'World-class' Archean orogenic gold deposits, eastern Yilgarn Craton: Diversity in timing, structural controls and mineralization styles

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Archean orogenic gold deposits are widespread in the Yilgarn Craton and account for almost 80% of cumulative Western Australian gold production. The Yilgarn Craton hosts more than 160 gold deposits containing more than 1 t Au, of which 19 deposits are 'world-class' (>100 t Au), and 15 of these are located in the eastern Yilgarn. A close examination of the geological characteristics of world-class gold deposits in the Yilgarn Craton reveals many common features: (i) strong structural control of orebodies, (ii) relative timing of gold mineralization with respect to peak metamorphism, (iii) consistent metal association, and (iv) broadly uniform, low-moderate salinity, mixed aqueous-carbonic hydrothermal fluid. In the past 10 years, however, detailed investigations reveal that the world-class deposits in the eastern Yilgarn Craton display a diverse range of depositional site characteristics (host lithologies, structural setting, mineralization styles), at both the camp- and deposit-scale, and a range in relative- and absolute-timing. This contribution explores the variability in deposit characteristics, and its implications for generic genetic models for this deposit-class (cf Hagemann & Cassidy, 2000).

Relative- and absolute-timing constraints

Orogenic gold deposits are generally interpreted to have formed as a result of focussed fluid flow late during active deformation and metamorphism of volcano-plutonic terranes (Groves et al. 1998, Hagemann & Cassidy 2000, Kerrich et al. 2000). Based on relative timing constraints, most authors interpret gold mineralization in the EGP to be late in the relative structural framework of an individual deposit and, as a broad generalization, generally consistent with ENE-WSW-directed regional compressional deformation (Groves et al. 1995, Davis & Maidens 2001). Available geochronology on gold deposits in the Yilgarn Craton is consistent with this interpretation (Kerrich & Cassidy 1994, Yeats et al. 2001). Many of the world-class gold camps and deposits in the EGP have relative timing chronologies consistent with gold mineralization having formed during regional ENE-WSW-directed regional compression. For example, the deposits in the Mt Pleasant and Victory-Revenge camps, and the Darlot-Centenary, Kanowna Belle, Sunrise Dam and Wallaby deposits, are interpreted to have formed late during ENE-WSW-directed compression. In some deposits in the Mt Pleasant camp, gold mineralization accompanied the last Archaean deformation event, whereas in some other deposits detailed studies demonstrate that gold mineralization was overprinted by late veins (Kanowna Belle: Davis et al. 2000) and/or faults (Tarmoola: Duuring et al. 2001). Recent studies, however, indicate that the relative timing of mineralization in some world-class gold camps and deposits (Kalgoorlie camp: Bateman et al. 2001; Leonora camp: Witt 2001; Jundee-Nimary camp: Yeats et al. 2001) with respect to the structural evolution of the host terrain is equivocal. There is evidence for multiple episodes of gold mineralization at the individual deposit- or camp-scale, as well as the terrane-scale, and for these mineralizing events to have taken place over an extended time interval in the late Archean. Correlation of deposit- and camp-scale deformation histories with regional deformation chronology is difficult with gold camps containing field evidence both supporting and negating correlation with regional deformation events. The complexity of the deformation sequence identified at the deposit scale is often not present, or at the least not preserved in the rock record, at a regional scale.

Diversity in host rocks, structural controls and mineralization styles

There are a number of deposit characteristics that differ between the world-class gold camps and individual deposits. These include: (i) host lithologies, (ii) styles of mineralization, (iii) hydrothermal alteration systematics, and (iv) various aspects of fluid and ore chemistry (oxidation state, gold fineness).

Athough Archean lode-gold deposits are predominantly hosted in mafic-ultramafic extrusive and intrusive rocks (Groves et al. 1995, Hagemann & Cassidy 2000, 2001), it is clear that all lithologies in the eastern

Yilgarn host economic gold mineralization. For example, felsic-intermediate volcaniclastic and sedimentary rocks host mineralization at Kanowna Belle and Sunrise Dam, and felsic to mafic sedimentary rocks host mineralization at Wallaby and New Holland (Agnew-Lawlers camp). At present, however, there are no world-class deposits hosted solely within granitoids. The largest deposit hosted solely within a granitoid is the Golden Cities deposit with a resource of over 1 Moz Au (Kehal & Stephens 2000). The world-class Tarmoola deposit, with a resource of over 4 Moz Au, is partly granitoid-hosted with over 50 percent of the gold mineralization hosted in ultramafic lithologies (Duuring et al. 2001).

The world-class individual deposits in the EGP, like many of the deposits in the world-class gold camps, are controlled by a range of structures that developed and/or were reactivated during ENE-WSW-directed regional compression (Groves et al. 1995). Reactivation of preexisting structures is important in localizing gold mineralization in several deposits. For instance, the Kanowna-Belle deposit is controlled by reactivation of the Fitzroy Shear Zone (Davis et al. 2000), and mineralization at Sunrise Dam is controlled by reactivation of early thrust structures (Sunrise Shear Zone: Davis & Maidens 2001). The Tarmoola deposit is controlled by heterogeneous deformation along the deformed margin of a small granitoid pluton. Change in the local stress field to NW-SE-directed compression is interpreted to have controlled development of the mineralized structures and gold mineralization (Duuring et al. 2001). Subsequent approximately E-W-directed compression truncated the mineralized structures. Two recently discovered world-class deposits, Sunrise Dam and Wallaby, contain mineralization in subhorizontal to shallow-dipping shear zones and/or quartz vein systems (Davis & Maidens 2001). This is in contrast to the majority of world-class gold camps and individual deposits in the EGP that have mineralization associated with moderately- to steeply-dipping shear zones and/or quartz vein systems (Groves et al. 1995).

World-class gold camps and individual deposits in the EGP are characterized by a variety of mineralization styles, including (in approximate order of decreasing gold endowment): (i) brittle-ductile shear zones with quartz vein systems (e.g. Golden Mile, Victory-Revenge, Jundee-Nimary, Sunrise Dam, Bronzewing, Mt Pleasant), (ii) disseminated lodes associated with shear zones or fault systems (e.g. Leonora, Wiluna, Agnew-Lawlers), (iii) sheeted quartz vein sets or stockworks (e.g. Mt Charlotte), and (iv) quartz 'reefs' (e.g. Norseman). Many deposits contain more than one style of mineralization, even in the same stage of mineralization. Overprinting relationships are common; for example, Mt Charlotte-style sheeted quartz vein sets overprint the Fimiston-style mineralization at the Golden Mile deposit in the Kalgoorlie gold camp, and strike-slip fault controlled orebodies crosscut earlier emplaced quartz reef-style of gold mineralization in the Wiluna gold camp. The styles of mineralization are influenced by: (i) host rock rheology, (ii) heterogeneous stress configuration at the oreshoot- to regional-scale, (iii) fluid pressure variation, and (iv) type of fluid flow (pervasive versus focussed fluid flow).

Low-moderate salinity, mixed aqueous-carbonic hydrothermal fluids capable of carrying Au, Ag and several other metals, but with limited capacity to transport base metals, are generally invoked for gold deposits in the EGP. Given that similar hydrothermal fluids are present in most gold deposits, alteration mineralogy and zonation in hostrocks, resulting from fluid-wallrock interaction, is largely controlled by the composition of the host rocks, prevailing temperature-pressure conditions and the fluid to rock ratio (cf. McCuaig & Kerrich 1998). The changes in alteration mineralogy with inferred paleocrustal level of gold mineralization for a variety of host rocks have been characterized in a number of studies, including Groves (1993) and Cassidy et al. (1998). Variations in the composition of the hydrothermal fluids are present in some camps and/or deposits, however, and may have significant impact on the alteration systematics present in an individual deposit. For instance, methane-rich fluids are present in some deposits (early fluids at Wiluna; late fluids at Granny Smith) and may change the redox conditions and resultant gold precipitation. Most deposits are considered to be relatively reduced (see Ridley & Diamond 2000) although several Archean deposits (Fimiston- and Oroya-style mineralization at the Golden Mile) contain hematite and/or anhydrite as part of their alteration assemblage indicating relatively oxidizing conditions during gold mineralization. Hagemann et al. (2000) speculate that hematite may result from: (i) intrinsically oxidized ore-fluids (e.g., oxidized magmatic fluids), (ii) fluid buffering of redox conditions during cooling, (iii) fluid-rock interaction with oxidized wallrocks, (iv) phase separation during ore deposition; or (v) mixing between ore fluids and oxidized fluids.

In summary, the world-class camps and deposits in the eastern Yilgarn Craton demonstrate a number of common features as well as great diversity in a number of geological characteristics. The diversity of the deposits reflects the complex interplay of physical and chemical processes at a trap (depositional) site localized at various paleocrustal levels ranging from sub-greenschist to upper-amphibolite facies metamorphic environments, with gold precipitation occurring over a correspondingly wide range of pressures and temperatures.

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