Deformation history and multiple gold mineralisation events within the Bardoc Tectonic Zone, Eastern Goldfields, Western Australia

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Abstract. This study focuses on three gold deposits within the late-Archaean Bardoc Tectonic Zone (BTZ) Western Australia, namely Paddington, New Boddington and Yunndaga. The styles, characteristics and relative timing of deformation and gold mineralisation have been constrained at each of these deposits. These local events have then been correlated to provide an understanding of regional controls of gold mineralisation within the BTZ.

Results imply that gold mineralisation chiefly occurred relatively early (D_2) within the deformation history of the region. However at Paddington, there are two phases of gold mineralisation. One is associated with D_2 and the other is associated with a local NNW–SSE-directed shortening event (D_{NS}) that has been interpreted to occur between D_2 and D_3.

These findings are in contrast with other regional studies of gold endowment within the Eastern Goldfields, which have reported that gold mineralisation occurred late (D_3-D_4) within this terrane. Furthermore, no large-scale strike-slip faulting (D_3) has been observed and late oblique faults (D_4) are unmineralised. Associating gold mineralisation with relatively early D_2 and D_{NS} deformation provides important relative timing constraints on gold mineralisation within the BTZ.

Keywords. Gold mineralisation, shear zones, Late Archaean, Yilgarn Craton

1 Introduction

The Late Archaean Eastern Goldfields Province (EGP) within the Yilgarn Craton, Western Australia hosts one giant and over ten world-class orogenic lode-gold deposits (Hagemann and Cassidy 2001). These types of gold deposits are genetically associated with major regional shear zones and are commonly sited on second- or third-order faults that splay off first-order structures (e.g. Groves et al. 2000).

The BTZ has been a significant gold-producing shear system, but it has received little scientific attention in comparison to the along-strike Boulder-Lefroy Shear Zone (BLSZ) (Fig. 1), which hosts the giant Kalgoorlie gold camp and other world-class gold deposits (e.g. Weinberg et al. 2004).

This study has focussed on three well-spaced gold deposits within a portion of the BTZ that stretches between the Paddington and Menzies areas. These are Paddington, New Boddington and Yunndaga (Fig. 1). The outcomes of field-based structural and gold mineralisation studies are reported herein, and provide a new framework for understanding structural deformation and gold mineralisation within the BTZ. Evidence is presented to introduce a previously undocumented gold mineralisation event as well as further constraining the relative timing of gold mineralisation within the shear zone.

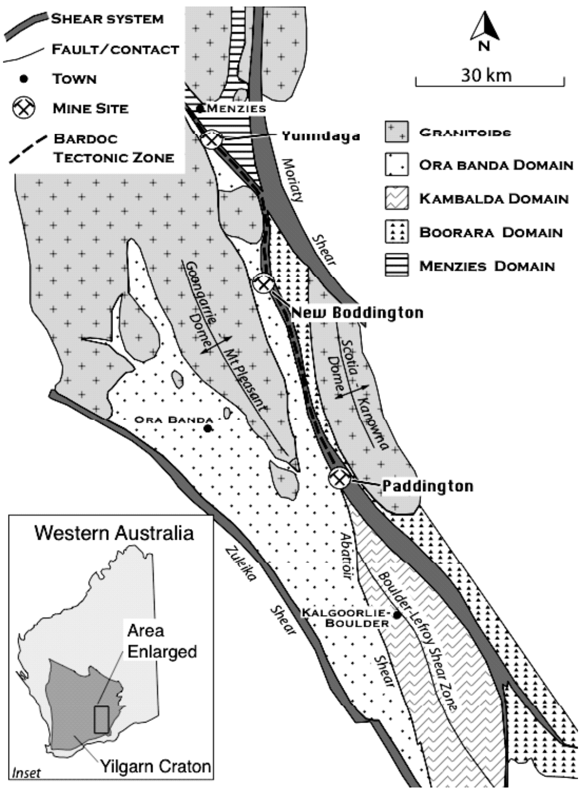


Figure 1: Map of a section of the southern Eastern Goldfields Province showing the location of the deposits studied and a selection of its tectono-stratigraphic domains and shear zones (modified from Swager and Griffin 1990).

2 Regional geology

The composite Yilgarn Craton (inset, Fig 1) is dominated by metamorphosed granitoid rocks, as well as less abundant portions of greenstones. The Late Archaean EGP constitutes the eastern portion of the Yilgarn Craton, and is characterised by a number of elongate NNW-trending granite-greenstone sequences that have been partitioned into various tectono-stratigraphic terranes and domains (e.g. Swager and Griffin 1990; Swager 1997). A number of major shear systems exist either at the boundary of, or within these domains and they control the location of many of the EGP's gold deposits.

The BTZ is an example of one of these mineralised shear systems. It is regarded as a major, deep-penetrating shear system that is also the boundary structure between the Ora Banda and Boorara domains (Fig 1) (Swager and Griffin 1990).

3 Local deformation and gold mineralisation events

3.1 Deformation at the Paddington gold deposit

The Paddington gold deposit (~37 t Au, Fig. 1) is made up of two elongate NNW-trending open pits. Out cropping lithologies comprise ultramafic schists, mafic extrusive and intrusive rocks, interbedded shales and volcano-sedimentary rocks.

At Paddington, the first recognised deformation event (D_{1P}) is characterised by a pervasive NNW-trending foliation that is axial-planar to a number of upright, tight to isoclinal folds (F_{1P}). This foliation also defines the regional fabric of the BTZ. These folds and associated foliations are overprinted by moderate, easterly-dipping reverse faults. Both of these structures can be attributed to a maximum shortening axis oriented in an ENE–SWS direction (D_{1P}).

Post-D_{1P} shortening is characterised by open F_{2P} structures that fold $S_0//S_{1P}$. These fold axes are steeply plunging, trend N70° and indicate that shortening was directed towards NNW–SSE, orthogonally to the D_{1P} maximum shortening axis.

The final deformation event (D_{3P}) at Paddington is characterised by NE-trending, brittle-ductile faults that divide the deposit in two. Movement along these steeply-dipping faults is indicated by drag folds, which give a composite dextral/reverse movement sense. These faults indicate a change to strike-slip motion through ENE–WSW shortening.

3.2 Gold mineralisation at the Paddington gold deposit

There are two major styles of gold-bearing lode structures at Paddington; *laminated* and *ladder* lodes. Both types of lode are hosted within the competent mafic units. The quartz-carbonate laminated lode trends NNW, dips steeply east and runs along the length of the open pit. It characteristically has alternating selvages of vein and wall rock material at its margins. Arsenopyrite (asp)-dominated + gold assemblages occur within the highly sericitised wall rock to this lode. The alteration assemblages at the margin of the lode are sheared in a reverse fashion by the pervasive D_{1P} fabric. This implies that the laminated lode and its gold-bearing alteration assemblage are either syn- or pre-D_{1P}.

The ladder lodes are an array of thin (1-10cm thick) quartz-carbonate veins not affected by D_{1P} folding or reverse faulting – and hence must have post-dated D_{1P}. From analysis of diamond drill core, Sheehan and Halley (2002) also reported the ladder lodes overprinted the laminated lode. A stereo plot (Fig. 2) shows that the poles to ladder veins define a great circle, and indicates that a maximum shortening axis oriented NNW–SSE can explain the formation of these veins. This is the same shortening direction inferred for D_{2P}, and suggests the ladder lodes formed after the laminated lode and that these veins represent two different generations of gold mineralisation.

3.3 Deformation at the New Boddington gold deposit

The New Boddington gold deposit (~2 t Au) is situated approximately half way between Paddington and Menzies (Fig. 1). Lithological contacts trend towards NNW and have a steep westerly dip. The exposed rock units comprise an ultramafic schist unit on its western flank and two mafic units within its central and eastern portions. There is a thin (<1 m) shale unit at the contact between these mafic units.

A steep, westerly-dipping, NNW-trending foliation (S_{1NB}) pervades all units and is the first, most prominent deformation structure. Stretching lineations (L_{1NB}) are steep towards N335° with limited variation, indicating the maximum stretching axis is down-dip. Kinematic indicators orthogonal to S_{1NB} and parallel to L_{1NB} consistently show reverse movement along foliation planes. This movement sense on S_{1NB} therefore suggests a maximum shortening axis oriented ENE–WSW (D_{1NB}).

Faults with sub-metre dextral displacement striking N310 overprint S_{1NB} planes. This faulting event has also been noted by Colville et al. (1990), and requires N–S-directed shortening (D_{2NB}) to explain its movement.

3.4 Gold mineralisation at the New Boddington gold deposit

Gold mineralisation within this open pit is hosted within the mafic rocks, associated with a number of stockwork and planar lode structures. Based on the observation that lodes are undeformed, Colville (1990) inferred that gold mineralisation was relatively late. Witt (1992) further reported that gold mineralisation was associated with sinistral strike-slip shearing.

Our field work failed to find evidence for strike-slip deformation at New Boddington. Instead, microstructural and structural analysis of mineralised stockwork and planar lodes demonstrate that the veins and wall rock sulphide assemblages are deformed by S_{1NB}. These results challenge the previous conclusions of Colville (1990) and Witt (1992) and imply that gold mineralisation occurred prior to or during D_{1NB}.

3.5 Deformation at the Yunndaga gold deposit

The Yunndaga deposit (~9 t Au) is located approximately 5km south of the township of Menzies (Fig. 1). This open pit exposes NNW-trending quartz-rich sedimentary rocks, minor ultramafic schist, a carbonaceous shale and a mafic doleri-te rock unit. The western contact between the mafic unit and the sedimentary rocks hosts the gold-bearing lode structure.

As with the previous two deposits, D_{1Y} is characterised by a NNW-trending, steep westerly-dipping pervasive foliation (S_{1Y}) that is most pronounced within the sedimentary and ultramafic rock units. S_{1Y} is axial planar to a number of tight to isoclinal folds (F_{1Y}) that plunge moderately to the south. In contrast to the other deposits, lineations along S_{1Y} have a shallow to moderate plunge, which indicate that a component of strike-slip movement occurred during D_{1Y}. Kinematic analysis suggests reverse-sinistral movement along these planes. This folding and shearing (D_{1Y}) can be related to a maximum shortening axis oriented in a ENE–WSW direction.

Within the northern section of the deposit, prominent sets of NW-trending, steeply-dipping, dominantly brittle faults cut across all lithologies and structures. The reverse-sinistral movement sense along these faults can be explained by the same shortening direction associated with D_{1Y}, however the offset of earlier S_0//S_{1Y} structures, as well as their brittle nature suggest that they are later (i.e. D_{Y2}) than D_{1Y}.

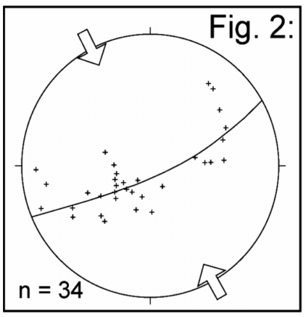
3.6 Gold mineralisation at the Yunndaga gold deposit

Gold mineralisation at Yunndaga is localised at the contact between the dolerite and sedimentary rock unit. Mineralised structures are characterised by boudinaged laminated quartz-carbonate veins with asp-dominated + gold assemblages within wall rock. The boudinaged lodes, as well as the deformed and rotated asp + gold grains, are deformed by D_{1Y} deformation. Gold mineralisation is thus syn- or pre-D_{1Y}.

4 Regional synthesis of deformation and gold mineralisation within the BTZ

Figure 3 summarises the local deformation and gold mineralisation events at each deposit. These local events are also correlated with other regional deformation events, e.g. D_1–D_4 of Swager (1997).

This study has found that there is no evidence in the strongly deformed BTZ for early D_1 N–S-directed, recumbent folding and associated thrusting. Instead, the first known deformation at all localities is characterised by NNW-trending tight to isoclinal, upright folding and faulting, indicating pronounced ENE–WSW shortening. This style of deformation can be correlated with regional D_2. The majority of gold mineralisation within the BTZ is also associated with this relatively early event, and this provides the earliest timing constraint on gold mineralisation for this shear system. Results also indicate that there is a later gold mineralisation event at Paddington that occurred after D_2, and is associated with NNW–SSE shortening (herein termed D_{NS}, Fig.3). Evidence for ~N-S-directed shortening has been reported for the EPG (e.g. Ellis 1939), but it has not been placed within a contemporary regional deformation regime. Duuring et al. (2001) have reported that mineralisation within the Tarmoola gold deposit was linked to a similar shortening direction as D_{NS} (subhorizontal NW-SE shortening). These results highlight the potential for gold-bearing events within the EGP to be associated with shortening events that are at an angle to regional D_2. No large-scale sinistral strike-slip deformation (D_3) has been recognised within the BTZ. Small-scale, NNW-trending strike-strike slip deformation has been observed at the Yunndaga deposit but this was a result of transpressional



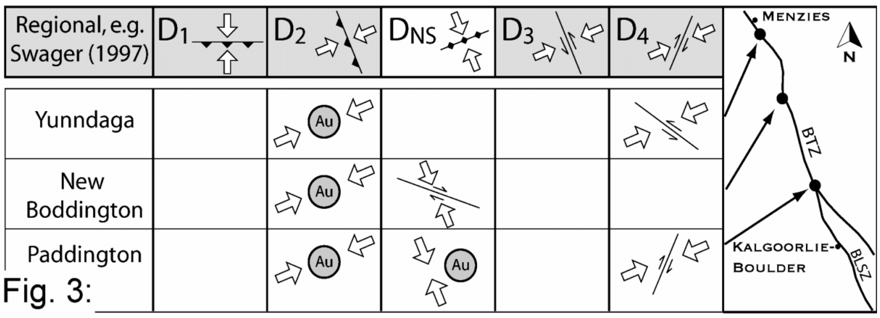


Figure 2: Lower hemisphere stereonet projection of poles to planes of ladder lodes from Paddington, indicating a NNW-SSE shortening axis.
Figure 3: Correlation between deformation and gold mineralisation events from each deposit studied and regional deformation phases.

movement related to D_2. The relatively late NE-trending dextral faults at Paddington and the NW-trending sinistral faults at Yunndaga are associated with D_4 of Swager (1997). These faults consistently overprint gold-bearing structures and indicate that D_4 deformation is not associated with gold mineralisation within the BTZ. Regional studies such as Groves et al. (2000) reported that mineralisation was relatively late within the deformation sequence (i.e. D_3-D_4). In contrast, this study has found that gold within the BTZ is mainly associated with earlier D_2 and D_{NS} deformation, implying that gold within the BTZ was protracted and occurred earlier than elsewhere within the EGP.

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References

Colville RG, Kelly D., Fish BL (1990) Goongarrie gold deposits, In: Hughes FE (ed) Geology of the mineral deposits of Australia and Papua New Guinea. Australian Institute of Mining and Metallurgy Monograph No 14, pp. 363–366

Duuring P, Hagemann SG, Love RJ (2001) A thrust model for gold mineralization at the Archean Trondhjemite-hosted Tarmoola Deposit: The importance of heterogeneous stress distributions around granitoid contacts. Economic Geology 96: 1379–1396.

Ellis HA (1939) The geology of the Yilgarn gold field, south of the Great Eastern Railway. Geological Survey of Western Australia Bulletin 97

Groves DI, Goldfarb RJ, Knox-Robinson CM, Ojala J, Gardoll S, Yun GY, Holyland P (2000) Late-kinematic timing of orogenic gold deposits and significance for computer-based exploration techniques with emphasis on the Yilgarn Block, Western Australia. Ore Geol Rev 17: 1–38

Hagemann SG, Cassidy KF (2001) World-class gold camps and deposits in the Eastern Goldfields Province, Yilgarn Craton: diversity in host rocks, structural controls, and mineralization styles, In Hagemann SG, Neumayr P, Witt WK (eds) World-class gold camps and deposits in the eastern Yilgarn Craton, Western Australia, with special emphasis on the Eastern Goldfields Province. Geological Survey of Western Australia Record 2001/17: pp. 7–44

Sheehan P, Halley S, (2002) Paddington Review 2001, Paddington Gold Pty. Ltd. Internal report, Unpublished.

Swager CP, Griffin TJ (1990) An early thrust duplex in the Kalgoorlie-Kambalda greenstone belt. Precambrian Research 48: 63–73