The tectonic history of the Waigen area, western Officer Basin, interpreted from geophysical data

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Abstract

A new filtering technique, using the wavelet transform to downward-continue magnetic data onto a variable surface, was used to enhance the data over the under-explored Waigen area of the western Officer Basin. The enhanced data show that the underlying basement is predominantly Mesoproterozoic Albany–Fraser Orogen extending to the northeast, where it is truncated by the Mesoproterozoic Musgrave Complex. Deep-seated, elliptical magnetic features are possible mantle material emplaced during a rifting event, or deep magma chambers related to an underplating event associated with a large mantle plume. These intrusions are likely to be related to either c. 1075 Ma or c. 510 Ma events.

KEYWORDS: geological interpretation, magnetic data, gravity data, Officer Basin, Albany–Fraser Orogen.

Introduction

The Waigen area is centred on COOPER, WAIGEN, and WANNA* in the eastern part of the western Officer Basin, Western Australia (Fig. 1), and appears to be continuous with the Birksgate Sub-basin in the eastern Officer Basin, South Australia. Gravity modelling shows there is a sedimentary section up to 11 km thick in the Waigen area (D'Ercole et al., in prep.), representing a Neoproterozoic – Lower Cambrian depocentre and possible underlying Mesoproterozoic basin (Apak and Tyler, 2002), covered in part by a thin Phanerozoic succession. Depth-to-basement calculations from isostatic residual gravity data show that basement generally shallows abruptly towards the north (Musgrave Complex) and west (Yilgarn Craton), although the thickness of the sedimentary section in the Cooper Graben, a northerly trending trough near the margin of the Musgrave Complex, is estimated to be up to 10 km (D'Ercole et al., in prep.).

Although there has been sporadic exploration in the Officer Basin since the 1950s, there is only one seismic line and one deep stratigraphic drillhole, Vines 1, in the Waigen area, and the ?Lower Cambrian section in this drillhole may be unrepresentative. BMR Wanna 1, the only other stratigraphic hole in the area, was completed in the Upper Carboniferous – Lower Permian Paterson Formation. There are several shallow mineral coreholes in the area, some of which have been useful for constraining gravity modelling. The closest petroleum exploration wells are Lennis 1, over 200 km to the west in the adjacent Lennis area, and Birksgate 1, 206 km to the east in the Birksgate Sub-basin. Regional potential-field data acquired in the early 1970s, and semi-regional gravity data acquired in 1998, are the only publicly available geophysical datasets covering the area.

* Capitalized names refer to standard 1:250 000 map sheets

Regional setting and stratigraphy

The Waigen area is flanked by four main areas of crystalline basement: the Mesoproterozoic Musgrave Complex, the Archaean Yilgarn Craton, and the Mesoproterozoic Albany–Fraser Orogen in Western Australia, and the Archaean–Mesoproterozoic Coompana Block in South Australia. The Musgrave Complex consists of igneous rocks (volcanic rocks, granites, and layered mafic–ultramafic intrusions) emplaced into granulite- and amphibolite-facies Mesoproterozoic orthogneisses and paragneisses, which may be migmatitic (Myers, 1990b; Glikson et al., 1996). The Albany–Fraser Orogen, which is longitudinally divided into the Biranup and Nornalup Complexes (Myers, 1990a), comprises stacked thrust sheets of metasedimentary rocks, orthogneiss, and granite, and includes mafic–ultramafic intrusions and remnants of basaltic dykes (Myers, 1990a; Fitzsimons, 2003). The Coompana Block comprises

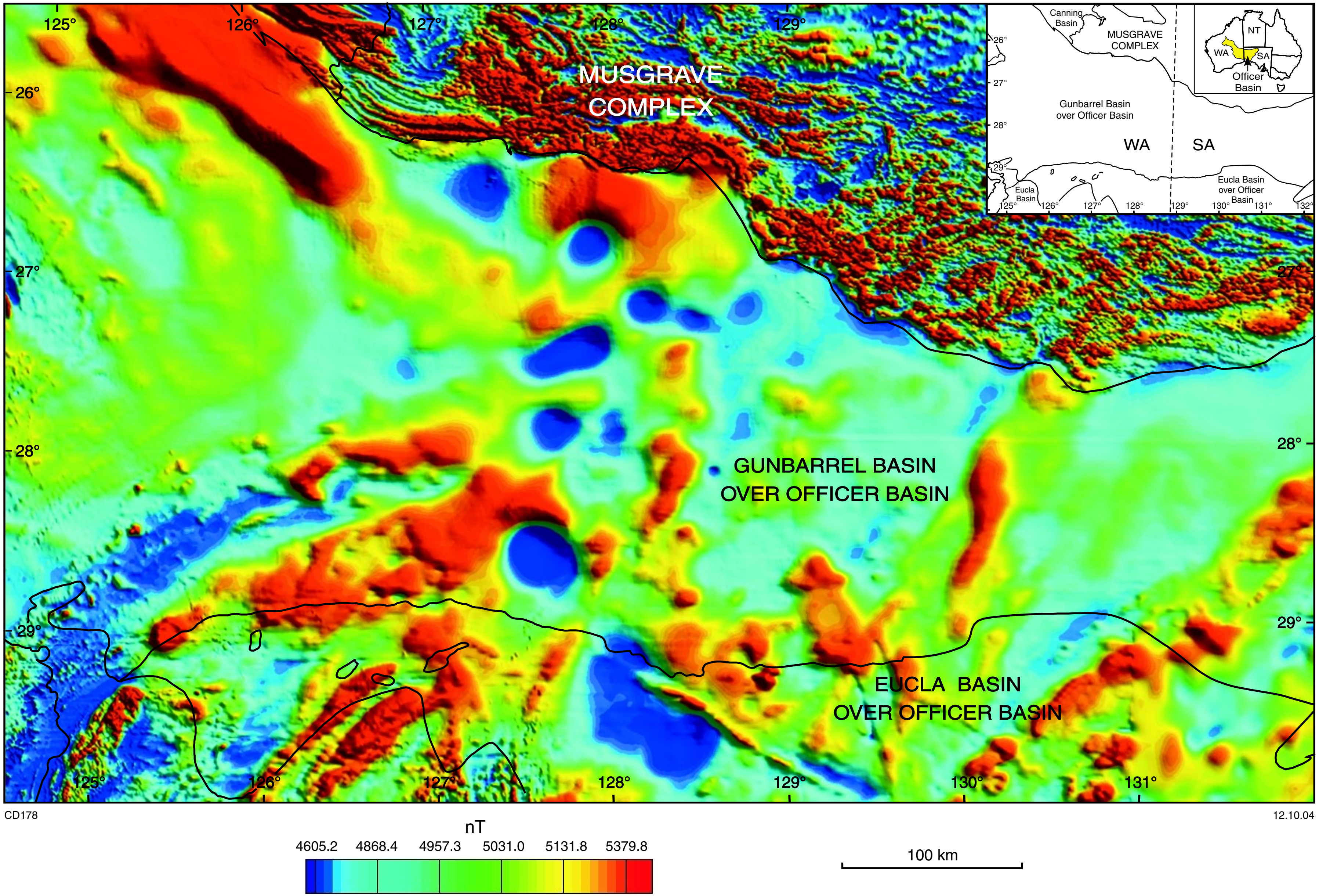

Figure 1. Total magnetic intensity, reduced to pole, of the Waigen area and surrounds. The location of the Waigen area and adjacent eastern Officer Basin are shown in the inset

Archaean to Mesoproterozoic gneiss and granite intruded by dolerite–gabbro plugs and dykes (Flint and Daly, 1993).

The stratigraphy of the western Officer Basin has been reviewed by Apak and Moors (2000) and Grey et al. (in prep.). Only the lower part of Neoproterozoic Supersequence 1 outcrops within the Waigen area. Isolated sandstone outcrops within the area may be the upper part of Supersequence 1, but cannot be assigned unequivocally. Neoproterozoic – Lower Cambrian Supersequence 4 strata are present in Vines 1, and there are outcrops of Supersequence 4 and Supersequence 3 strata in the area. Outcropping rocks of the overlying Gunbarrel Basin include Palaeozoic volcanic and sedimentary rocks.

Potential-field data

Conventional filtering of total magnetic intensity (TMI) images, such as the first vertical derivative of reduced-to-pole images, are useful for enhancing magnetic anomalies associated with shallow structures, but are limited when it comes to better defining anomalies associated with deep structures. The Fourier-transform-based downward continuation filter can be a useful tool for delineating deep structures because it applies the same enhancement over all areas of a dataset. However, this filter is only effective for regions covered by a relatively constant thickness of non-magnetic sedimentary rocks, and any attempt to downward continue data using Fourier-based methods is unstable over areas of shallow basement. Over the Waigen area, the use of a Fourier-based downward-continuation filter to delineate structures in basement beneath the Officer Basin is problematic because of outcropping, highly magnetic Musgrave Complex in the north (Fig. 1).

The wavelet transform is an alternative to the Fourier transform for potential-field data processing, which can be made to vary spatially (Ridsdill-Smith and Dentith, 2000). This is the basis of a new filtering technique called variable downward continuation. A depth-to-basement model, derived from gravity data, is used to determine the optimal downward continuation distance for each datum in the TMI image. The wavelet transform is then used to vary the level of enhancement of the TMI data according to the corresponding thickness of the sedimentary section.

For this study, an isostatic correction (Simpson et al., 1983) was applied to the Bouguer gravity data to remove the effect of large-scale crustal structure consistent with the topography, although there is some evidence that the crust is not in a state of isostatic equilibrium (Haddad et al., 2001). The resulting corrected Bouguer gravity was used to estimate the depth to basement over the Waigen area. The wavelet transform was then used to simulate the magnetic field observed at 200 m above basement, producing the variably downward continued image (Fig. 2).

The variably downward continued image highlights subtle features not seen in the TMI image, particularly over the Officer Basin, where the magnetic response of basement structures is attenuated by the overlying sedimentary rocks. This new image, together with first vertical derivative images, was used to refine the tectonic subdivisions and interpret the tectonic history of this part of the Officer Basin (D'Ercole et al., in prep.).

Interpretation of geophysical data

The gravity (D'Ercole et al., in prep., fig. 9) and magnetic data highlight complex basement structures within the Waigen area. Nine domains of distinct magnetic character (Figs 2 and 3) are evident on the variably downward continued image of the Waigen and surrounding region. A detailed interpretation of the domains, their geophysical signatures, and associated tectonic history is given in D'Ercole et al. (in prep.). A similar tectonic framework of this area was included in an Australia-wide, crustal-scale study by Shaw et al. (1996), but the tectonic evolution of the region was not included in their study.

Domain 1

The complex, mainly west-northwesterly to northwesterly trending structures and narrow, well-defined, high-amplitude anomalies in domain 1 are due to lithological variations and intense deformation within the Musgrave Complex (Fig. 2). The sharp boundary of domain 1 with the Officer Basin is marked by a northerly dipping thrust fault.

Domain 2

Domain 2 consists of basement (?Musgrave Complex or possibly Palaeoproterozoic Rudall or Gascoyne Complex) below a thin cover of Officer Basin strata. The anomalies are slightly deeper and broader compared with outcropping Musgrave Complex in domain 1, but this domain displays similar northwesterly trending lineaments (Fig. 2). Some of the lineaments represented by magnetic lows appear to correlate with either salt walls or salt-related features noted in the western Officer Basin by Japan National Oil Corporation (1997) and Apak and Moors (2000, 2001); for example, the Browne Diapir in the Yowalga area corresponds to a magnetic low flanked by magnetic highs (Fig. 2). The salt has probably migrated up a corresponding structural feature to form the salt wall.

A small, triangular zone of low magnetic response lies between domains 1, 2, and 4 (Figs 2 and 3). A corresponding gravity low in this zone represents the Cooper Graben (Figs 3 and 4), which contains a sedimentary section up to 10 km thick (D'Ercole et al., in prep.). Other magnetic features within this zone indicate areas of shallow, fault-controlled Musgrave Complex basement and the presence of a deep, circular intrusive body.

Domain 3

Domain 3 represents the Yilgarn Craton, with the eastern corner covering the junction between the Yilgarn Craton, Musgrave Complex,

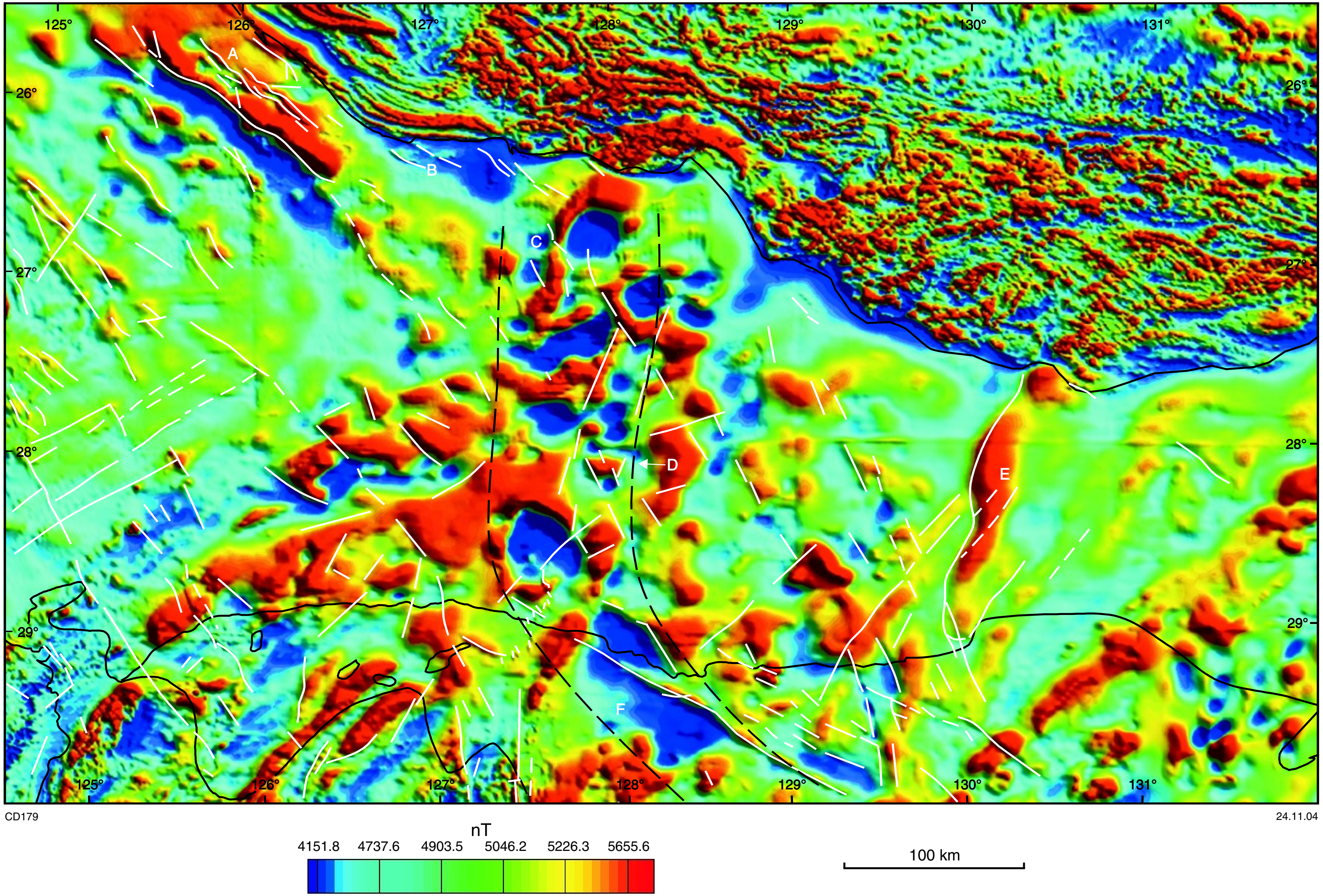

Figure 2. Variably downward-continued image of the total magnetic intensity, showing interpreted magnetic lineaments (white lines). A = Browne Diapir (low related to salt wall); B = triangular zone of low response; C = Cooper Graben; D = northerly trending feature of circular intrusive bodies; E = Nurrai Ridge; and F = circular intrusive body in domain 7

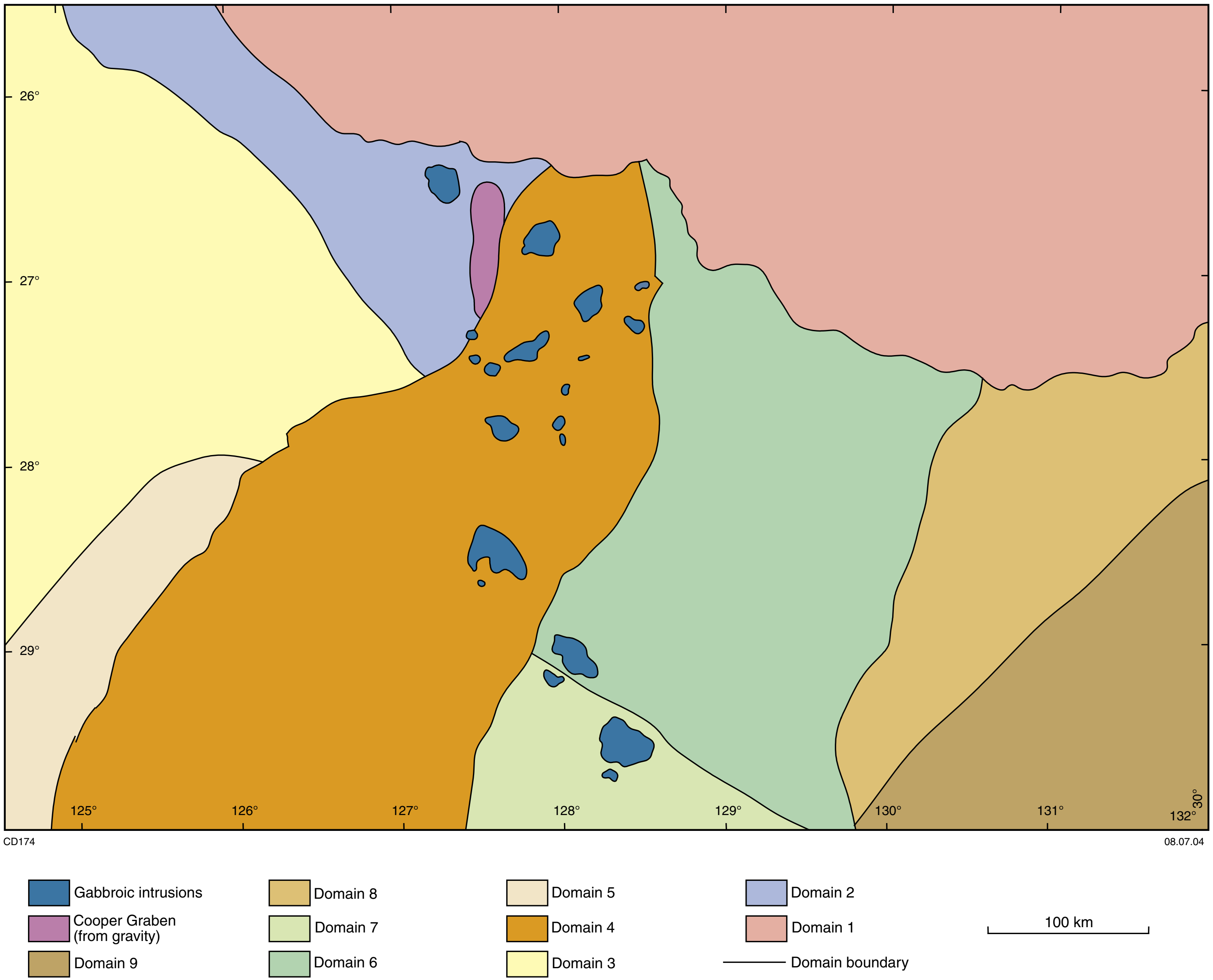

Figure 3. Synthesis domain map of the Waigen area and surrounds interpreted from geophysical (magnetic and gravity) and drillhole data

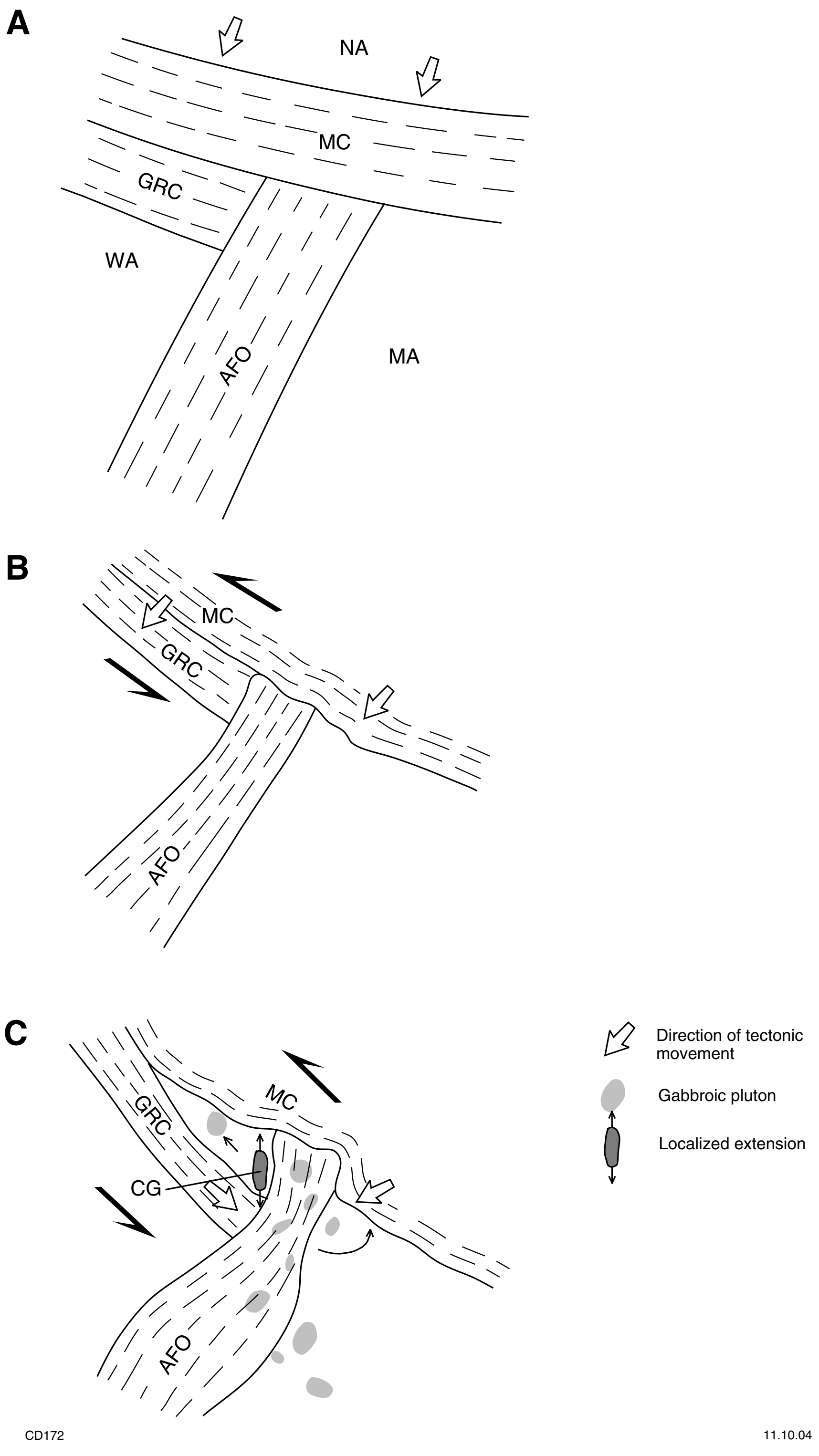

Figure 4. Schematic diagram of the Mesoproterozoic tectonic history of the Waigen area: a) formation of the Albany–Fraser Orogen (AFO) and Musgrave Complex (MC). Initiation of thrusting of MC and rotation around pre-existing Gascoyne or Rudall Complex (GRC); b) continuation of uplift and thrusting of MC, and initiation of AFO rotation and sinistral transpression of GRC; and c) completion of thrusting of MC and rotation of AFO, initiation of local extension (Cooper Graben; CG). Impact of mantle plume (~c. 1075 Ma) and emplacement of mafic–ultramafic intrusions. WA = West Australian Craton, MA = Mawson Craton, and NA = North Australian Craton

and Albany–Fraser Orogen. The domain is characterized by subdued, narrow, northwesterly trending magnetic anomalies truncated or displaced by minor northeasterly trending lineaments (Fig. 2). Some of these anomalies roughly coincide with northwesterly trending salt-related features noted by Apak and Moors (2000, 2001) in the northwestern portion of the area, near the boundary between domains 2 and 3. These anomalies may represent structures related to salt migration.

Drillhole and seismic data confirm that depth to basement is very shallow to the west of this area (~40–100 m), and seismic and gravity data show that this depth increases to the east (~2–5 km; D'Ercole et al., in prep.), consistent with the thickening of the Officer Basin (Apak and Moors, 2000) and a ?Mesoproterozoic basin (Apak and Tyler, 2002) towards the Musgrave Complex. Thus some of the underlying anomalies may represent crystalline basement within the Yilgarn Craton.

Domain 4

Domain 4 has the most complex magnetic pattern within the region, and apart from a few northerly trending major crustal lineaments, it has no dominant structural trend (Fig. 3). The lineaments range in orientation from northwest to northeast (Fig. 2). The area contains broad, high-amplitude anomalies and low-amplitude circular features, ranging from 2 to 21 km in diameter, with sharp, curvilinear, discordant contact zones (Figs 2 and 3). Magnetic modelling indicates depths of between 8 and 19 km for some of these circular magnetic sources, implying that they are mid-crustal features (D'Ercole et al., in prep.). Typically the presence of large intrusive bodies within the crust is expected to influence sedimentary thickness estimates derived from the gravity data, due to a density contrast between crystalline basement and the deep intrusive bodies (Lockwood and D'Ercole, 2003). However, the depth-to-basement model (D'Ercole et al., in prep., fig. 12) shows no strong perturbations above the modelled sources of these anomalies, suggesting little or no density contrast between the lower crust and these intrusions. Magnetic modelling (D'Ercole et al., in prep., fig. 15) suggests the intrusions are reversely remanently magnetized, with the induced field cancelled by the remanent field (Konigsberger ratio of about 1), and are interpreted here as magma chambers, possibly of mafic–ultramafic composition. These intrusions all possess the same polarity, indicating virtually simultaneous emplacement and rapid crystallization during a period when the Earth's magnetic field was reversed relative to the present field.

These circular anomalies form a broad, northerly trending feature (Fig. 2) that seems to coincide with a set of northerly trending lineaments, which collectively form part of a regional crustal-scale feature termed the Lasseter Shear Zone (Braun et al., 1991), the southern extension of which may correlate with the Mundrabilla Fault (Myers and Hocking, 1998). At the southern end of the domain, this feature bends around to the southeast, seemingly lining up with similar anomalies in the Coompana Block, South Australia, that are sourced from shallower mafic intrusives (Flint and Daly, 1993).

The magnetic data clearly show that the Albany–Fraser Orogen extends farther east than previously implied by Hocking (1994; Neale Arch). It swings around to the northeast within the Waigen area, is truncated by lineaments that relate to the Lasseter Shear Zone on its eastern side, and continues northwards to the Musgrave Complex (Fig. 2). The majority of magnetic highs within domain 4 probably correspond to mafic–ultramafic rocks and mafic granulites of the Fraser Complex (part of the Biranup Complex). Outcropping Fraser Complex rocks southeast of domain 4 appear to be continuous with gravity and magnetic anomalies farther northwest.

Domain 5

Domain 5 covers outcropping and subcropping granitic rocks, gneisses, and minor sedimentary rocks of the Biranup Complex within the Albany–Fraser Orogen. This domain is characterized by low magnetic relief compared to the high-amplitude anomalies of the adjacent mafic–ultramafic rocks of the Fraser Complex in domain 4. The change in magnetic character defines the boundary between these two domains. An arcuate belt of high-amplitude magnetic anomalies on the northwestern edge of domain 5 forms the boundary with domain 3 (Fig. 2). Mineral exploration holes drilled on these anomalies intersected metagabbros and norites (Perincek, 1998, appendix 3).

Domain 6

Domain 6 is characterized by smooth magnetic anomalies, indicating deep sources (Fig. 2). The sedimentary section in domain 6 deepens to the north, ranging from about 5 to 11 km, and onlaps the Coompana Block to the south and Gawler Craton to the east. Magnetic and gravity lineaments in this domain are predominantly northwesterly to north-northwesterly trending. North-northeasterly trending magnetic highs, such as the Nurrai Ridge (Fig. 2), mark the boundary between domains 6 and 8. Rankin (2003) interpreted these ridges as folded belts of mafic intrusives.

Domain 7

Magnetically low, circular to elliptical features in domain 7 (Figs 2 and 3) are similar to those within domain 4 and farther south in the Coompana Block. Several holes targeting these circular anomalies in the Coompana Block intersected mafic–ultramafic intrusions, specifically gabbro and dolerite (Flint and Daly, 1993). The intrusive bodies within the Albany–Fraser Orogen in domain 4 may be compositionally similar and part of the same suite of intrusions, but are at considerably greater depths (8–19 km from modelling in domain 4 compared with ~300 m in the Coompana Block).

Domain 8

Domain 8 is magnetically 'quiet', with only minor anomalies, and represents the thickest part of the Officer Basin. The thickness of the sedimentary section increases dramatically towards the northeast (6–11 km) into the Munyarai Trough. The boundary between domains 8 and 9 is marked by a major northeasterly trending magnetic feature, which could be a major thrust fault (Fig. 2).

Domain 9

Domain 9 contains high-amplitude, elliptical anomalies that correlate with granitoids of the Hughes Subdomain (Rankin, 2003) and Gawler Craton (Fig. 2). This area is covered by a veneer of sedimentary rocks. The coincident gravity high indicates higher density lithologies than in surrounding domains.

Synthesis of geophysical and geological data

The basement beneath the Officer Basin in the Waigen area is predominantly Albany–Fraser Orogen, which is interpreted as a northeasterly trending Mesoproterozoic suture along which oceanic crust was consumed as fragments of continental crust were assembled into the Rodinia supercontinent (Condie and Myers, 1999; Fitzsimons, 2003). The Albany–Fraser Orogen is truncated by the northwesterly trending Musgrave Complex of the Paterson Orogen (Fig. 4a), and was deformed and rotated during uplift and thrusting of the Musgrave Complex during the Neoproterozoic. The magnetic data indicate that the Musgrave Complex was indented by the Albany–Fraser Orogen as it thrust over the Officer Basin to the southwest (Figs 2 and 4b). From the shape of domain 4, the orogen appears to have rotated around the shallow basement in domain 2 during sinistral transpression, creating a zone of local extension between the basement elements underlying the Officer Basin (Fig. 4c). This zone of extension is marked by the small, triangular area of low magnetic response between domain 2, the Musgrave Complex, and the Albany–Fraser Orogen (Figs 2, 3, and 4), and by the deep Cooper Graben (Figs 2 and 3). Of the two Neoproterozoic deformation events recognized in the Officer Basin, the c. 550 Ma Petermann Orogeny is interpreted as a dextral transpressive event (Camacho and McDougall, 2000); therefore, the sinistral event recognized here may represent the c. 750 Ma Areyonga Movement.

The broad, circular to elliptical magnetic features in domains 4 and 7 are interpreted as mafic–ultramafic magma chambers deep within basement. Similar features around the world have been linked to mantle plumes (Pirajno, 2000). Four possible mantle plume events and associated volcanism are documented within continental Australia: c. 1075 (Wingate et al., 2004), c. 800 (Zhao et al., 1994), c. 755 (Wingate and Giddings, 2000), and c. 510 Ma (Hanley and Wingate, 2000); however, the timing of the episodes at c. 800 and c. 755 Ma is only constrained by tentative correlations to large dyke swarms. Wingate et al. (2004) inferred that a large mantle plume beneath central Australia produced the Warakurna large igneous province (LIP) event (c. 1075 Ma) and linked this with plate-boundary forces along the Australian–Antarctic continental margin. The overall arcuate trend of magnetic features in the Waigen area follows the boundary between domains 6 and 7 and the northeastern part of domain 4, possibly outlining a lithospheric break. If a plume were present, the magma would have followed this zone of weakness, and intruded the Albany–Fraser Orogen. Such intrusions would then pre-date the Neoproterozoic deformation event affecting the western Officer Basin. Alternatively, the magnetic features may be related to the c. 510 Ma Kalkarinji LIP, which includes the Antrim Plateau Volcanics and possibly the Table Hill Volcanics, and the intrusions would post-date the deformation event.

Conclusions

The resolution of basement over the deeper parts of the Officer Basin was enhanced, compared to the TMI image, by a new downward-continuation filtering technique based on the wavelet transform. The new image shows that the entire Waigen area and surrounds, excluding the Musgrave Complex and subcropping Gawler Craton, is characterized by northwesterly trending anomalies truncated or displaced by minor northeasterly and northerly trending features. Deformation and local extension may be related to a Neoproterozoic sinistral transpression. Circular magnetic bodies within the Waigen area may be related to either the c. 1075 Ma Warakurna LIP or the c. 510 Ma Kalkarinji LIP.

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