The tectonic framework and geological evolution of the Archaean Pilbara granite-greenstone terrane: integration of geology and geophysics

R.S. Blewett

Australian Geological Survey Organisation
GPO Box 378
Canberra, ACT, 2601, Australia
Richard.Blewett@agso.gov.au

The Pilbara granite-greenstone terrane (GGT), a classic Archaean province, is located in the northwest of Western Australia. It has been the focus of numerous studies on the tectonics of early Earth, and its characteristic dome and basin geometry has been cited as a good example of different tectonic processes in the Archaean (e.g, vertical tectonics or diapirism). Regional geophysical datasets (e.g., gravity, magnetics, seismic refraction) when integrated with geology provide additional constraints on the tectonic evolution of the Pilbara GGT. Repeated shortening events, largely partitioned into greenstone belts between competent granite batholiths, resulted in fold inference patterns and the development of the characteristic dome and basin geometry of the Pilbara GGT. Limited vertical accommodation of granites in the crust may have further enhanced this geometry.

Geological Framework

Recent geological studies, supported by new geochronology, have divided the Pilbara GGT into three domains; the east, west, and central Pilbara GGTs (Hickman 1999). The regional geophysical data broadly support these subdivisions, and also map their boundaries under cover.

The Pilbara GGT is characterised by an ovoid pattern of composite granitoid batholiths up to 120 km in diameter (ave. ~75 km) that are encircled by composite greenstone belts. The batholiths were constructed by successive magmatic events from 3.65 Ga to 2.85 Ga, many of which were associated with coeval volcanism and sedimentation within the enveloping greenstone belts (3.5 Ga to 2.9 Ga). The encircling greenstones are made up of a succession of packages that are separated in time by regional angular unconformities. Most of the greenstone packages were deposited in an extensional setting, after a previous shortening event (Blewett 2000). This cyclic nature of shortening followed by extension, magmatism, and volcanism, may be analogous to 'orogenic' collapse.

Geophysical constraints

Much of our knowledge of the Pilbara GGT is obtained from the exposed parts, mostly in the north (North Pilbara region). This relatively small area constitutes only 25% of the 600 km by 550 km aerial extent of the Pilbara GGT, and provides a biased view of the geology and possible tectonic evolution. This outcrop data is complemented by regional geophysical datasets, which provide additional parameters (e.g. depth constraints and under cover information), not readily appreciated by views of the exposed parts alone.

On a continental scale, the Pilbara GGT corresponds with a regional gravity low (reflecting extensive granitoids in the upper crust), with gravity highs parallel to the reworked margins. Geophysical data show that the reworking extends up to 50 km inwards from the defined outer edge of the Pilbara GGT.

Regional geophysical data show that the characteristic ovoid pattern, typified by the east Pilbara outcrop geology, extends across the entire Pilbara GGT under late Archaean and younger cover rocks. This pattern is complicated by the (younger) western and central parts of the North Pilbara region (exposed GGT), which have an elongate geometry. This elongate geometry, however, passes into typical ovoid geometries along strike and under cover to the south and southwest, reflecting east Pilbara-type basement and the thin nature of the younger parts of the GGT.

The geophysical data also show that the ovoid granitoid-greenstone contacts are mostly steep, extending to the mid crust at ~14 km (Wellman 2000), making the greenstones some of the deepest known in the world. In 3D, the batholiths are disc shaped with an average vertical over horizontal ratio of 0.2.

Many of the steeply dipping greenstone belts of the east Pilbara GGT contain a highly magnetic banded iron-formation (BIF) marker unit, the 3240 Ma Gorge Creek Group (Hickman 1983), which envelopes the batholiths. The magnetic properties of this marker unit permit mapping the ovoid geometry under cover to the northern and eastern margins of the Pilbara GGT (Wellman 2000). This magnetic marker unit also provides constraints on the timing and possible mechanism of formation of the dome and basin geometry. A maximum age limit of 3240 Ma must exist on the development of much of the ovoid geometry, as defined by the marker unit. This timing constrains deformation processes. This is because there was little magmatism at, or after this time, in the batholiths around these BIF-bearing greenstone belts (except for small amounts in the Yule and Muccan Batholiths). The implications are that the 'doming' process(es) could not have been a function of active magma emplacement (diapirism) as suggested by Collins et al. (1998), and certainly not at ca 3325 Ma when much of the east Pilbara GGT granites were emplaced.

The fact that these magnetic marker units are mostly undeflected around, and between, the ovoid batholiths indicates that much of the Pilbara GGT is not dissected by post 3240 Ma strike-slip faults of any significance. Krapez (1993) defined a number of domains with domain-bounding strike-slip faults through the east Pilbara GGT. These faults (the Mulgandinnah and Lionel Faults) do not offset the 3240 Ma marker unit, and therefore, if significant, have movements older than this time.

In the west and central Pilbara GGTs, two domain-bounding faults are mapped (the Sholl and Wallaringa Shear Zones-also defined by Krapez 1993 as important). These faults record a complex multiple strike-slip and dip-slip kinematic history, and they partly define the extent of the central Pilbara GGT. These faults, and the central Pilbara GGT are likely to be relatively shallow, and are probably underlain by older (thinned?) east Pilbara GGT crust with the characteristic ovoid geometry.

The regional gravity data show that there is little mass loss due to buried granites under the main greenstone 'domes' (McPhee and North Pole). This suggests that 'doming' processes are unlikely to be due to buried granitoid diapirs. The geophysical data also provide constraints on the <3.0 Ga basins (Mallina and Mosquito Creek). Both are arcuate in shape and may be no more than 5 km thick.

Structure

Recent work by Blewett (2000, in press) documented episodic shortening events within all regions of the Pilbara GGT. As already demonstrated, the dome-and-basin geometry, characteristic of the east Pilbara GGT, was established after 3240 Ma. Blewett (in press) recognised a number of regional (subhorizontal) shortening events across the Pilbara GGT after this time. The result has been a locally complex development of polyphase structural elements with consistent overprinting relationships that can be correlated across much of the Pilbara from 3.2 Ga. Repeated orthogonal shortening resulted in fold interference patterns that enhanced the dome and basin geometry. Basins (greenstone packages) repeatedly formed during extension and strike-slip deformation, mostly following a proceeding shortening event. This process may be analogous to 'orogenic' collapse. The intensity of compressive deformation appears to have not been sufficient enough to destroy the ovoid geometry, rather it probably amplified the geometry due to fold interference. Strain was also partitioned into the greenstone belts, and did not significantly modify the competent deep-seated batholiths.

Density contrasts from granite-greenstone juxtaposition may have created gravitational instability, which was likely to have been relieved by limited vertical rise of some batholiths. This vertical force may have attenuated the fold limbs and interference patterns developed during successive shortening events in the narrow intervening greenstone synforms, further enhancing the dome and basin geometry.

Conclusions

Regional geophysical datasets provide 4D constraints on the geological evolution of the crust, and are therefore essential information for any meaningful geological analysis. In the Pilbara GGT, they provide tools to understand the construction of the ovoid geometry, the aerial and depth extents of this geometry, the timing of formation of this geometry, subdivisions of the GGT and, the nature of the domains and their bounding surfaces. Integrate these observations with structural and stratigraphic mapping supported by modern geochronology, and we begin to more fully understand the processes that operated in early Earth's evolution.

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