Metamorphic fluids and gold

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Abstract

Low-salinity fluids ($T > 200\,°C$, reduced S, modest CO_2) and high geothermal gradients are common to many gold deposits and provinces. In contrast, host rocks, hosting structures, depth of formation (in the crust during deposition), subsequent metamorphic overprint, alteration mineralogy and isotopic signatures can vary dramatically within single deposits or provinces. Gold deposits with co-product base metals are an exception to the above comments, and probably relate to saline fluids.

The low salinity fluids inferred for major gold-only deposits are not easily explained by seawater, basinal brines, meteoric fluid or common magmatic processes. In contrast, metamorphic devolatilisation of mafic/greywacke rocks is one effective way to produce low-salinity metamorphic fluids with characteristics matching the gold fluids. Such an origin also explains the link to geothermal gradients.

The transition from chlorite—albite—carbonate assemblages to amphibole–plagioclase assemblages (commonly greenschist—amphibolite facies boundary) involves considerable loss of metamorphic fluid whose composition is buffered by the mineral assemblage, and is a function of P and T. This low salinity, H_2O–CO_2 fluid is evolved at $T > 400\,°C$, commonly carries reduced sulphur, and may contain Au complexed with this sulphur. This auriferous fluid is likely to mix with other fluid types during times of elevated temperature, especially magmatic fluids at depth, and upper crustal fluids at higher levels.

Gold deposits in Archaean greenstone belts exhibit good evidence of low salinity, H_2O–CO_2 fluids of $T > 300\,°C$; these include examples from Canada, Australia, Brazil, Zimbabwe, India, and South Africa. Turbidite-hosted (slate-belt) deposits exhibit similar evidence for such fluids but commonly with appreciable CH_4; the Victoria and Juneau (Alaska) goldfields are examples. The Witwatersrand goldfields also show evidence of low salinity, H_2O–CO_2 fluids carrying reduced sulphur and gold, but their distribution and timing are not well established. Epithermal (*sensu lato*) gold deposits have evidence for low salinity fluids carrying Au and S, but are much more diverse in character than those from the previously mentioned gold provinces: this probably arises from mixing of several fluid types at high crustal levels. Together these four types of gold provinces account for over 80% of the primary gold mined to date.

KEYWORDS: metamorphic fluids, gold, low-salinity fluids

Introduction

ALTHOUGH Fyfe *et al.* (1978) had already discussed the generation of fluids during metamorphism, until ten years ago metamorphism was rarely linked to ore genesis. Previously, metamorphism had been attributed a role of modifying existing deposits (metamorphosed deposits) or being synchronous with deposit formation (metamorphic deposits) but such processes were rarely spelled out in detail.

Such a peripheral role of metamorphism had evolved despite the existing knowledge that heat during diagenesis/metamorphism was a key element in turning carbonaceous sediments into hydrocarbon energy resources (petroleum, gas, coal), and elevated temperatures were required to achieve significant levels of metal concentration in solution for many ore elements.

Today, metamorphism is seen as an important control on grain-size in some massive sulphide deposits where extractability by flotation can make or break an operation. Even more directly, metamorphic processes have been implicated in the formation of many diverse types of gold deposits—some substantial in size.

An important limitation on our ability to characterize metamorphic fluids comes from methods of sampling natural examples of these fluids. In fact, there are very few places where

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fluids can be sampled and where there is no doubt that they represent pristine metamorphic fluids (compare the situation with seawater, meteoric water or connate fluids); it is then difficult to demonstrate that such samples of metamorphic fluid are representative of all metamorphic fluids. Consideration of crustal fluid regimes would suggest that mixing of different fluids in the upper crust should make the occurrence of pristine metamorphic fluids near the surface quite unlikely. As such, many of our ideas on metamorphic fluids must come from more indirect modelling, and some assumptions.

This paper focusses on the major gold provinces (i.e. Archaean greenstone, Archaean Witwatersrand, slate-belt and epithermal/porphyry). Rather than emphasizing differences between deposits and provinces, as successfully done in many classification schemes, the focus here is on *similarities* between gold provinces. An important distinction is made in this study between deposits and provinces that essentially produce gold ('gold-only'), from examples where gold is a co-product or bi-product of silver and/or base metal (Cu, Pb, Zn) mining. The concentration here is on the former.

An increase in detailed research on Archaean and slate-belt gold deposits in the late 1970s led to recognition of similarities between metamorphic fluids and those found in gold deposits (e.g. Wall and Ceplecha, 1976; Kerrich and Fryer, 1981). The timing, overall composition and auriferous nature of these fluids were inferred to best match that of fluids formed through devolatilization processes (Smith *et al.*, 1984; Ho *et al.*, 1985). A combination of fluid studies and predictions from gold geochemistry led to a model in which Archaean gold deposits hosted by banded iron formations might also relate to epigenetic metamorphic fluids, and that gold transport was by sulphur complex rather than chloride complex (Phillips and Groves, 1983). This model provided a means of greatly enriching gold relative to base metals in these deposits, and implied synchronous formation of the vein style and more statabound gold occurrences. Testing of a metamorphic model for gold in Archaean terrains was severely restricted by inherent limitations on dating and knowledge of detailed tectonic events in the Earth's early history. However, the much younger (50 m.y.) Juneau district of SE Alaska provides an area where there are two major gold deposits and a detailed tectonic history, well-constrained by geochronology (Goldfarb *et al.*, 1991). Studies at Juneau suggest gold mineralization over a very short time interval, and a complex later fluid history essentially unrelated to the main mineralization. Modelling of devolatilization processes by Powell *et al.* (1991) provided a semi-quantitative confirmation of the important role in producing auriferous metamorphic fluids that had been suggested for the greenschist to amphibolite facies transition (Fyfe and Kerrich, 1984).

Common characteristics of gold deposits and provinces

Features related to fluid transport and site of deposition are typically diverse even in single deposits (Table 1). Hosting structures can include shear zones, stockworks and breccias; alteration mineralogy can vary on a similar scale from mica to sulphides to carbonates. Similarly, host rocks can be highly variable and include ultramafics, mafics, shales, quartzites and conglomerates, even though one lithology may dominate gold-production. In searching for parameters essential (or highly favourable) to the formation of major gold-only provinces, the features related to the site of deposition are unlikely to hold the key.

Two features related to regional setting and source areas are typical of gold-only deposits regardless of their age or geographic setting (Table 2). A high thermal gradient is either well-established (e.g. Pacific Rim of Fire) or inferred (e.g. Victorian Slate Belt gold province) for all major gold-only provinces. A low salinity, H_2O–CO_2 fluid with reduced sulphur complexed to gold is also widely recognized, although the proportion of CO_2 is decidedly lower in some epithermal deposits and NaCl may be appreciable in others. These parameters of high thermal gradient and a low salinity, H_2O–CO_2 fluid may be key features in major gold-only provinces. High thermal gradients are conducive to the movement of most fluid types; the origin of the low salinity, H_2O–CO_2 fluid is of considerable interest here.

Origin of low salinity, H_2O–CO_2 fluids

Certain constraints can be placed on the origin of the low salinity fluid on the basis of its overall composition and *P–T* character. Comparison between these features and modern fluid types appears to eliminate several fluid types.

Seawater and basinal brines seem unlikely sources on the basis of their elevated salinity: both these fluids are known to play important roles transporting gold *plus* base metals. Meteoric fluids are relatively oxidizing and contain typically low CO_2 (reflecting the partial pressure of CO_2 in

TABLE 1

Diversity of geological features at the site of deposition of gold.

Lithologies mined for gold (e.g. Sheba gold mine, South Africa)	
ultramafic rocks	"Swartkoppie"
mafic rocks	
cherty rocks	"Bars"
quartz veins	Golden Quarry
quartzites	Margaret section
conglomerates	Royal Sheba
shales	MRT section
Variable structural settings (e.g. Kalgoorlie district, Western Australia)	
quartz stockwork	Mt Charlotte
shear zones	Fimiston
quartz veins	Paringa area
telluride ores/veins	Golden Mile
breccias	Golden Mile

the atmosphere) and low reduced sulphur in solution.

Magmatic fluids are quite variable, and some may be chemically similar to the gold-only fluids. However, most magmas, except those that are quite alkaline, would be eliminated because of their low to very low solubility of CO_2 in the melt; some of these remaining types might be eliminated on the basis of high salinity or an oxidizing nature. It appears most unlikely, therefore, that magmas could be the main source of this gold-only fluid, given the need for such a specialized igneous body through time and space, plus the lack of field evidence in many deposits for such a magma.

In certain circumstances, fluids derived from metamorphic devolatilization can adequately account for the nature of the gold-only fluids (Powell *et al.*, 1991), whereas other crustal fluids do not appear to be suitable. However, this does not rule out the potential involvement of any (or all) fluid types in some deposits.

Generation of the gold-only fluid by devolatilization

Whole rock analysis and the modal mineralogy of greenschist and amphibolite facies rocks indicate that a considerable loss of volatiles would take place near the boundary between those two facies. In mafic (and greywacke) sequences, this loss can involve H_2O, CO_2 and S, and more specifically corresponds to the destruction of chlorite, calcite and pyrite with growth of amphibole (note: this change need not exactly coincide with the formal greenschist to amphibole boundary defined on the basis of tetrahedral Al in calcic-amphiboles).

Semi-quantitative modelling of the breakdown of chlorite-bearing assemblages in a slightly simplified mafic system (Powell *et al.*, 1991) demonstrates the critical role of the mineral assemblage in determining the composition of the evolved metamorphic fluid. The 'rock-dominated' nature of this devolatilization arises from the inferred low porosity of rocks at temperatures and pressures appropriate for the reaction (i.e. T between 400 and 500 °C). The low porosity, combined with the absence of halogen-rich minerals in these sequences, ensures the resulting fluid is of low salinity.

The H_2O/CO_2 ratio of the evolved fluid is a function of P and T, and can vary from $\leq$10% to 40% (mole) CO_2 in the fluid phase for low and high geothermal gradients, respectively. Such values of $X(CO_2)$ are higher that found in most other fluid types, but coincide with compositions from gold-only fluids.

For greenschist facies assemblages involving

TABLE 2

Similarity of geological features related to source areas for fluid (crustal or district-scale)

THERMAL REGIME	FLUID
	Archaean greenstone gold
high thermal gradient	H_2O-CO_2, low NaCl, S-Au
	Archaean Witwatersrand
high thermal gradient	includes H_2O-CO_2, low NaCl, S-Au
	Slate belt (turbidite)
Victoria high thermal gradient	H_2O-CO_2±CH_4, low NaCl, S-Au
Alaska - Juneau high thermal gradient	H_2O-CO_2±CH_4, low NaCl, S-Au
	Epithermal/Porphyry
high thermal gradient	variable generally H_2O±CO_2, low NaCl for gold-only, commonly S-Au association.
	Gold-base metal deposits (i.e. NOT gold-only)
	commonly moderate to high salinity, negligible CO_2, may be oxidizing with SO_4.

pyrite, elevated levels of reduced sulphur in the fluid will result from buffering with sulphide minerals in the rock. This sulphur has particularly important implications for gold solubility. The stability of Au^{1+} in deeper crustal environments (rather than trivalent Au) and the very soft (covalent) nature of Au^{1+} means soft–soft combination like $Au(HS)_2^-$ form very stable complexes. In contrast, Au complexing with Cl^- is much less stable under reduced metamorphic environments. Base metals and transition metals do not show the strong 'soft' characteristics that gold does, and as such, form less stable complexes with reduced sulphur. The net result is that these low-salinity, reduced-sulphur fluids have limited capacity to carry base metals, but considerable potential to transport Au.

The above comments about the generation of auriferous, low salinity, H_2O–CO_2 rich, reduced-sulphur-bearing fluids have been restricted to assemblages involving chlorite–calcite–pyrite–quartz (i.e. generally mafic or greywacke rocks). For sequences dominated by pelites, carbonates or evaporites different assemblages will be relevant during devolatilization and hence a quite different metamorphic fluid would be predicted.

It should be recognized that the studies are still semi-quantitative and variants on (or additions to) the chlorite–calcite–quartz assemblage may occur. The critical point is not the exact *P, T* and $X(CO_2)$ nor the exact source lithology; the critical point is that rock-buffered metamorphic devolatilization of a common rock type could yield a common fluid type through time and space. This predicted fluid closely matches the general character of the gold-only fluid.

These discussions are not meant to suggest that amphibolite facies metamorphism of mafic material is the only way to generate the auriferous fluids. Other rock types and mineral assemblages may prove equally likely, and further reaction of mafic rocks into the granulite facies should also evolve metamorphic fluids until melting commences. The reason for stressing the greenschist to amphibolite facies transition in mafic rocks and greywackes is the potential to generate large volumes of similar fluids from common lithologies in variable place, tectonic settings and time periods.

Involvement of other fluid types

Periods of elevated thermal gradient are likely to be periods of high activity of all fluid types. Melting at depth will be followed by subsequent evolution of magmatic fluids as magmas crystallize; similarly, at shallower levels, geothermal activity, basinal dewatering and circulation of seawater through a rock pile will all be enhanced.

The similarity in time and space between metamorphic devolatilization and magmatic activity will be accentuated if the fluids and magmas use the same structural channelways. Thermal perturbations could lead to mantle melting (e.g. lamprophyres) as well as deeper crustal melts (e.g. granitoids), giving a variable but close spatial and temporal relationship between metamorphic fluids, lamprophyres and granitoids; this is well illustrated in Archaean greenstone belts (Wyman and Kerrich, 1988; Rock and Groves, 1988), and need not imply a mantle source for gold.

In shallower parts of the crust, mixing of metamorphic fluids with all other fluid types may potentially occur. Districts of mixed gold and base metal deposits (e.g. Pine Creek-Lawrie, 1991; Cobar-Hinman, 1990; Lawrie, 1990) might represent variable involvement of basinal brines. Epithermal deposits such as Lihir (Moyle *et al.*, 1990) suggest important involvement of seawater, whereas epithermal deposits in New Zealand and Nevada include signatures of magmatic and/or meteoric fluids.

The problem of what happens to metamorphic fluids in the uppermost crust (i.e. 'Where do they reach the surface?') is reasonably understood if their potential to mix with all other fluid types is appreciated. The places where clearly metamorphic fluids debouch at the Earth's surface should be specialized (e.g. Craw, 1988) and limited.

Definitive testing of fluid type

Although stable and radiogenic isotopes are widely used to determine the origin of gold-only fluids, they would be particularly unsuitable for this purpose within the above scenario of widespread fluid mixing.

As metamorphic fluids rarely have a distinctive or diagnostic isotopic signature (e.g. S, H, C, O, Sr, Pb, K), it is most improbable that isotopic studies could categorically identify a metamorphic component within a mixed fluid. Far more likely, such studies will reveal 'accidental' incorporation of some other signature during fluid ascent and/or identify the non-metamorphic component to a fluid. Apart from the lack of a clear isotopic signature for metamorphic fluids, further difficulties arise in higher crustal levels (i.e. epithermal environment) where the potential for multiple fluid sources is so much greater.

Perhaps the major problem with using 'minor' components of a fluid to trace the source of that fluid can be illustrated by taking the Pb system and some idealized Pb isotopic compositions (Fig. 1). If a metamorphic fluid and a magmatic fluid both with 1 ppm Pb were to mix, the result would be midway (A, Fig. 1). If equal volumes of metamorphic (1 ppm Pb) and magmatic (9 ppm Pb) fluid mixed, the resulting Pb isotopic signature would be 90% of the way towards 'magmatic' (B). Furthermore, if the magmatic fluid had three orders of magnitude more Pb in solution, even one percent magmatic fluid mixed with a metamorphic fluid would give a magmatic signature (C). Such vastly different levels of Pb in solution could easily be achieved by differing salinities, and the metamorphic fluid is likely to have low salinity and thus low Pb. There is good reason to believe that B or C are a fair approximation to some gold systems where Pb is demonstrably not added during alteration.

The danger of over-reliance on single isotopic systems is well illustrated by Sr and Pb studies on Archaean greenstone belts. Neither Pb nor Sr is systematically enriched during alteration related to greenstone gold mineralization. In some cases, either or both of these elements are actually depleted during alteration (e.g. Kerrich, 1986; Phillips, 1986), and extreme care would be needed in interpreting Sr- or Pb-isotopes in such cases. Most such studies using isotopes such as Pb are cautious to point out that they have traced the source of the Pb (not the fluid or the gold), but given that the source of Pb (*per se*) is largely irrelevant in a gold deposit, the clear implication of doing such a study is that it might bear on the source of the fluid and/or gold. Unfortunately,

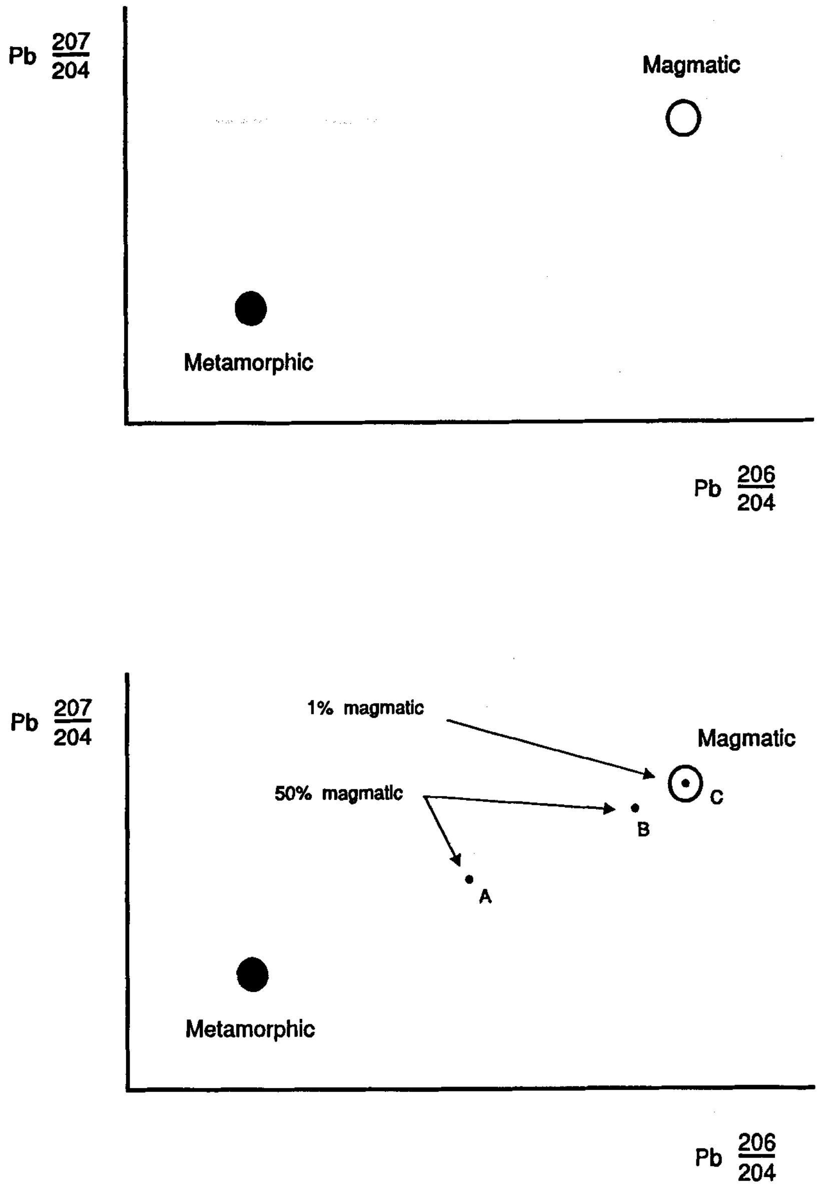

FIG. 1. Schematic Pb–Pb isotopic plot showing how the isotopic composition of a mixture of two fluids is a function of both the proportion of each type, and the solubility of metal (Pb) in each fluid. A magmatic signature can result from 1% magmatic fluid if the Pb concentration in the magmatic fluid is high compared to the Pb concentration in the metamorphic fluid. A = equal proportions of each fluid, equal concentrations of Pb in each fluid. B = equal proportions of each fluid, much greater Pb concentration in the magmatic fluid. C = a dominantly metamorphic fluid with much greater Pb concentrations in the minor magmatic component—the isotopic signature is swamped by the minor magmatic component.

once the studies are complete the uncertainties inherent in the interpretations are commonly forgotten. For these gold systems where the chlorinity is low, borderline to hard acids may be poorly soluble; hence the reservations for Pb also apply to Sr studies.

Our lack of knowledge about the isotopic composition of many source reservoirs (see carbon systematics, Golding *et al., 1989*) compounds a problem that already seems intractable within our current understanding. A more fruitful methodology to understand the source of gold-only fluids is likely to follow from the separation of *fundamental* fluid characteristics of wide geographic and temporal persistence (see Table 2, H_2O–CO_2–H_2S, S–Au, low salinity) from *accidental* characteristics that relate to some deposits only, and may reflect specific local source rocks and/or the chance involvement of magmas and different fluids (e.g. Sr, Pb, O, C, H, S). On its own, the H_2O–CO_2, low salinity, S–Au character is rather limiting on potential origin.

The problems of selection of material for isotopic study extends to geochronology. Rutile and zircon grains from hydrothermal veins in Archaean greenstone gold deposits provide material very amenable to Pb-dating by ion microprobe and Pb–Pb analysis (Clark *et al.*, 1986; Jemielita *et al.*, 1990]. However, other studies (Cassidy, 1988; Kerrich, 1986; Phillips and Groves, 1984) have shown that both Ti and Zr are remarkably immobile during greenstone gold alteration, so much so that these two elements form the basis for protolith determination after extensive alteration (e.g. Kerrich, 1986). Regardless of how accurate the dating is, considerable care is needed in extrapolating data from specific situations where Ti and Zr are major vein components, to provinces in which Ti and Zr are widely regarded as immobile in the typical gold mineralizing process. In almost all cases, the impressively small errors associated with dates reflect the analysis process, but do not allow for uncertainties associated with sampling geological control.

The preferred way to determine the source of a fluid is to look at the major components, but even this approach has weaknesses. In many studies, fluid characteristics are determined by examining alteration assemblages and/or fluid inclusions in situations where the fluid would have already undergone interaction with the wallrock. Peripheral to the main channelways (where the better assemblages usually are), the fluid/rock ratios may have been low, and considerable evolution of the fluid composition would have occurred.

Application to gold-only provinces

Archaean greenstone gold depostis. Most of the Archaean greenstone gold comes from gold-only deposits, and a low salinity (Table 2), H_2O–CO_2 fluid with S–Au derived from a setting with a high geothermal gradient is widely inferred. It is possible that some less gold-prospective greenstone terrains (e.g. Pilbara Block of Western Australia) coincide with a lower geothermal gradient during metamorphism (Bickle *et al.*, 1985). Notwithstanding the close match between the above observations, and predictions from metamorphic devolatilization, opposition is still levelled at the concept of a metamorphic origin for the auriferous fluid. This opposition has, in general, been based on specific isotopic studies (see discussion above), dating of individual minerals (see discussion above) and difficulties in separating pre-from syn-peak metamorphic gold introduction in high-grade terrains: little of this opposition has focussed on the fundamental nature of the 'gold-only' fluid (an exception is the thorough discussion of Perring *et al.*, 1987). Unravelling the timing of gold in high metamorphic grade terrains is in need of a quantum methodological advance.

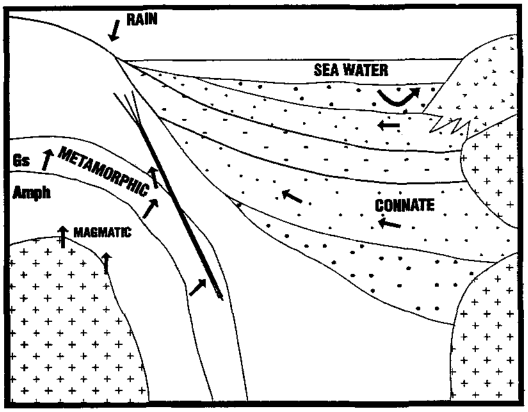

FIG. 2. Schematic section of the Earth's crust showing the potential for interplay between diverse fluid types, particularly in the upper crustal levels. At depth, magmatic and metamorphic fluids will be active (see left); at shallower levels, all fluid types may be important.

Slate belt (turbidite-hosted) gold deposits. Slate-belt gold is predominantly 'gold-only', and the inferred fluids are typically low-salinity, H_2O–CO_2 rich with reduced sulphur and gold (Cox *et al.*, 1986, 1991; Goldfarb *et al.*, 1991). CH_4 and N_2 are widespread but variable components of the fluid phase that are likely to relate to lithologies near to the site of deposition. A spatial association to igneous rocks is pronounced in some terrains (e.g. Victoria; Pine Creek—Lawrie, 1991) but not in others (Juneau—Goldfarb *et al.*, 1991). The type of associated igneous rock includes a wide range of peraluminous granites, granodiorites and lamprophyres (Phillips, 1991).

The young age, excellent outcrop and detailed

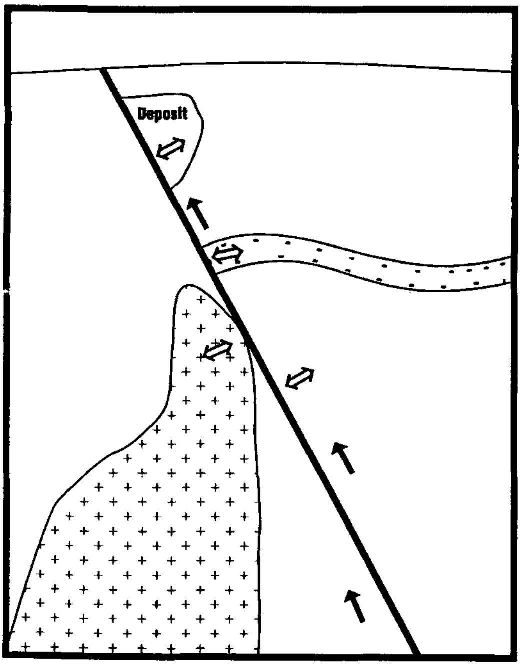

FIG. 3. Schematic fluid pathway from a source area to a depositional site, showing the potential for incorporation of 'accidental' isotopic signatures en route (such as from intrusions or from chemical sediments). Several unknowns in this system severely limit the use of isotopes as geochemical tracers of the fluid source. These unknowns can include the isotopic composition of source reservoirs, the source temperature and fractionation between fluid and source minerals, accidental exchanges along the fluid pathway, and commonly a lack of diagnostic isotopic signatures for potential fluid sources.

research (e.g. Goldfarb, this volume) in the Juneau gold district (7 million oz Au) allows some reconstruction of the gold mineralization event. God mineralization at several deposits in this district appears to have formed synchronously (55 million years b.p.) coincident with a change from compressional to transcurrent tectonics, and intrusion nearby of the major Coast Range Batholith. A substantial meteoric water signature has pervaded the auriferous quartz veins after formation and seems unrelated to gold introduction. The concentration of gold deposits in the greenschist facies is possibly better developed in Alaska then any other major mesothermal gold province: this might reflect the lack of any subsequent higher metamorphic grade overprint in this young terrain.

Archaean Witwatersrand gold deposit. The problems with treating Witwatersrand gold as purely of placer origin have been documented elsewhere (e.g. Phillips *et al.*, 1987): low pressure regional metamorphism appears reasonably well-established for most mines (Phillips and Law, 1992), several phases of deformation have been outlined (Myers *et al.*, 1990; Roering *et al.*, 1990), and widespread alteration is inferred, especially around reef packages (Phillips *et al.*, 1989). The abundant uranium is interpreted to result from an event that is quite separate from gold introduction (see Phillips and Myers, 1989), and as such the gold event is clearly 'gold-only'.

A number of fluid types are suggested by fluid inclusion studies in the Witwatersrand, and these include hydrocarbon-bearing fluids, saline fluids, and H_2O–CO_2 fluids of low salinity (Phillips *et al.*, 1988). Geological constraints on any link between these fluids and gold is not yet conclusive, but the presence of the low salinity, H_2O–CO_2 fluid warrants serious attention.

Epithermal gold deposits. The term *epithermal* has been used loosely in the literature to embrace high level deposits that include acid sulphate, adularia–sericite, Carlin and porphyry types characteristic of the Cainozoic Pacific Rim); such a use of *epithermal* is adopted here. The epithermal environment is where the greatest opportunity for mixing of diverse fluid types is predicted; and as such is where the most difficulty in defining a source for the gold-only fluid might be expected. Debate on the origin of the fluid responsible for gold mineralization has traditionally focussed on meteoric and magmatic sources. Neither of these models fully addresses the low-salinity, moderate-CO_2 and Au–S link in the auriferous fluids; and little consideration had been given to a metamorphic origin in most studies. The trend to gold with silver, or gold with base metals, found in epithermal provinces is likely to coincide with high salinities, and the probable involvement of multiple fluid types.

Discussion and summary

The philosophy of looking for common features between different gold deposits and provinces provides an alternative viewpoint to supplement the many schemes that highlight differences between deposits. Stressing common features is likely to be less useful at the mining stage, but can potentially contribute to understanding the essential processes in the evolution of a major gold-only province. A high thermal gradient and a low salinity, H_2O–CO_2, S–Au fluid appear to be common features to gold-only provinces. Both reflect processes on a regional or provincial scale, in contrast to the more local scale of many features that vary between deposits (structural geometry, alteration, host rock, role of immiscibility, role of Fe- or C-rich rocks). The thermal gradient and special fluid are potentially repeatable (but yet specific) characteristics through time and space. Many of the geochemical methods used to distinguish between different origins for the gold-only fluid are unlikely to identify a metamorphic component after accidental mixing with other fluid types. Instead, consideration of the main characteristics of the gold-only fluid provide considerable limits to its possible origins.

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