Deformation and gold mineralisation of the Archaean Pilbara Craton, Western Australia

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Early to late Archaean (3600–2780 Ma) lithostratigraphy and structures in the north Pilbara granite–greenstone terrain are so well preserved over wide areas, despite locally intense deformation, that we can link the chronology of crustal/craton-scale events to episodes of mineralisation. Mineralising events coincided with the formation, deformation, and stabilisation of the Pilbara craton over its 800-Ma evolution, and with the subsequent initiation of the Hamersley Basin (~2780–2400 Ma). As a contribution to the joint AGSO–GSWA (Geological Survey of Western Australia) 'North Pilbara' project for the National Geoscience Mapping Accord, we discuss the tectonothermal and related mineralising events of the north Pilbara granite–greenstone terrain (Fig. 11).

Geological framework

Lithostratigraphic mapping in the north Pilbara granite–greenstone terrain distinguishes up to nine greenstone (volcanic–sedimentary) packages and at least 10 largely coeval felsic intrusive events (e.g., Hickman 1983: GSWA Bulletin 127; Krapez 1993: Precambrian Research, 60, 1–45; Fig. 12). Recent lithostratigraphic and geochronological studies have revealed substantial differences between the eastern and western parts of the terrain (Hickman 1997: GSWA Annual Review, 76–81).

In the eastern, older part of the craton, younger granitoid phases tended to be intruded into older granitoid rocks (although not exclusively), forming large (100+ km diameter) granitoid complexes. Contemporaneous greenstones accumulated episodically in synforms between the developing granitoid complexes, most across unconformable contacts (e.g., Buick et al. 1995: Nature, 375, 574-577; Van Kranendonk 1998: GSWA Annual Review 1997–98, 63–70). These observations have led some workers to suggest that crustal overturning and/or passive gravity-driven tectonics was the driving force behind the crustal evolution of the east Pilbara (Hickman 1997: op. cit.; Collins et al. 1998: Journal of Structural Geology, 20, 1405–1424).

In the west Pilbara, two distinct greenstone packages — the 3270-Ma Roebourne Group and 3120-Ma Whundo Group — occur on either side of the Sholl shear zone, a multiphase strike-slip fault (Smithies et al. 1999: Precambrian Research, 94, 11–28). Locating a boundary or suture between the east and the west Pilbara is a continuing problem. This search is frustrated by deep crustal boundaries interpreted from gravity and magnetic data not corresponding to faults at the surface.

We have established an event chronology based on macro- and mesoscale structural observations (new work and published compilations; details at *http://www.agso.gov.au/minerals/pilbara/table.html*). In it, we identify eight phases of penetrative deformation manifested by such features as folds, schistosity, and shear zones (Fig. 12), and thus extend the fourfold division of Hickman (1983: op. cit.). What caused the deformation? A number of models have been proposed, including:

- intraplate (extensional and compressional) tectonism with changes in far-field horizontal stresses controlling the system;
- subduction-related marginal processes and accretion similar to those operating during the Phanerozoic; and
- diapirism and partial crustal overturn caused by density contrasts between the granitoids and greenstones.

Instead of one single mechanism, all these processes may have been involved in shaping the Pilbara over the 800 Ma of its development. Such interpretations have an impact on metallogenic models in terms of linking deposits in time and space (e.g., far-field or marginal tectonic forces) rather than them being random, isolated occurrences (diapirism).

Implications for gold mineralisation

Gold mineralisation was episodic in the Pilbara, in concert with magmatism and deformational events (Fig. 12). Lead-isotope data suggest that epigenetic gold deposits formed at ~3410 Ma (D_2), ~3200 Ma (D_3), ~2990 Ma (D_4), and ~2900 Ma (D_7), and structural relations suggest further events at <3000 Ma (D_4 or D_5) and <2880 Ma (D_8; Fig. 12, Table 1). Although these structural and absolute-age data constrain gold mineralisation temporally, they need the support of information that discriminates the structural controls on mineralisation before we can effectively explore for deposits and understand the mineral systems. These controls are summarised for a number of deposits in Table 1.

The host rocks, structural controls, and structural levels of gold mineralisation in the Pilbara are varied (Table 1). Most deposits, including the largest ones, are hosted by either mafic to ultramafic volcanics of the Warrawoona Group or turbidites of the Mallina Formation or Mosquito Creek Group.

Many of the gold deposits are associated with shear zones and the faulted contacts between units of contrasting competencies and lithologies. These shear zones and faults vary in strike length, throw, geometry, and structural level now exposed. The important control of tensional zones in regional faults is illustrated at the Withnell deposit, one of the important new gold prospects along the Mallina Fault Zone (Smithies 1998: Yule 1:100 000 geological map, GSWA) in the Mallina–Indee district (Fig. 11). Analysis of the regional structure, coupled with mapping and logging drillcore, indicate that gold mineralisation postdated D_7, and formed under a moderate- to high-level structural (e.g., brittle) and fluid regime. The deposit appears to be hosted in a tension-gash array developed during normal faulting with downthrow to the north (Fig. 13A).

Sheared contacts between units with a marked competency contrast controlled mineralisation in the Lynas Find district (Fig. 11), where the sheared (D_4) contacts between ultramafic rocks and highly altered mafic schists typically host gold deposits. As some of the shear zones have displacement indicators of high-angle reverse-faulting, blind (stacked) orebodies may have developed in the footwalls of thrust-planes (Fig. 13B).

A pervasive subvertical lineation formed by the intersection of two orthogonal foliations (S_2 and S_5?) is prominent in the complex geology of the Klondyke district in the Warrawoona Syncline (Figs. 11 and 13C). Boudinaged and sheared sulphide-bearing veins (S_2?) developed with long axes plunging gently in a steeply dipping fabric. Other boudin axes plunge steeply. Vearncombe (1995: Report to CRA Exploration, p. 45) identifies four phases of deformation; the main schistosity was associated with mineralisation and S-directed thrusting. An alternative view (Collins et al. 1998: op. cit.) is that the deformation is a function of partial crustal overturning and granitoid diapirism.

At Golden Eagle, in the Mosquito Creek Belt (Fig. 11), gold is stratabound in the upward-facing limb of a reclined anticline (F_4) that plunges subhorizontally to the east (Fig. 13D). The timing of mineralisation is unknown, but this ‘favourable’ structure continues eastwards with a shallow plunge. Shear zones and high-strain zones (D_5) control the Middle Creek line (Fig. 11). Their late dextral (D_5) kinematics is consistent with movement on the regional Kurrana Shear Zone, which marks the southern margin of the belt.

Study of these individual districts demonstrates the variability and importance of structural control on gold mineralisation in the Pilbara. Moreover, it indicates that, unlike the temporally constrained Yilgarn gold events (see Yeats & McNaughton 1997: AGSO Record 1997/41, 125–130), gold mineralisation developed at many periods in the evolution of the Pilbara Craton. In addition, much of the mineralisation appears to have been syntectonic rather than post-tectonic. An understanding of these structural and temporal controls on mineralisation is essential for gold exploration in the Pilbara.

Conclusions

- Regional structural analysis combined with district- and deposit-scale studies have improved our understanding of the Pilbara gold mineral systems. Further detailed and regional studies are clearly needed.

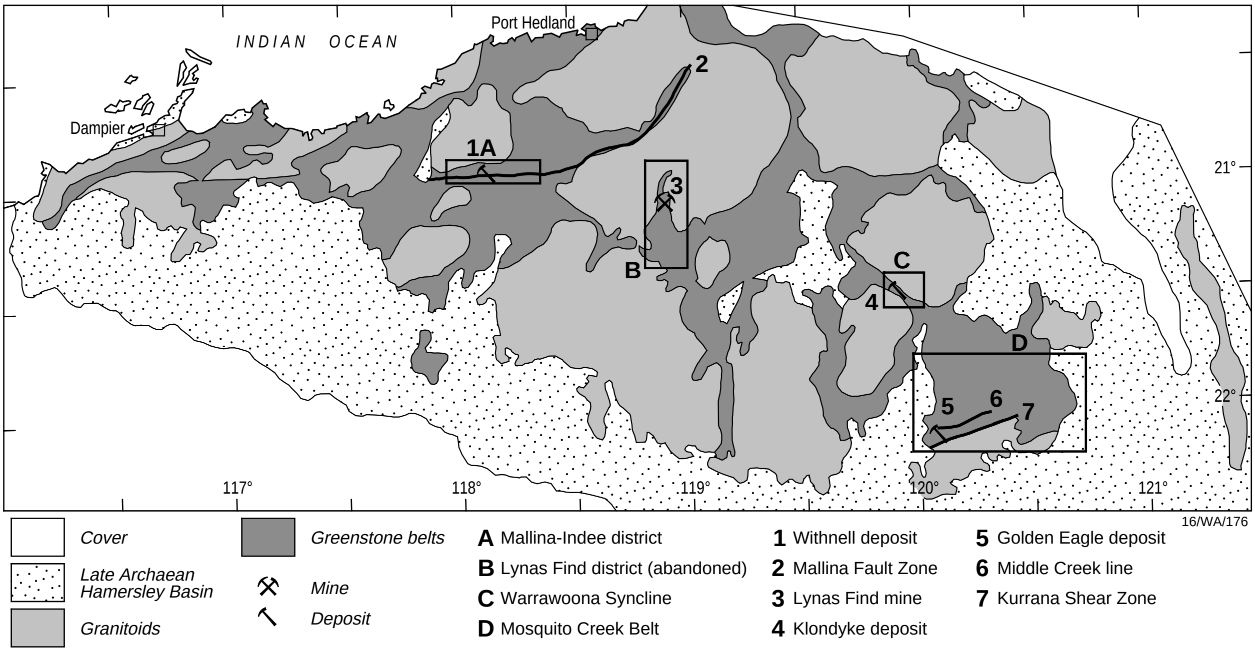

Fig. 11. North Pilbara Craton generalised geology, and localities discussed in the text.

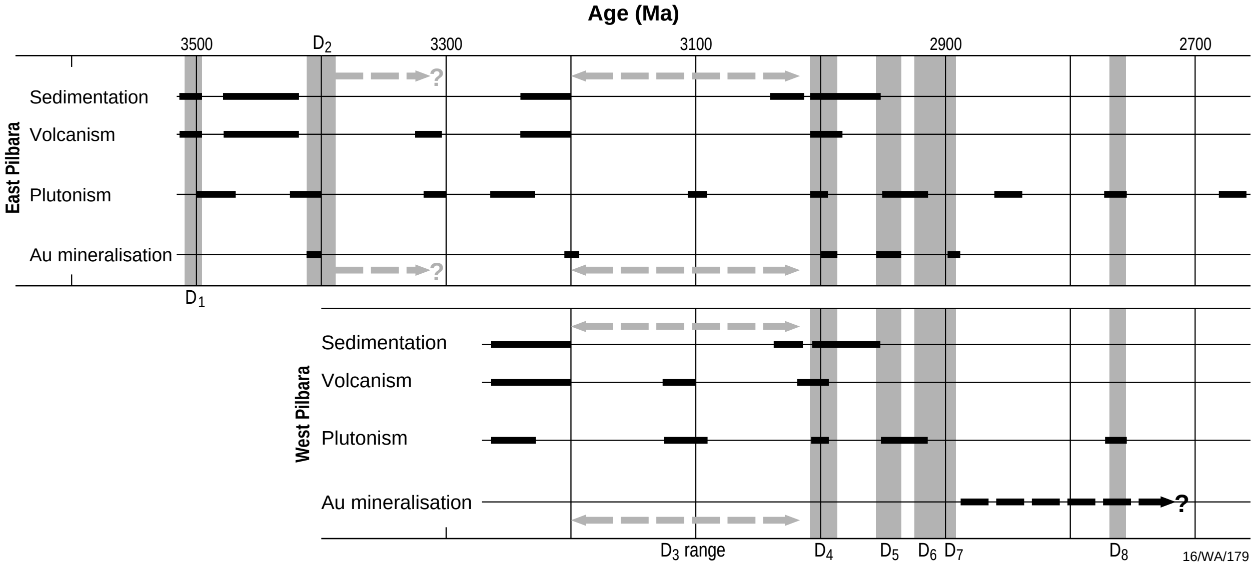

Fig. 12. Pilbara Craton event chart, showing correlative penetrative deformational, plutonic, volcanic, and mineralising events from 3500–<2700 Ma.

Table 1. Host and structural and age parameters of gold mineralisation at selected locations in the Pilbara Craton

District/deposit	*Host rocks*	*Structural controls*	*Structural level*	*Absolute age (Ma)*	*Structural age*
Bamboo Creek	Komatiite, Warrawoona Group	E–W-trending mylonitic shear zones (sinistral NE up shear)	Moderate to deep	3410	Syn-D_2
North Pole/Normay	Mafic schist, Talga Talga Subgroup	E–W-striking, N-dipping veins		3405	Syn-D_2
Warrawoona/Klondyke	Mafic and ultramafic schists, Warrawoona Group	Subvertical lineation caused by intersection of S2? and S5?	Moderate to deep	3400	Syn-D_2
Lalla Rookh/Lalla Rookh	Basalts, basal part of Salgash Subgroup	Dilational zones in axial regions of E–W-oriented ‘kink’ folds	Moderate?	3200	Syn-D_3?
North Shaw/Big Bertha	Metabasalts, Warrawoona Group	Moderately east-dipping veins		2990	D_4?
Nullagine/Golden Eagle	Turbidites, Mosquito Creek Group	Upright limb of reclined, south-verging F4 fold	Moderate to deep	2905?	Syn-D_4 or -D_5 (3000–2950 Ma)
Lynas Find	Amphibolite and talc schist, Warrawoona Group	Highly sheared contact (thrusted?) between amphibolite and ultramafic schist		2890	Syn- or post-D_4
Indee–Withnell	Turbidites, Mallina Formation	Tension-gash array developed on E–W normal faults (S side up)	Moderate	?	Post-D_7 (<2880 Ma)
Indee–Peawah	Turbidites, Mallina Formation	Tension-gash array developed on E–W normal faults (S-side up)	Moderate	?	Post-D_7 (<2880 Ma)
Indee–Becher	Turbidites, Mallina Formation	N–S veins	Shallow	?	Post-D_7 (<2880 Ma)

- The recognition of late (e.g., post-D_7) high-level gold associated with normal faults has implications for greater Pilbara prospectivity, especially close (in time and structural level) to the Hamersley unconformity.
- There is currently little consensus on the tectonic evolution of the Pilbara Craton, for which models including intraplate, marginal/subduction, and diapirism have been proposed. It is possible that all three mechanisms have occurred at some time in the craton’s long history.

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Fig. 13. ***(A, top)*** **Stylised diagram of tension-gash veins developed in a competent unit with bedding-parallel faulting (viewed north), where σ_1 is vertical (normal Andersonian faulting). Vein tips intersect the surface and strike east–west. The geometry predicts 'stacked' veins, each of which has a limited vertical extent.** ***(B, upper middle)*** **Sheared altered ore zone in McPhees pit in the Lynas Find district (viewed southeast).** ***(C, lower middle)*** **Intense intersection lineation at the Klondyke deposit (viewed southeast).** ***(D, bottom)*** **Reclined parasitic F_4 fold in the centre of the Golden Eagle deposit (viewed east).**