The Boddington gold mine: A new style of Archaean Au-Cu deposit

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The Boddington Gold Mine (BGM), Western Australia (current gold resource and past production >26 Moz Au) is one of the largest Au deposits in the world. The bedrock resource also contains a recoverable copper resource of 800 kt and appreciable amounts of molybdenum. The genesis of the deposit has been attributed to various genetic models, from a deformed and metamorphosed porphyry deposit formed broadly synchronous with host intrusions (Roth 1992); to a post-peak-metamorphism, shear-zone hosted deposit post-dating the intrusive host rocks by at least 25 m.y. (Allibone et al. 1998). A three-year study of the character of mineralisation at Boddington, including aspects of structure, alteration petrography, whole-rock geochemistry, fluid inclusions, and radiometric dating (U-Pb and Re-Os), in combination with the results of research of earlier workers, has formulated a new model for the deposit.

Regional Geology

The deposit is hosted in 2715-2690 Ma intrusive and volcanic rocks (diorite-andesite) of the Saddleback Greenstone belt, Southwest Yilgarn Block, WA (Allibone et al. 1998, Fig. 1). The element chemistry of these intrusions indicates that they were likely emplaced into an island arc tectonic setting. These rocks have been subjected to a ductile deformation event (D1-D2). A second period of supracrustal deposition (intermediate volcaniclastic rocks) and coeval granodiorite-tonalite intrusion has been identified at ca. 2675 Ma. Chemistry of these rocks is again consistent with formation in an arc setting, but the extent of this event, and geological controls upon it are poorly constrained. All rocks were then metamorphosed to upper-greenschist to lower-amphibolite facies at ca. 2640 Ma, and deformed by brittle-ductile faults (D3-D4). A late monzogranite intrudes the greenstone belt just east of the BGM mine area. This intrusion is distinct in terms of its texture (K-spar phyric, associated aplites and rare pegmatites), magnetic signature (distinctive magnetic low), radiometric signature (elevated U-Th and K), and age (ca. 2612 Ma). The major trace element chemistry of the granite is consistent with its genesis by melting of mid-crustal rocks in an intraplate setting (post-tectonic, or 'A-type' granite; Fig. 2).

Mineralisation

Size of the BGM mineralising system

A regional geochemical database has allowed the scale of the hydrothermal system to be appreciated. Images of abundance of Cu, Au, Mo, Bi and W show remarkable overlap and are taken to represent the core of the main BGM hydrothermal system. The periphery of this hydrothermal system displays marked enrichment in the metals Pb, Zn and Ag (Fig. 3). This metal zonation delineates the surface extent of the BGM hydrothermal system.

Alteration-mineralisation-deformation paragenesis

Two mineralisation stages are recognised at Boddington. The earliest mineralisation comprises widespread silica-biotite alteration, and complex quartz+albite+molybdenite±clinozoisite±chalcopyrite veins variably deformed by ductile shear zones. Re-Os ages from molybdenite in these veins indicates a formation age of ca. 2700 Ma (Stein et al. this volume). The second and main stage of mineralisation cuts all of the above lithologies, and comprises: (1) complex quartz+albite+molybdenite±muscovite±biotite± fluorite±clinozoisite± chalcopyrite veins (controlling the Mo distribution); (2) Clinozoisite-sulphide-quartz-biotite veining (controlling the bulk of the low-grade skarn Au-Cu mineralisation); (3) Actinolite± sulphide±quartz, carbonate-chlorite-sulphide, and sulphide veins (controlling high grade mineralisation). Re-Os dates from these mineral assemblages yield ages of ca. 2625-2615 Ma, broadly synchronous with the Wourahming monzogranite (Stein et al., this volume). Similar alteration assemblages and Re-Os ages of molybdenite in monzogranite and ore and metal zonation support a genetic link between the monzogranite and the BGM mineralisation. Although Au is paragenetically associated with both 2700 Ma and 2612 Ma mineralising events, the main stage of mineralisation, particularly high-grade mineralisation, appears synchronous with the later event.

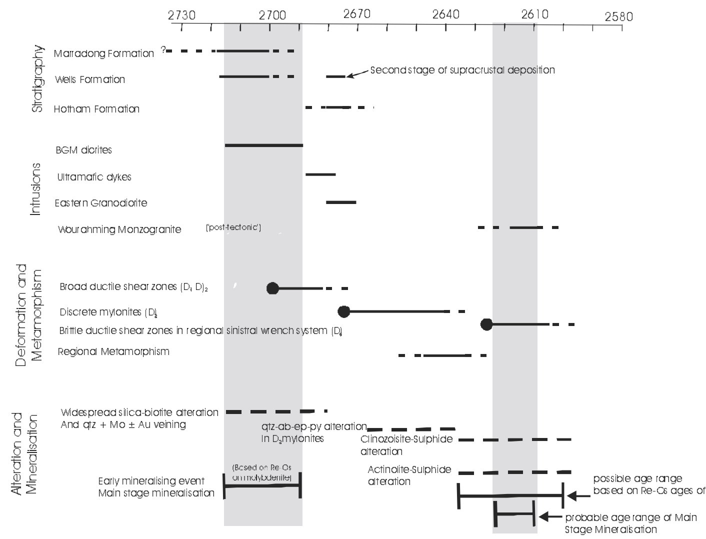
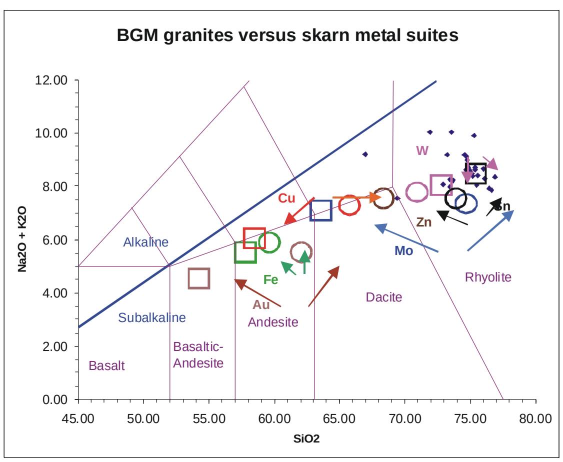


Figure 1. Geochronology of the Saddleback Greenstone Belt. References Stein et al (this volume), Allibone et al (1998), Roth (1992), Wilde & Pigeon (1986) and Nemshin & Pigeon (1996).



The BGM monzogranite data (diamonds) versus the mean composition of magmatic suites associated with Au, Cu, Fe, Zn, Mo, Sn and W skarn mineralisation. Squares = data from Ray & Dawson (1998), circles = data from Meinert (1995).

Figure 2. Discrimination plot of Na_2O+K_2O versus SiO_2.

Geometric controls on the Wandoo Deposit

Integration of all geochemical and geology datsets has determined the following controls on ore positions, in increasing order of importance (1) A late brittle-ductile fault network (WNW or NW-strike and subvertical dip), showing elevated metal abundances and mineralisation-related alteration assemblages. (2) Intersection of this fault network with structurally favourable lithologies (competent bodies). (3) Intersection of late faults with early ductile quartz-sericite shear zones. (4) NE-striking fault corridors. The NE-striking fault corridors appear to compartmentalise the deposit, having offset favourable host rocks pre-mineralisation.

Fluid character and fluid history in the Wandoo deposit

Combining fluid inclusion microthermometry with careful paragenetic documentation of samples has allowed a fluid history to be constructed for the Wandoo deposit. (1) Exsolution of a volatile phase directly from a magma (at ca. >600ºC, >60 wt% NaCl equivalent, £1.5 kbars). (2) Cooling of this magmatic fluid and transient depressurisation (likely structurally induced) whereby boiling of the fluid occurs over a large P-T range (ca. 300-550ºC, 0.6-0.15 kbars). These inclusions are directly associated with mineralisation. (3) Incursion of meteoric water (ca. 150-300ºC, <10 wt% NaCl), which possibly represents collapse of the hydrothermal system. Roth (1992) reports Au associated with these inclusion trails. (4) Overprinting of mineralisation by a late CO_2-H_2O-CH_4 fluid (ca. 300ºC, <10 wt% NaCl), showing evidence for extensive phase immiscibility. No mineralisation was observed associated with these inclusions.

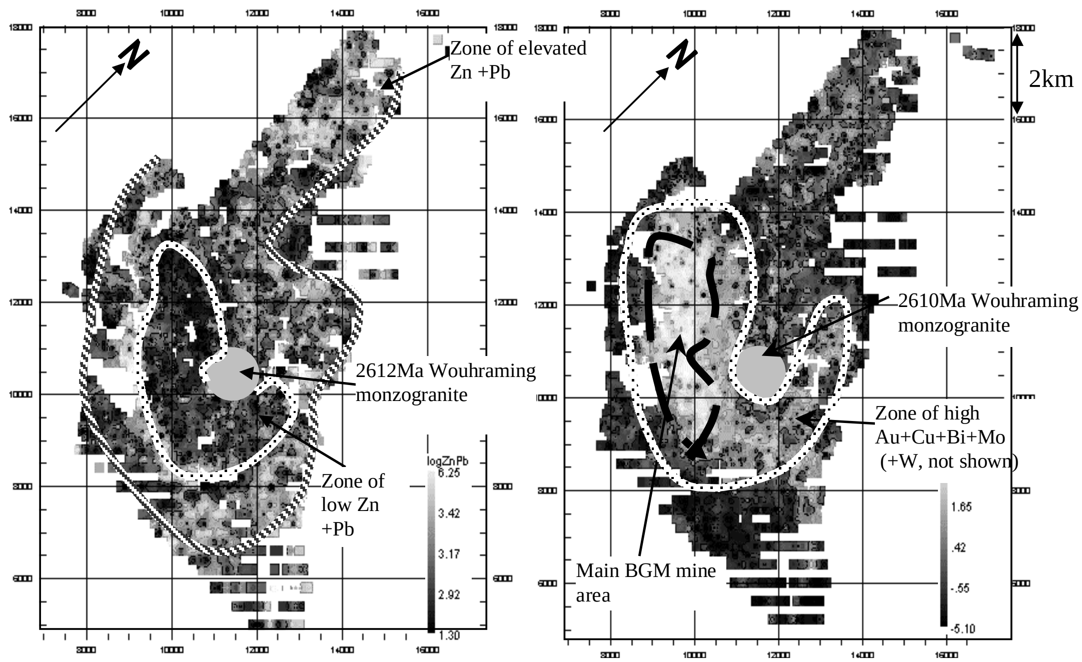


Figure 3. Images of metal abundances from the base of oxidation, illustrating the zonation of metals around the BGM system and the Wouhraming monzogranite. Left = log Zn+log Pb; Right =log Au+log Cu+log Bi+log Mo.

Summary

The Boddington deposit is interpreted as a structurally-controlled, intrusion-related Au-Cu deposit formed by two overprinting magmatic-hydrothermal systems, one at ca. 2700 Ma, and one at ca. 2612 Ma. The bulk of the mineralisation appears to be associated with the later event and a K-rich post-tectonic magmatic suite. This class of intrusion-related gold deposits has recently regained attention in younger terranes (cf. Lang et al. 2000), but this is the first well-documented occurrence of a major Archaean Au-Cu deposit associated with post-tectonic granitoids.

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