Granitoid complexes and greenstone belts in the Pilbara Craton interpreted to extend down to the mid-crustal boundary at 14 km

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The depth extent of outcropping major basement features, an important parameter for many geological applications (e.g., modelling mineral systems), is unknown for most areas in Australia. Whereas reflection seismic images show that granites and detachments have moderately shallow bases (5–10 km) in some areas, geophysical evidence demonstrates that basement structures in the north Pilbara Craton extend to the base of the upper crust (14 km deep), and that the boundaries of the granitoid complexes are close to vertical.

The Pilbara Craton occupies an area (~650 × 500 km) of Archaean rocks in the northern part of Western Australia. It is older (~3500–2800 Ma) than other areas of Australian crust, from which it differs structurally in consisting of mainly (60%) domal granitoid complexes 50–100 km diameter separated by synformal greenstone belts. The granitoid complexes have been formed by multiple intrusions over a long period, and parts are intensely deformed. The greenstone belts include a variety of sedimentary and intrusive rocks and felsic, mafic, and ultramafic lavas, and commonly reflect only greenschist metamorphic grade. This basement is in places overlain by Late Archaean and Permian–Tertiary cover rocks, but it forms extensive, largely unweathered outcrops in the north Pilbara Craton.

As a contribution to the joint AGSO–GSWA (Geological Survey of Western Australia) 'North Pilbara' project for the National Geoscience Mapping Accord, I have computed the depth extent of this basement from seismic refraction data, and gravity and magnetic anomalies (Wellman 1999: AGSO Record 1999/4).

Pilbara crustal modelling

According to Drummond (1983: BMR Journal of Australian Geology & Geophysics, 8, 35–51), seismic refraction data represent the Pilbara Craton as a two-layer crust in which the velocity increases gradually in the upper and lower parts and more sharply between them (Fig. 14). The crust thickens slightly to the south. The mid-crustal boundary averages ~14 km depth; and the base of the crust, ~30 km.

Granite–greenstone contacts have been geologically mapped in outcrop areas, and geophysically mapped (using short- and medium-wavelength magnetic anomalies) in subcrop areas. This contact is commonly irregular in plan at the outcrop/subcrop surface, and is likely to be equally irregular at deeper levels. The steepest gradient (inflection) of the gravity anomalies gives a smoothed estimate of the position of the granite margin about halfway down the side of the granite bodies (Fig. 15). This gradient generally follows the average position of the mapped contact, so for most granites the margin slope averages near vertical.

The relative thicknesses of the granites can be determined from the residual gravity anomalies. The residual amplitudes of gravity lows over the granites are consistent for about two-thirds of the granites, which have a similar depth; the remainder are 80–50 per cent shallower.

The approximate thickness of the granitoid complexes and greenstone belts can be determined by 3D modelling the gravity gradient between them. A vertical boundary to 14 km depth between granitoid complex, represented by a prism, and greenstone belt produces a gravity anomaly consistent with the observed grid to within the accuracy of the 5-km-spaced observations. An example of this is shown in Figure 15.

In theory the depth to the base of the granite–greenstone layer can be calculated from the mean gravity difference and the mean density difference. However, both the mean density of the greenstone belts at the surface, and the change in the density difference with depth, are poorly known.

Very large, long-wavelength magnetic anomalies occur intermittently over the greenstones (Fig. 16). With an amplitude of 1000–3600 nT, width at half-amplitude of ~9 km, and strike length of 10–30 km, they are some of the largest in Australia. The mean depth to the top of these bodies is 1.5 km in the west and 2 km in the east. Modelling shows that the widths of causative bodies cannot be narrow, but must be similar to the anomaly widths at one-half amplitude — generally about 9 km. The shapes of the tails of the anomalies are consistent with depths to the bases of bodies of 14 km (Fig. 17). The amplitudes of observed anomalies are consistent with an average apparent susceptibility that falls within the range of 0.05–0.2 SI units in the anomalous bodies. The only likely rock type fitting this profile in the Pilbara Craton is banded iron formation, whose bedding-parallel susceptibility is typically 0.5–2.0 (SI), ratio of remanent to induced magnetisation is typically 1–2, and susceptibility and remanence are both close to the plane of bedding owing to geometrical effects. Averaging the above susceptibility ranges (for the observed anomalies and bedding-parallel banded iron formation) implies that banded iron formation constitutes ~4 per cent of the volume of the greenstones.

Conclusion and implications of the Pilbara upper crustal model

Gravity and magnetic data for the Pilbara Craton are consistent with the structures of the Early Archaean basement extending down near-vertically, from the surface, to the base of the upper crust ~14 km deep.

This upper crustal model (Fig. 14) is an important constraint on models of geological evolution and mineral systems because it:

- defines the present shape of the geological elements (though it does not discriminate the mode of emplacement of the granitoid complexes);
- shows that any low-angle detachment must be at the base of the upper crust or deeper (cf. Yilgarn Craton interpretations; Swager et al. 1997: Precambrian Research, 83, 43–56);
- shows that gravity and magnetic data can in certain circumstances reveal important information about the significance of the mid-crustal boundary;
- defines the depth extent of surface rocks, an important parameter for delimiting the volume of rock of various types that can be scavenged for metals by solution; and
- indicates that faulted margins between granites and greenstones extend to great depths, facilitating plumbing and fluid flow.

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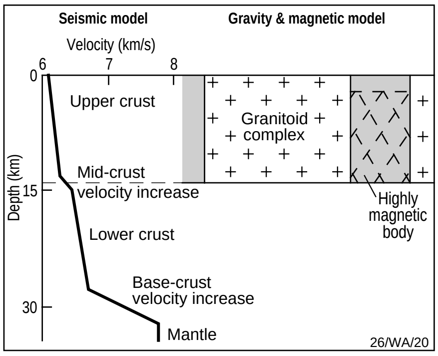

Fig. 14. Comparisons between the seismic refraction model and the gravity and magnetic model for the crust of the Pilbara Craton.

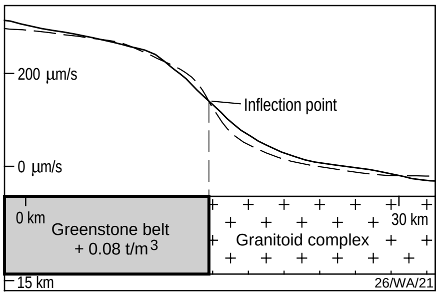

Fig. 15. An example of modelling the gravity gradient between a granitoid complex and greenstone belt (computed at lat. 21.4°S, long. 117.1°E). Observed profile, continuous line; modelled profile, dashed line.

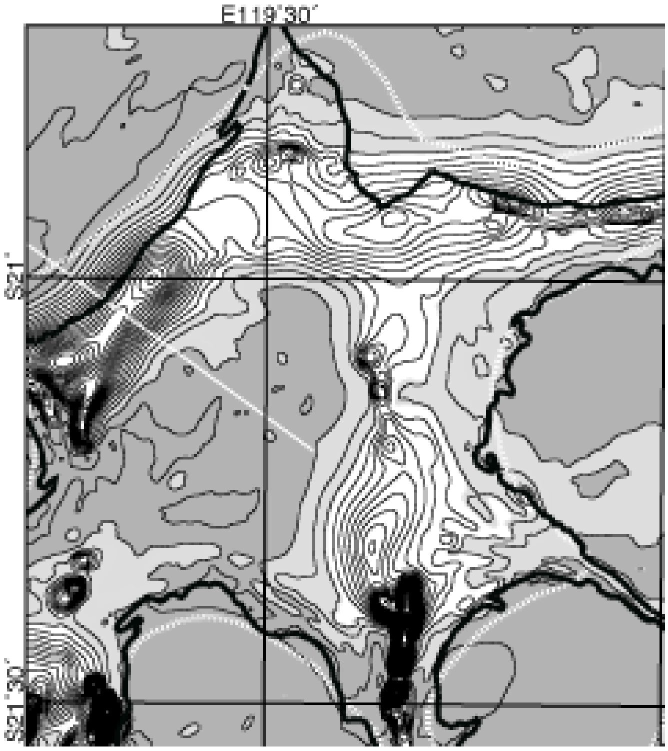

Fig. 16. Large magnetic anomalies expressed by greenstones in a 115 x 105-km area of the Pilbara Craton. Contours (at 250-nT intervals) show magnetic anomalies reduced to the pole on the assumption that the magnetic inclination is close to the near-vertical dip of the greenstones (i.e., 80°). Thick black lines trace the outcrop/subcrop contact between granitoid complexes and a greenstone belt. The white dotted line represents the steepest gravity gradient, showing the smoothed position of the margin of the granites at depth. The northwesterly oriented straight line in the west marks the position of the magnetic profile in Figure 17.

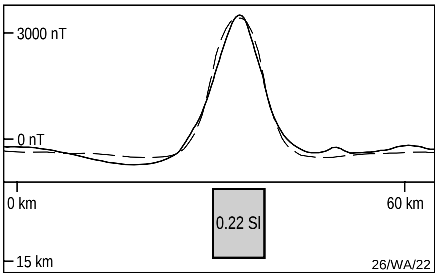

Fig. 17. An example of modelling the large magnetic anomaly over the greenstone belt in Figure 16 (q.v. for location of profile). Observed profile, continuous line; modelled profile, dashed line.