid. Pyrite is the dominant associate of gold and silver and basemetals are common in the lower part of the boiling zone. In the andesite systems similar veins, replacements and precipitates may occur but there may also be a distinctive association of quartz-aliomite-pyrite-enargite cross-cutting or overlying the pyrophyllite-bearing advanced argillic alteration. In this situation an underlying porphyry Cu-Au deposit is a likely source of the ore components.

Application of geothermal/epithermal models has been a major stimulus to exploration in eastern Australia in the last few years. However several important deposits (e.g. Kidston, Mungana) do not fit in this class and of the known epithermal types many are better evaluated using the andesite rather than the rhyolite model.

Of particular importance here is the interpretation of pyrophyllite-bearing advanced argillic alteration and the possible association with quartz-alunite-pyrite-enargite mineralisation.

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The relationship of gold to base metals in some volcanogenic ore systems

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A comparison of gold mineralisation in three distinctly difference volcanogenic ore systems - Tennant Creek (Northern Territory), Mt. Chalmers (Queensland), and Rosebery (Tasmania) - suggests that significantly different chemical processes are involved in the transport and deposition of gold (in relation to the base metals and silver) within each deposit.

At Tennant Creek gold is concentrated toward the footwall of magnetite-rich lode zones, and associated with high bismuth levels, high Se/S ratios, low Ag/Au ratios and elevated uranium values. Copper mineralisation overlaps the gold and extends into the stratigraphic hangingwall, while lead and zine are virtually lacking.

At Mount Chalmers the gold and copper are intimately related. The gold is concentrated in the footwall stringer pyrite-chalcopyrite zone and immediately overlying copper-rich massive sulphides. The ores have moderate Ag/Au ratios and zinc/lead rich distal portions.

At Rosebery the major gold mineralisation is not related to the footwall copper zones, but concentratecd in the stratigraphically higher lead-zinc laminated sulphide horizons. The Ag/Au ratios are very high, with anomalous arsenic levels.

By comparison, the Archaean greenstone-hosted gold deposits of Western Australia exhibit high arsenic levels, low Ag/Au ratios, pyrite±pyrrhotite assemblages and a common telluride association.

It is suggested that these variations in metal association, gold zonation, and trace-element geochemistry can be explained by two possible mechanisms.

1. Primary zonation of gold and base metals dependent on variations of fO_2, pH, and temperature of the respective hydrothermal systems (see figure 1).

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2. Secondary remobilisation of gold from lower footwall zones to higher distal lenses associated with late-stage hydrothermal-solution reworking.

In the oxidised ore systems such as Tennant Creek and Mount Chalmers, gold transport probably occurs as the chloride complex, however in the weakly-reduced systems such as Rosebery both chloride and bisulphide complexing may have played a part (see figure 2).

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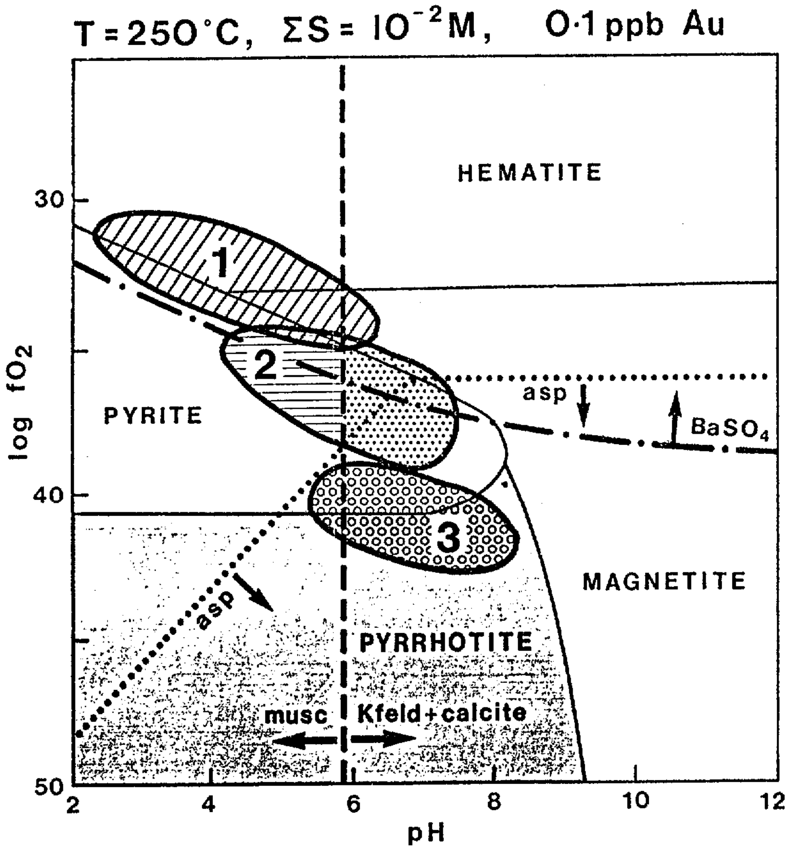

Figure 1: Stability fields in log fO_2 Vs pH space for common gangue minerals associated with gold mineralisation (for $a_{K^+} = 10^{-2}$, $a_{\Sigma C} = 10^{-1}$, $a\ H_3AsO_3 = 10^{-4}$).
Field 1 = zone of deposition of Tennant Creek ores.
Field 2 = zone of deposition of Mt. Chalmers and Rosebery ores.
Field 3 = zone of deposition of py-po-asp Archean Greenstones ore assemblages.

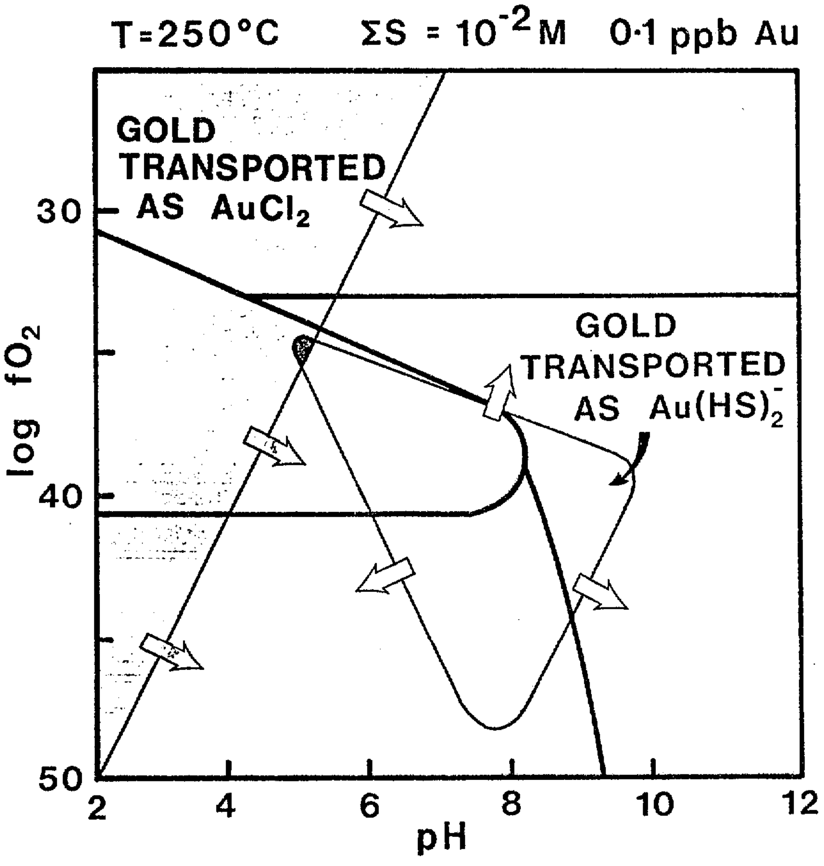

Figure 2: Regions of gold transport in log fO_2 Vs pH space for a hydrothermal solution carrying 0.1 ppb Au at 250°C and $a_{\Sigma S} = 10^{-2}$M. (using data from Seward, 1982 in GOLD-82). Arrows show direction of decreasing gold solubilities.

N O T E S

A case study of hydrothermal research : Emperor Gold Mine, Fiji

M Ahmad (Northern Territory Geological Survey), M. Solomon (BMR)
& J. Walshe (Australian National University)

The Emperor gold-telluride deposit consists of a system of quartz-filled fractures lying on the margin of a caldera in the Mba Volcanics, of Miocene age, in the north of Viti Levu, Fiji. The veins filled fractures that developed mainly in pre-caldera basalts but also in igneous rocks that filled the caldera. The veins are both pre- and post-faulting, contain vughs, and show evidence of repeated opening.

The veins are dominantly quartz with minor pyrite, tellurides, gold, sphalerite, arsenopyrite, chalcopyrite, tetrahedrite, galena, dolomite, calcite, and mica (part V-rich). Flanking wall-rocks show inner K-feldspar-mica-quartz alteration and outer chlorite-carbonate alteration.

Crustification and replacement textures allow establishment of a generalised paragenetic sequence dominated by five stages of quartz and two of ore minerals. Pyrite was among the first and the last of the minerals to precipitate, and is the most common sulphide. Within each ore-mineral stage there are small-scale cycles of sulphide deposition indicating widely-fluctuating fluid conditions. The first of the two ore-mineral stages is dominated by calaverite, krennerite, sylvanite and native tellurium, the second by petzite, hessite and native gold. A third of the Emperor gold is thought to be in solid solution in pyrite and arsenopyrite.

Fluid inclusions in quartz indicate temperatures from 300 to 160°C for vein formation. The presence of coexisting vapour and liquid-vapour inclusions in much of the vein system indicates the solutions were boiling, and the depth of boiling coincides with the depth of mineralisation. Tentative reconstructions of the water table through the paragenesis indicate a dramatic fall between the two main ore-mineral stages.

Short-lived fluctuations in fluid parameters calculated from mineral assemblages and fluid inclusion leachate analyses involve rapid changes in temperature (50°C from fluid inclusions), $^{a}O_2$ and ^{a}S, during a longer-term

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decrease in temperature and decline of $^{a}Te_2$ between stages II and IV.

Carbon isotope ratios of carbonates indicate a sedimentary carbon source, believed to be carbonate-bearing sediments (the Vatukoro Formation) underlying the host basalts (Mba Volcanics). $\delta^{18}O$ and δD analyses indicate the ore fluid was mainly composed of magmatic water and sea water with a possible meteoric component.