WALLROCK ALTERATION AND ITS USE IN EXPLORATION FOR OROGENIC (MESOTHERMAL) GOLD DEPOSITS

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Summary

Despite extensive variation in host-rock type, structural style and formation conditions, there are a number of consistent features in the alteration haloes of orogenic (mesothermal) gold deposits: 1) zoning perpendicular to mineralisation in all cases, 2) rare along-strike and down-dip zoning, 3) carbonation and formation of muscovite or biotite, 4) low-degree of sulphidation, 5) significant enrichment in CO_2, S, K, H_2O, LILE, Au ± Ag, As, Bi, Sb, Se, Te and W, 6) rare base-metal enrichment, 7) significant SiO_2 enrichment only evident from the commonly large volumes of quartz veins.

At sub- to mid-greenschist facies, alteration is characterised by distal calcite-chlorite and proximal sericite-ankerite zones. At upper-greenschist facies, biotite replaces sericite and calcite gradually replaces the other carbonates. At higher metamorphic grades, distal alteration is characterised by biotite, and proximal alteration by calc silicates and calcite.

Identification of alteration, alteration zoning sequences, geochemical alteration indices and metal dispersion haloes provide a useful guide for exploration of orogenic gold mineralisation.

Introduction

In this paper, the term orogenic gold mineralisation is used for the deposit class which is elsewhere called, for example, mesothermal, lode-, vein-metamorphogenic, Mother-Lode type, structurally-hosted, or greenstone-hosted gold mineralisation. From the perspective of understanding wallrock alteration haloes around these deposits, the following characteristics of the orogenic-gold deposits (e.g. Groves 1993; Eilu et al. 1998; McCuaig and Kerrich 1998) provide important constraints and must be taken into account:

1. The deposits may be sited in, or controlled by, a number of different structures, including faults or shear zones with variable kinematics (Fig. 1), or fold hinge-zones.
2. These structures may be brittle, brittle-ductile or ductile.
3. The mineralised structures may be reactivated earlier-formed structures which had their own associated wallrock alteration, thus leading to superimposed alteration zones rather than simple one-stage gold-related alteration.
4. The deposits may be sited in almost any lithology in volcanic belts or sedimentary basins. Hence, there is a variable bulk-rock compositional control on the alteration mineralogy produced by the low-salinity H_2O–CO_2±CH_4 fluid that is the norm for this deposit style.
5. This is further complicated by the fact that the deposits form a crustal continuum in which they may be sited in metamorphic domains that range from sub-greenschist to upper-amphibolite (or lower-granulite) facies.
6. Deposits in sub-amphibolite facies domains tend to be slightly post-peak metamorphism, whereas deposits in amphibolite facies domains tend to be syn-peak metamorphism.
7. The variable bulk-rock composition and PT conditions may affect the stability of several of the mineral phases (e.g. arsenopyrite-loellingite, stibnite, telluride minerals) which contain elements potentially used as pathfinder elements in the alteration haloes.

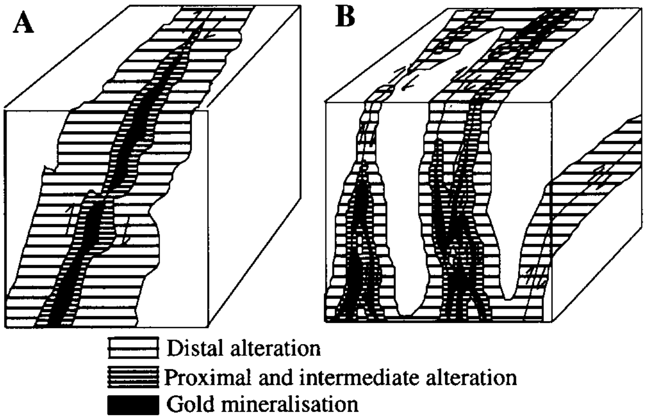
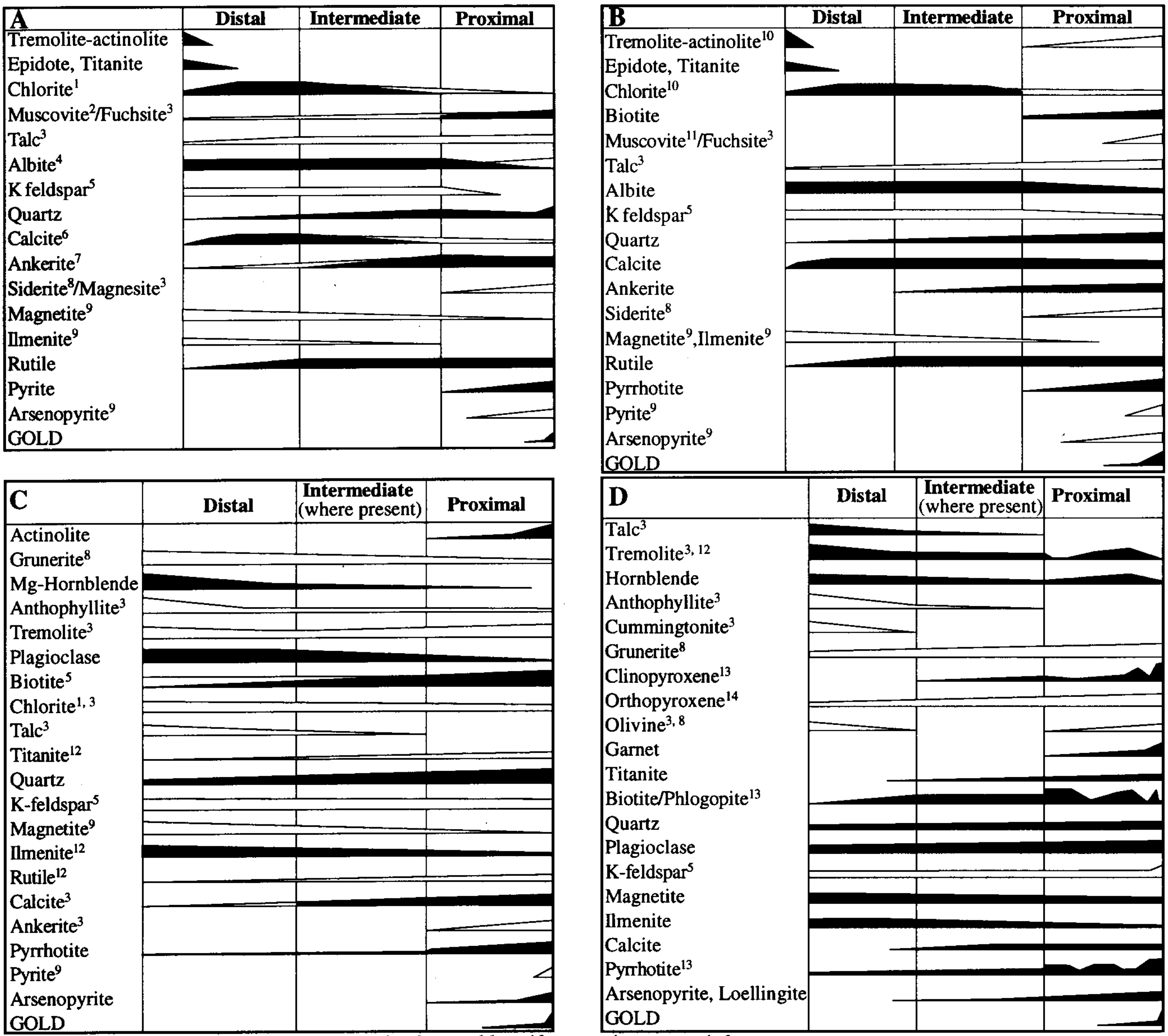


Figure 1. Examples of the extent of alteration and form of the alteration halo around an orogenic gold deposit. A) a simple case with one quartz vein or shear zone and a tabular alteration halo; B) a complicated case with several subparallel veins or shear zones adjacent to each other with partially overlapping alteration haloes (Colvine et al. 1988; Mikucki et al. 1990; Ridley and Barnicoat 1990).

Types of alteration zoning

Alteration related to lode-gold mineralisation displays zonation 1) laterally away from mineralisation, with each alteration zone characterised by a distinctive mineral assemblage, 2) between host lithologies of differing bulk composition, and 3) regionally with temperature and pressure of formation:

The lateral alteration zonation, which is present in practically all cases and summarised in Figure 2, reflects decreasing fluid/rock ratio and related chemical gradients, and represents progressive infiltration of the fluid into the wallrock. Boundaries between alteration zones may be sharp or gradational over centimetres to metres, with sharp boundaries common in proximal alteration zones, while diffuse boundaries tend to predominate in distal zones. The most distal alteration assemblage grades into the 'unaltered' regional metamorphic mineral assemblage. The greatest complexity in zonation occurs within the inner alteration zones due to restricted zone widths and the episodic nature of deformation and fluid infiltration, which act in concert to produce proximal alteration zones with cross-cutting and mutually overprinting relationships.



1) Chlorite may also be part of the most proximal assemblage if muscovite content is low.
2) Alteration may produce some sericite in the intermediate zone and pre-alteration sericite may be present in clastic sedimentary rocks.
3) Present only in ultramafic rocks. C: calcite may be present throughout the sequence in ultramafic rocks, and anthophyllite may also be present in proximal zones in BIF. D: Olivine in the distal zone is a regional metamorphic mineral.
4) Locally, significant albite formation occurs in the areas of most proximal alteration.
5) Detected in the alteration sequence where also present in unaltered rock. Otherwise, K feldspar possibly present only in the proximal zone.
6) In felsic rocks, calcite may be present also in the proximal zone.
7) In ultramafic rocks, ankerite may be present also in the distal zone.
8) Detected in BIF.
9) May be present.
10) In the proximal zone, Fe-rich amphibole and chlorite may be present in BIF; chlorite also in other rock types.
11) Some sericite or fuchsite may be present in the most proximal domain of alteration.
12) Ilmenite present with or without titanite and/or rutile.
13) May be part of thin, mono- and bi-mineralic subzones within the domain of proximal alteration.
14) Only in the highest-temperature rocks.

Figure 2. Schematic summaries of the paragenetic alteration sequence around orogenic gold deposits in A) sub- to mid-greenschist, B) upper-greenschist, C) lower-amphibolite, and D) mid-amphibolite to lower-granulite facies environments. Black represents the common case, and white indicates a less common occurrence which is further explained in the footnotes. Proximity to mineralisation increases to the right. Zone widths shown here bear no resemblance to actual widths in the field. Based on Eilu et al. (1998, 1999) and references therein.

Very little variation in alteration occurs parallel to the structures hosting lode-gold mineralisation within a deposit, especially within a single host rock. Such variation has, so far, only been recorded with variation in formation temperature (i.e. metamorphic grade), when an mineral isograd cross-cuts the deposit (e.g., Mikucki et al. 1990). On the other hand, if a fluid conduit transects lithologies with contrasting compositions, somewhat different alteration assemblages may be formed in different host rocks without any change in PT conditions, as also noted in the diagrams in Figure 2.

Alteration assemblages associated with lode-gold mineralisation vary systematically with regional metamorphic grade (Fig. 2). This variation is evident between individual deposits or deposit groups.

Lateral alteration zonation

Figure 2, above, depicts paragenetic alteration sequences enveloping the orogenic gold deposits under the range of metamorphic PT conditions where these deposits may form.

In general, the alteration halo comprises two or three main zones, each of which characterised by a diagnostic mineral assemblage and distinct changes at the zone boundaries. Also, each of the main zones can, in many cases, be subdivided into 2-4 subzones according to more subtle changes in their mineral assemblage. The entire width of the alteration halo may be from 5 cm up to 2 km, and the individual zones can be from 1 mm to 100 m wide. Commonly, the lateral extent of alteration is less in amphibolite- than in greenschist facies rocks.

Under sub- to mid-greenschist facies conditions, the most diagnostic paragenetic sequence, from the distal to the proximal alteration zone, is: chlorite-calcite -> chlorite-calcite-ankerite -> sericite-ankerite-pyrite (Fig. 2A). At upper-greenschist facies, sericite is gradually replaced by biotite, ankerite by calcite and pyrite by pyrrhotite (Fig. 2B). At higher metamorphic grades, distal alteration is characterised by biotite and proximal alteration by the presence of calcite and calc silicates, especially diopside (Figs. 2C and 2D). The most distinct feature in mid-amphibolite and higher-grade rocks is the repetitions of one to five, 1-5 cm wide, mono- and bimineralic calc-silicate (± biotite, pyrrhotite, calcite, K feldspar) bands and selvages along quartz veins in the domain of proximal alteration (Fig. 2D). At all metamorphic grades, the degree of sulphidation is low (highest in BIF), and carbonation in most intense in mafic and ultramafic host rocks.

Despite the above-described, extensive variation in the mineral assemblage, there is significant consistency in the chemical changes related to alteration (e.g., Eilu et al. 1998; McCuaig and Kerrich 1998): rocks are enriched in CO_2, S, K, H_2O and LILE. In addition, there is variable enrichment in Ag, As, Au, Bi, Sb, Se, Te and W, whereas Cu, Fe, Pb and Zn concentrations are generally close to background values. In certain Proterozoic deposits, Cu shows a significant enrichment (e.g., Davidson and Large 1994), but it is unclear if any of these deposits can be classified into same group as the typical orogenic (mesothermal) gold mineralisation. Significant SiO_2 enrichment is evident from the commonly large volumes of quartz veins. However, silicification *sensu stricto*, that is addition of silica not involving quartz veins, has convincingly been documented only in a few greenschist-facies, metasediment-hosted deposits. Rather, SiO_2 released by alteration reactions is redeposited in host rocks as quartz veins.

Use of alteration in exploration

There are two steps in using alteration haloes in lode-gold exploration. First, it is possible to define target areas for exploration by recognising alteration characteristics for these deposits and, once an alteration halo is recognised, the sequence of alteration zones (Fig. 2) can be used to define a rough vector towards potential gold mineralisation.

Primary geochemical dispersion can also be used both in defining exploration targets and gradients (vectors) towards likely mineralisation in any area selected for exploration, as exemplified in Figure 3.

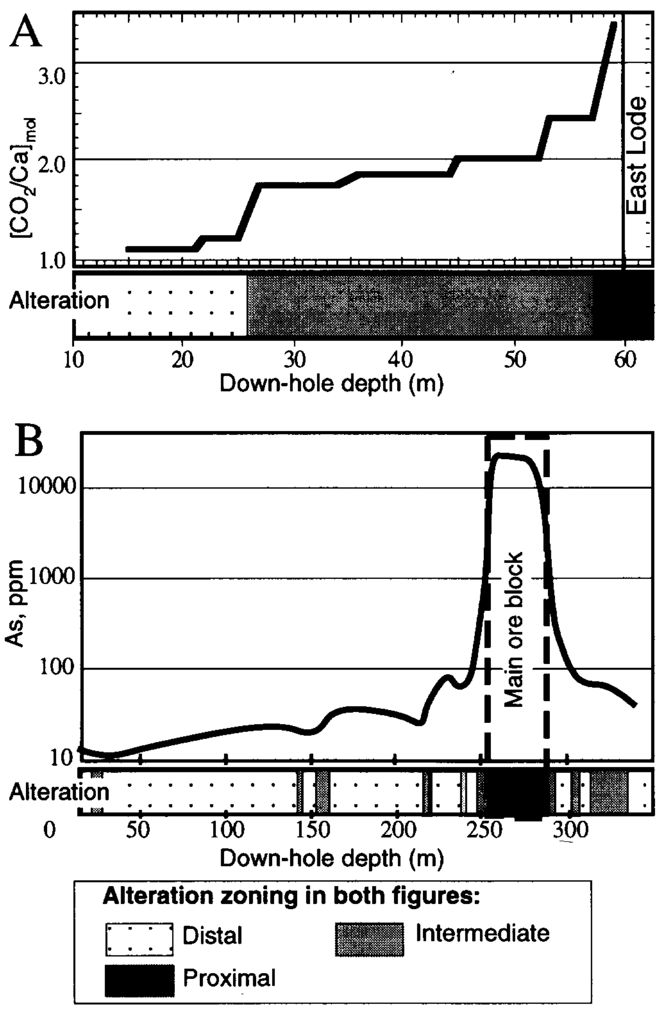


Figure 3. A) Carbonation index trend from inner distal through intermediate and proximal alteration zones to the East Lode at Lake View, Golden Mile, Western Australia (after data from Phillips 1986). B) Variation in As concentration across a sequence of altered rocks, to the main ore block at Bulletin, Wiluna, Western Australia (after Eilu and Mikucki 1998).

The most useful geochemical indicators are those that show the most widespread dispersion around all or most of the deposits. These include As, Au, Bi, Sb, Se, Te and W, and the alteration indices describing the intensity of carbonation and sericitisation or biotitisation (Fig. 3). Multi-variate geochemical techniques (e.g., Chork and Rousseeuw 1992) may also provide parameters defining anomalies useful in exploration, but these parameters generally are different for each area investigated.

Log-normal cumulative frequency plots (Sinclair 1991) provide a reasonable and simple way to estimate thresholds between background and anomalous values for Au and the pathfinder elements. However, to get the most reliable background thresholds for an area under exploration, the threshold values achieved from the cumulative frequency plots must also be compared with element concentrations given for unmineralised rocks in the literature, and with the spatial distribution of the data within the area studied.

Conclusions

Orogenic (mesothermal) gold mineralisation may form under sub-greenschist to lower-granulite facies PT conditions. The deposits may be hosted by practically all rock types in an orogenic belt of any age. Despite this variation, there are certain consistent features in their alteration haloes: 1) zoning perpendicular to mineralisation in all cases, 2) rare along-strike and down-dip zoning, 3) carbonation and formation of muscovite or biotite, 4) low-degree of sulphidation, 5) significant enrichment in CO_2, S, K, H_2O, LILE, Au ± Ag, As, Bi, Sb, Se, Te and W, 6) silicification reflected by the commonly large volumes of quartz veins, and 7) rare base-metal enrichment.

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