Structural framework of the northeastern Yilgarn Craton and implications for hydrothermal gold mineralisation

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The geological history and associated mineralisation of a complex Archaean granite–greenstone terrane can be understood only in the context of its structural evolution. Accordingly, we present a new regional structural synthesis for the northern Eastern Goldfields (Fig. 24) derived from an integration of the results of recent geological mapping with interpretations of aeromagnetic and gravity data*. This synthesis builds on an earlier one presented for a smaller area (Farrell 1997: in AGSO Record 1997/41, 55–57). It identifies four deformation events (D_1–D_4; Table 2), of which two — D2 (regional ENE–WSW-directed compression) and D3 (E–W-directed transpression) — largely shaped the region's crustal structure. The structural framework is broadly similar to that documented in the southern Eastern Goldfields (Swager 1997: in AGSO Record 1997/41, 49–53).

Deformation history

First deformation event (D_1)

The earliest recognisable structures (D_1) include bedding-parallel foliations, tight to isoclinal folds, and faults. They are evident where they are at high angles (e.g., ENE-trending) to the regional NNW-trending D_2 structures, which commonly overprint them. Elsewhere, they are difficult to distinguish unless overprinting relationships are apparent. Examples of regional D_1 structures include:

- the isoclinal fold refolded by a NNW-trending D_2 antiform at Dingo Range (1);
- bedding-parallel S_1 foliations and associated tight to isoclinal D_1 folds refolded by the D_2 Lawlers Anticline (Platt et al. 1978: Precambrian Research, 7, 3–30);
- several isoclinal D_1 folds refolded by D_3 southwest of Melita (Witt 1994: Melita 1:100 000 geological map explanatory notes, GSWA); and
- the Rio Tinto and Kilkenny synclines [(2) & (3)] and that in the Benalla Hill area (4) recently recognised as D_1 structures by Stewart (this issue, pp. 4–5).

At the southern or northern ends of some granitic domes, an early foliation (S_1) developed subparallel to the granite–greenstone contact, and was folded during D_2. Regional D_1 folds apparently are more extensive in the northern Eastern Goldfields than in the south, and so are granite domes.

The exact nature of D_1 is not well understood to date and controversial, but the tight to isoclinal folds reflect compression — at least locally. According to Hammond & Nisbet (1992: in J.E. Glover (Ed.), 'The Archaean: terrains, processes and metallogeny', Geology Department and University Extension, University of Western Australia, Publication 22, 39–50), their D_E extensional structures are overprinted by all other deformation events (D_1 to D_3). They also expressed their inability to distinguish between D_E tectonic slides, D_1 thrusts in greenstone, and younger D_2 thrusts. Extensional ductile shear zones of low to medium metamorphic grade are also reported in the Leonora area (Skwarnecki 1987: in S.E. Ho & D.I. Groves (Eds.), 'Recent advances in understanding Precambrian gold deposits', Geology Department and University Extension, University of Western Australia, Publication 11, 109–135; Williams & Whitaker 1993: Ore Geology Reviews, 8, 141–162; Passchier 1994: Precambrian Research, 68, 43–64). Hammond & Nisbet (1992: op. cit.) and Williams & Whitaker (1993: op. cit.) suggested north-to-south movement for the early extension, which Passchier (1994: op. cit.) suggested was multidirectional.

We suspect that synvolcanic granite doming during progressive D_1 deformation initiated both extensional shear zones along granite–greenstone contacts, and tight to isoclinal folds between the domes.

Second deformation event (D_2)

Regional ENE–WSW-directed shortening during D_2 resulted in the development of prominent NNW-trending folds, faults, and greenstone belts. Regional D_2 folds have wavelengths of 5 to 30 km and are accompanied by penetrative upright axial-planar foliations (S_2). The deformation intensity is heterogeneous because of rock type differences and deformation partitioning. Overprinting relationships between D_2 structures and D_1 and D_3 structures are locally preserved. For example, near the north shore of Lake Miranda at the southeastern end of an elongate island 3 km south of Bellevue gold mine (5), pillows in metabasalt are markedly flattened and aligned north-northeasterly (parallel to S_1). The flattened pillows are transected by a prominent N-trending near-vertical cleavage (S_2) overprinted by D_3 upright folds and S_3 spaced axial-planar crenulation cleavage trending about 330°.

Owing to their style, scale, orientation, and association with granite emplacement, regional D_2 folds and associated S_2 axial-planar foliations can be correlated across the entire northern Eastern Goldfields and with similar structures in the southern Eastern Goldfields. Both provide references for the identification of earlier and later structures where overprinting relationships are preserved. It is not known, however, if D1 structures (and similarly for D3 structures) developed contemporaneously in different areas.

Some D_2 faults and shear zones show evidence of reverse movement. For example, the D_2 Waroonga shear zones (the West Waroonga Shear Zone, Waroonga Shear Zone, and possibly another shear zone between them), up to 5 km wide and more than 100 km long, have an arcuate geometry convex to the east, and coincide with a gravity high (extending east–west across them from greenstone to foliated granitoid) that apparently reflects abundant greenstone below the granitoid. Together, these observations suggest that the shear zones dip to the west. In addition, the West Waroonga Shear Zone is associated with foliations that imply sinistral movement along its northern arm but dextral movement along its southern arm, and dextral movement has been reported along the Waroonga Shear Zone (Platt et al. 1978: op. cit.), which parallels the southern arm of the West Waroonga Shear Zone. These opposing senses of movement indicate eastward differential thrusting. Further, we have interpreted thrust duplexes suggesting westward thrusting along the Eleven Mile Fault (6). The opposing senses of movement along the Waroonga Shear Zone and Eleven Mile Fault probably reflect E–W-directed compression during D_2.

Reverse movement on D_2 faults generated elongate compressional basins in which the polymictic Jones Creek Conglomerate (7) and Yilgangi Conglomerate (8) were deposited. These conglomerates were deformed in late D_2, and evince the regional S_2 foliation.

Third deformation event (D_3)

E–W-directed transpression during D_3 resulted in the development of regional N- to NE-trending folds, faults, and shear zones. Some N- to NE-trending structures were initiated in D_3, but others may be reoriented earlier structures. The N- to NE-trending structures developed in D_3 are developed mainly in local compressional areas:

- within newly recognised antidilational jogs defined by NNW-trending sinistral strike-slip faults or lineaments (Chen in press: GSWA Annual Review 1997–98), and
- in wedge-shaped areas defined by N- to NNE-trending and NNW-trending regional faults.

Overprinting relationships between D_3 and earlier structures are locally observed.

The NNE-trending Ockerburry Fault links the zones transected by the NNW-trending Ninnis Fault and Perseverance Fault–Mount George Shear Zone. Several NNE-trending folds with wavelengths of 0.5 to 1 km along the Ockerburry Fault probably developed

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during D_3. The sigmoidal geometry of the Koonoonooka monzogranite east of the Perseverance Fault might have been finally shaped by the D_3 transpressional deformation.

Between the NNE-trending sector of the Mount George Shear Zone and the NW-trending Melita Fault, three major open folds trending NNE to ENE are interpreted as D_3 structures (Witt 1994: op. cit.) due to local compression induced by dextral movement along the Mount George Shear Zone and sinistral movement along the Kilkenny and Melita Faults.

In the Kilkenny area, two macroscopic synclines (Rio Tinto (2) and Kilkenny (3)) with wavelengths of 3 to 10 km plunge gently to moderately to the SSW, and are bounded by NNE-trending reverse faults dipping to the east. Chen (in press: op. cit.) interprets them as D_3 structures or earlier structures reoriented by D_3 local compression induced by sinistral strike-slip movement along the Kilkenny Fault. Stewart (pp. 4–5, this issue) suggests that they are D_1 folds because an S_2 schistosity cuts the Kilkenny Syncline (3) almost at right-angles.

Fourth deformation event (D_4)

D_4 structures are dominated by E-trending normal faults and fractures. Some of the faults displace NNW- to NNE-trending D_2 and D_3 structures, greenstone belts, and gold-bearing veins. Some are filled with mafic/ultramafic dykes of probable Proterozoic age. Kink folds and subhorizontal crenulations, observed in many locations, postdate D_3, but their relationship with the D_4 faults is not clear.

Table 2. Major features of regional deformation events

D_4	East-trending normal faults and fractures
D_3	Regional E–W-directed transpression resulted in N-, NNE- to NE-trending folds, faults, and shear zones mainly within local compressional areas defined by NNW-trending sinistral strike-slip regional faults, and dextral movement along some N- to NNE-trending faults
D_2	Regional ENE-WSW-directed compression produced dominant NNW-trending folds, widespread axial-planar foliation, and regional-scale reverse faults associated with deposition of polymictic conglomerates in compressional basins, and emplacement of granitoids
D_1	Tight to isoclinal folds, bedding subparallel foliations and faults, commonly recognised at high angles to regional D_2 NNW-trending structures. Intrusion of granitoids comagmatic to late-stages of felsic volcanism

Comments on the timing of lode-gold mineralisation

Most lode-gold deposits in the Yilgarn Craton are structurally controlled and related to metamorphic and/or felsic magmatic fluids. The currently popular continuum model (Groves 1993: Mineralium Deposita, 28, 366–374) places the formation of most lode-gold deposits late in the tectonothermal history at 2640–2630 Ma. However, Witt (1997: in AGSO Record 1997/41, 151–156) presented evidence for gold mineralisation other than that readily explained by the continuum model. Indeed, each of the D_1–D_3 events could have favoured gold mineralisation.

Both heat and fluids for gold mineralisation would have been available when the pre- to syn-D_1 granites and their comagmatic felsic volcanics were emplaced. The recently discovered gold deposit at Kanowna Belle, near Kalgoorlie, apparently reflects porphyry-related mineralisation (Ren & Heithersay 1997: Proceedings of the 9th IAGOD Symposium, Beijing, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1–16); perhaps more are yet to be discovered. Williams et al. (1989: Australian Journal of Earth Sciences, 36, 383–403) suggested that gold mineralisation in the Leonora area was associated with D_1, and so did Harris et al. (1997: Australian Journal of Earth Sciences, 44, 503–508) in the Duketon area.

Granite emplacement during D_2 would have generated high temperatures, and fluids aplenty for the intensive regional ENE–WSW-directed shortening to mobilise. Similarly, the regional E–W-directed D_3 transpression should have been a favourable force for mineralisation.

Some mineralised veins evidently predate the cessation of tectonism because they are deformed — e.g., in the Bronzewing area (Phillips et al. 1998: in D.A. Berkman & D.H. Mackenzie (Eds.), 'Geology of Australian and Papua New Guinean mineral deposits', Australasian Institute of Mining & Metallurgy, Melbourne, 127–136; F. Robert, Geological Survey of Canada, personal communication 1997). Recent work suggests that lode-gold mineralisation at Jundee and Mount McClure occurred before 2656 ± 7 and 2663 ± 4 Ma respectively (Yeats & McNaughton 1997: in AGSO Record 1997/41, 125–130), probably pre- to syn-D_2. Most recently, Bateman et al. (1998: Geological Society of Australia, Abstracts, 49, 25) suggested that gold lodes at the Golden Mile in Kalgoorlie were formed during D_3 transpression, and that the mineralising event possibly began during D_2, rather than previously thought — late in the structural history (~2630 Ma). Perhaps more gold deposits diverse in style and timing, particularly those related to magmatism and to the early structural and metamorphic history, are yet to be identified/discovered.

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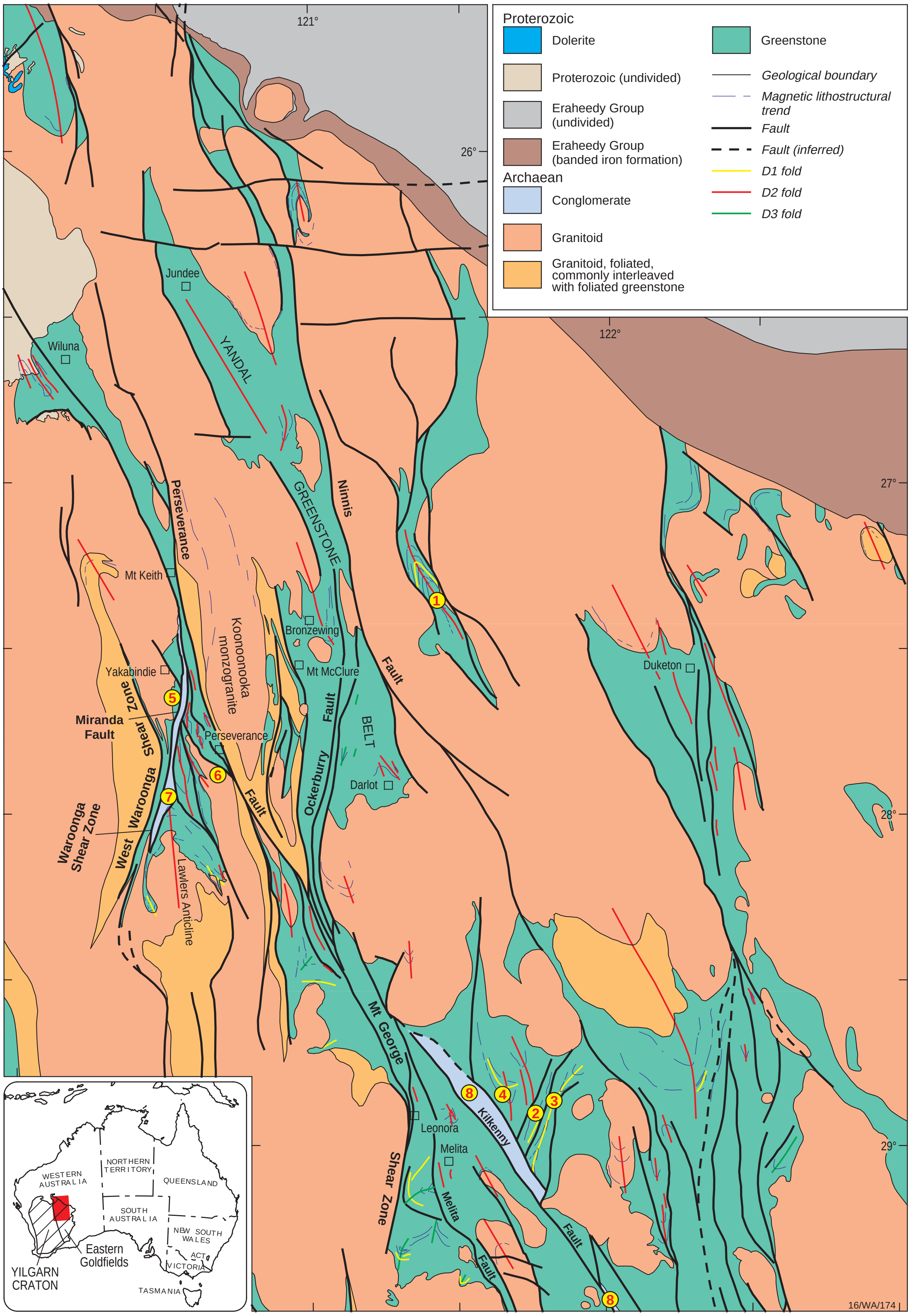
Fig. 24 *(facing page)*. Structural framework of the northeastern Yilgarn Craton compiled from published 1:100 000 and 1:250 000 geological maps and interpretations of aeromagnetic and gravity data. Note that a fold's assignment to D1–D3 relates to the deformation event that initiated it (as interpreted by us or compiled from published work cited in the text), and that some early folds may have been reshaped by subsequent deformation.


Proterozoic
Dolerite
Proterozoic (undivided)
Eraheedy Group (undivided)
Eraheedy Group (banded iron formation)
Archaean
Conglomerate
Granitoid
Granitoid, foliated, commonly interleaved with foliated greenstone
Greenstone
Geological boundary
Magnetic lithostructural trend
Fault
Fault (inferred)
D1 fold
D2 fold
D3 fold
121°
122°
26°
27°
28°
29°
Jundee
Wiluna
YANDAL
GREENSTONE
BELT
Ninnis
Fault
Perseverance
Mt Keith
Koonoonooka monzogranite
Bronzewing
Mt McClure
Yakabindie
Miranda Fault
Shear Zone
Perseverance
Ockerburry Fault
Darlot
West Waroonga
Waroonga Shear Zone
Lawlers Anticline
Duketon
Mt George
Shear Zone
Leonora
Melita
Kilkenny
Fault
Melita Fault
1
2
3
4
5
6
7
8
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
ACT
VICTORIA
TASMANIA
Eastern Goldfields
YILGARN CRATON
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