Three-dimensional Modelling of Lithospheric-scale Structures of South Australia

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Abstract Two- and three-dimensional forward modelling of gravimetric field data across South Australia has provided greater insight into the crustal architecture of the Archaean-Proterozoic Gawler Craton and its immediate surrounds. Profile modelling of the shallow crustal-level structures demonstrates that geometrical sources associated with the high frequency domain do not in general extend to depths greater than approximately 10km. A number of relatively high gravimetric anomalies which correspond to identifiable accretionary complexes show fundamental differences in the geometry, size and crustal levels from which the signatures are interpreted to be sourced. Profile modelling of the deeper crustal-level structures predominantly reflects the signature of the Archaean craton and the superposition of the shorter wavelength components of shallow-level sources. This modelling suggests fundamental differences in the response of the crustal architecture between the Gawler Craton and accreted margins of Palaeo- to Meso-proterozoic complexes. These two-dimensional interpretations were subsequently integrated into two different three-dimensional models, thereby providing a framework for property modelling in generating a synthetic gravimetric anomaly response for comparison with the measured data. The modelled gravimetric anomaly response of the shallow level structures demonstrates a poor level of correlation with the surveyed results, indicating strong disparities with geometry and rock density values. This suggests inadequate definition of the source geometries and rock properties, although well constrained in two-dimensions, in the three-dimensional modelling. The modelled gravimetric anomaly response of the deeper level structures demonstrates a moderate level of correlation with a match-filtered image of the gravimetric dataset, showing similar signatures of structures at an approximate depth of 16 km.

Introduction

Quantitative studies of potential field data have largely revolved around two-dimensional forward modelling of source geometries and depths using a variety of graphical techniques (Talwani, 1965; Bhattacharyya, 1966; Naudy, 1971; Hjelt, 1972; Nabighian, 1972; Spector & Grant, 1975; Coggon, 1976; Gunn, 1979; Oliva & Ravazzoli, 1997; Stavrev, 1997). The usefulness of such models can provide rapid and relatively accurate information of anomalies in the third dimension and other value-specific detailed estimates of the source geometry. A more comprehensive and realistic model representation of the geology of structures requires understanding the 3D geometry.

The focus of this investigation involves the forward modelling of gravimetric field data in both two- and three-dimensions to develop and test a three-dimensional geological and geophysical model of lithospheric-scale structures of South Australia.

Little is known about the lithospheric architecture and continental-scale structures across the Gawler Craton. This investigation aims to:

1. Define the geometry and structure of the crustal-scale architecture of the South Australian continent.
2. Define the structural and geophysical boundaries of the Gawler Craton.
3. Determine the origin of various gravimetric anomalies.

Geological Background

The Gawler Craton is an Archaean to Mesoproterozoic-aged crystalline basement of sedimentary, metamorphic and igneous complexes that underlies the greater part of central South Australia (Parker et al., 1993a). The craton forms a highly polygonal-shaped continental nucleus surrounded by faulted margins of Neoproterozoic and Phanerozoic basins to the northeast, northwest and western boundaries (Daly & Fanning, 1993) (Figure 1). The eastern and southeastern boundaries of the craton are delineated by the variable north-south trending Torrens Hinge Zone. The edge of the continental shelf marks the southern boundary of the Gawler Craton.

The Gawler Craton experienced a protracted evolution of crustal formation and tectonothermal events. The earliest of these events occurred during the protracted late Archaean to Early Proterozoic poly-deformation, regional granulite facies metamorphism and syn- to late orogenic granitic intrusions during the Sleafordian Orogeny (~2635-2450 Ma: Daly & Fanning, 1993). These sequences of metasedimentary, granitic and intrusive rocks are recorded in limited exposures of basement outcrop of the Sleaford and Mulgathing Complexes (Daly et al., 1998).

A period of collisional orogenesis followed and involved the accretion of supracrustal sequences onto the Archaean nucleus during Palaeo- to Meso-proterozoic events. The

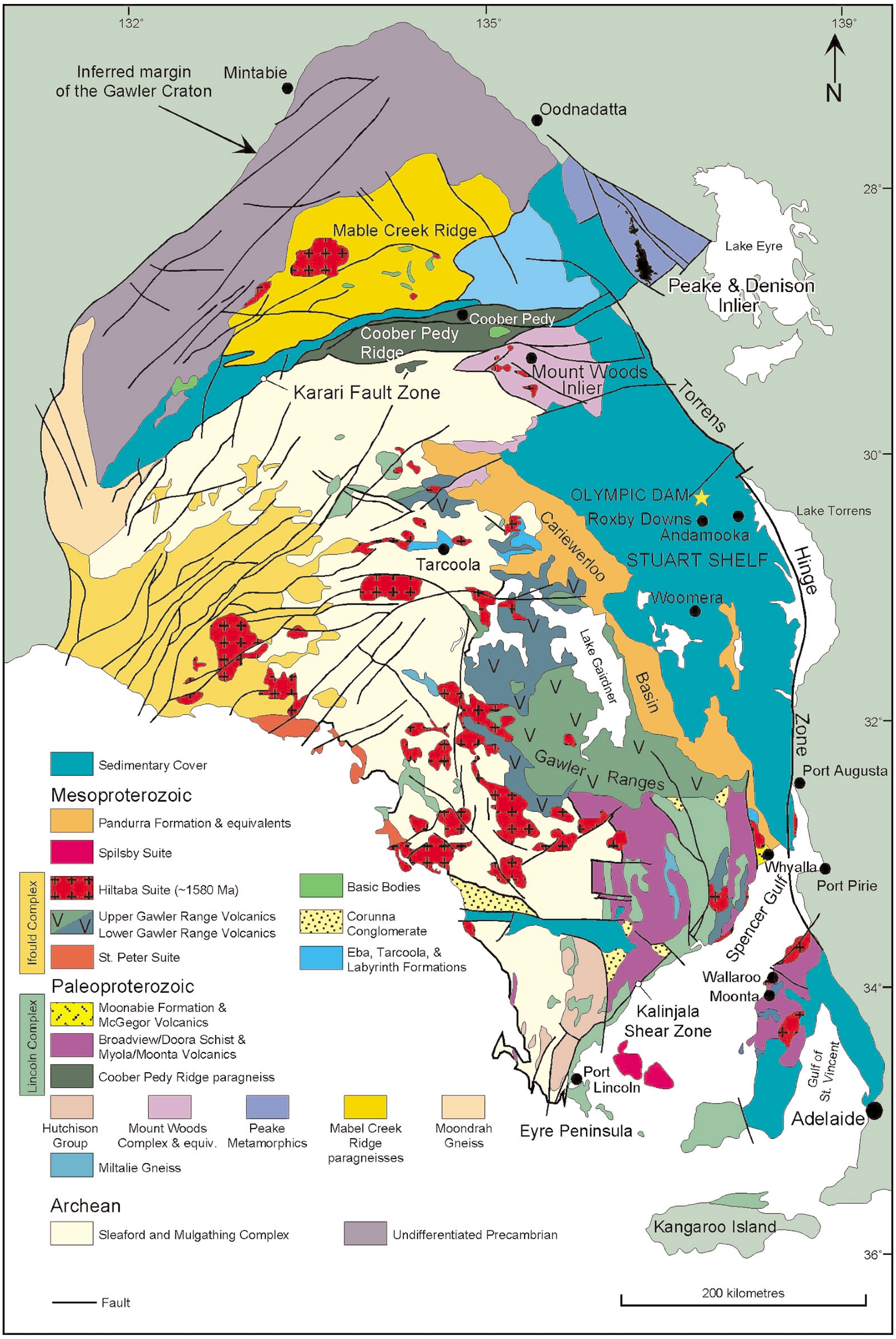

Figure 1. Tectonic map of the Gawler Craton (after Daly et al., 1998).

earliest of these tectonic events is termed the Kimban Orogeny (~1730-1700 Ma: Parker et al., 1993a; Vassallo and Wilson, 2002) and involved the deposition of shallow continental shelf sequences of the Hutchison Group, which are predominantly exposed on the eastern cratonic margin. The emplacement of syntectonic, complex granitoids and mafic intrusions referred to collectively as the Lincoln Complex (Parker et al., 1993b) occurred before and during this orogenic event (see Figure 1).

Deformation of supracrustal rocks occurred periodically and continued in the northern and western parts of the Gawler Craton. The Mount Woods Inlier and equivalent complexes (~1740-1650 Ma: Fanning, 1997) were deformed along the northern margin of the craton. Contemporaneous with this accretionary event was the emplacement of deformed, multiphase plutons of the Ifould Complex on the western margin of the craton (Daly et al., 1998) (see Figure 1). Supracrustal rocks of the Ifould

Complex are preserved in the Fowler Orogenic Belt, which exhibits complex anastomosing north to northeast trending shear zones similar in orientation to the regional-scale Karari Fault Zone (Daly et al., 1998).

At approximately 1600 Ma, an extensive magmatic thermal event occurred and resulted in the deposition of anorogenic magmas of the Gawler Range Volcanics in the central Gawler Craton (Flint et al., 1993) (see Figure 1). Co-magmatic with this event was the emplacement of the dominantly felsic Hiltaba Suite Granitoids (~1600-1580 Ma) (Creaser & White, 1991; Blissett et al., 1993; Flint, 1993a). This massive magmatic province has undergone little deformation and is overlain unconformably by the Mesoproterozoic Cariewerloo Basin and Neoproterozoic to Cambrian platformal sediments of the Stuart Shelf in the eastern and northeastern parts of the craton (Cowley, 1993; Priess et al., 1993).

The continuation of continental accretion progressed in the northern Gawler Craton following plutonism associated with the Hiltaba Suite Granitoids. Orogenesis is recorded in the Coober Pedy Ridge (~1565 Ma: Daly et al., 1998) and the Mabel Creek Ridge (~1540 Ma) (see Figure 1), Collectively this event is termed the Late Kararan Orogeny (Betts, 2002). Orogenesis is characterised by poly-deformational and high-temperature metamorphic-grade conditions (Daly et al., 1998). The Mabel Creek Ridge is thought to have developed under a thin-skinned tectonic regime with deformation more intense in the Coober Pedy Ridge (Daly et al., 1998; Betts, 2000).

Available Datasets

South Australian Geoscientific GIS dataset

The intensive data capture programs initiated by the Geological Survey of South Australia over the last few years has resulted in an extensive collection of data, the compilation of which has now been assembled into the South Australian Geoscientific Geographical Information System (GIS). This spatially integrated bibliographic collection of data is a state-wide integration of geological, geophysical, geochemical and cultural data aimed at distributing regional geoscientific information for exploration and research (www.pirsa.com). A number of selected databases were selected from the South Australian Geoscientific GIS dataset. These include summary digital geology of rock outcrops, basins and geological and tectonic provinces. In addition, databases of drillhole stratigraphy and geochemical sampling related to single points on the ground were selected for analysis and interpreted.

South Australian Gravimetric dataset

The regional gravimetric field dataset used in this study was derived from Primary Industry and Resources, South Australia (PIRSA). This dataset is a reduced and corrected Bouguer Gravity map covering the entire state of South Australia (Figure 2). The station spacing configured for acquisition of this dataset is variable with an average spacing of approximately 8 km. Each gridded image-cell is also of approximately 200m.

Image Enhancement

The gravimetric dataset gridded by MESA have been processed using the Intrepid™ software. This was performed using filtering algorithms to visually enhance the effects of selected geological features, thereby enhancing different facets of the dataset. The filter used in this investigation is a matched filter (Cowan & Cowan, 1993). A matched filter, in theory, provides a separation of frequencies for different depths. The image will ideally contain information from a certain depth level while signals from other depths are attenuated. All images were subsequently displayed in ERMapper™.

Petrophysical Investigations

Rock density data was used as the primary constraint for the geophysical modelling. However, published information on the measurements of densities for rocks of the Gawler Craton and its surrounds is limited. The average rock densities used in this study are presented in Table 1, the majority of which were derived from Gow (1997). Density estimates inferred for particular rock types are also presented in Telford et al (1995). All densities used in the modelling have assumed heterogeneous characteristics that are derived from geologically reasonable estimates and therefore represent a wide range of values.

Integrated Geological and Geophysical Modelling

There are many software packages designed to create three-dimensional geological models. It is not uncommon to find modelling packages specifically developed within a particular market, such as mine planning or seismic and basin analysis. The strengths and weaknesses of each usually reflect its origin. It has been necessary within the course of this investigation to combine the capabilities of more than one of the standard geology packages, which has involved using additional modules or ‘plug-ins’ developed in-house (Aillères, 2000). An approach involving the application of one geoscientific information system (MapInfo™) and three standard modelling packages (GM-SYS™, gOcad™ & Noddy™) was adopted.

GM-SYS™ - 2D & 2 3/4D Modelling

The GM-SYS™ modelling system is a two-dimensional forward modelling program for calculating the gravity and magnetic response of a geologic model. The system allows for interactively creating and manipulating models to match the observed gravity and or magnetic data by; (i) changing the selected modelling parameters; and or (ii) by adjusting the model geometry.

All geological bodies are modelled in the third dimension as dipping prisms of finite strike length in either 2 or 2 3/4 dimensions.

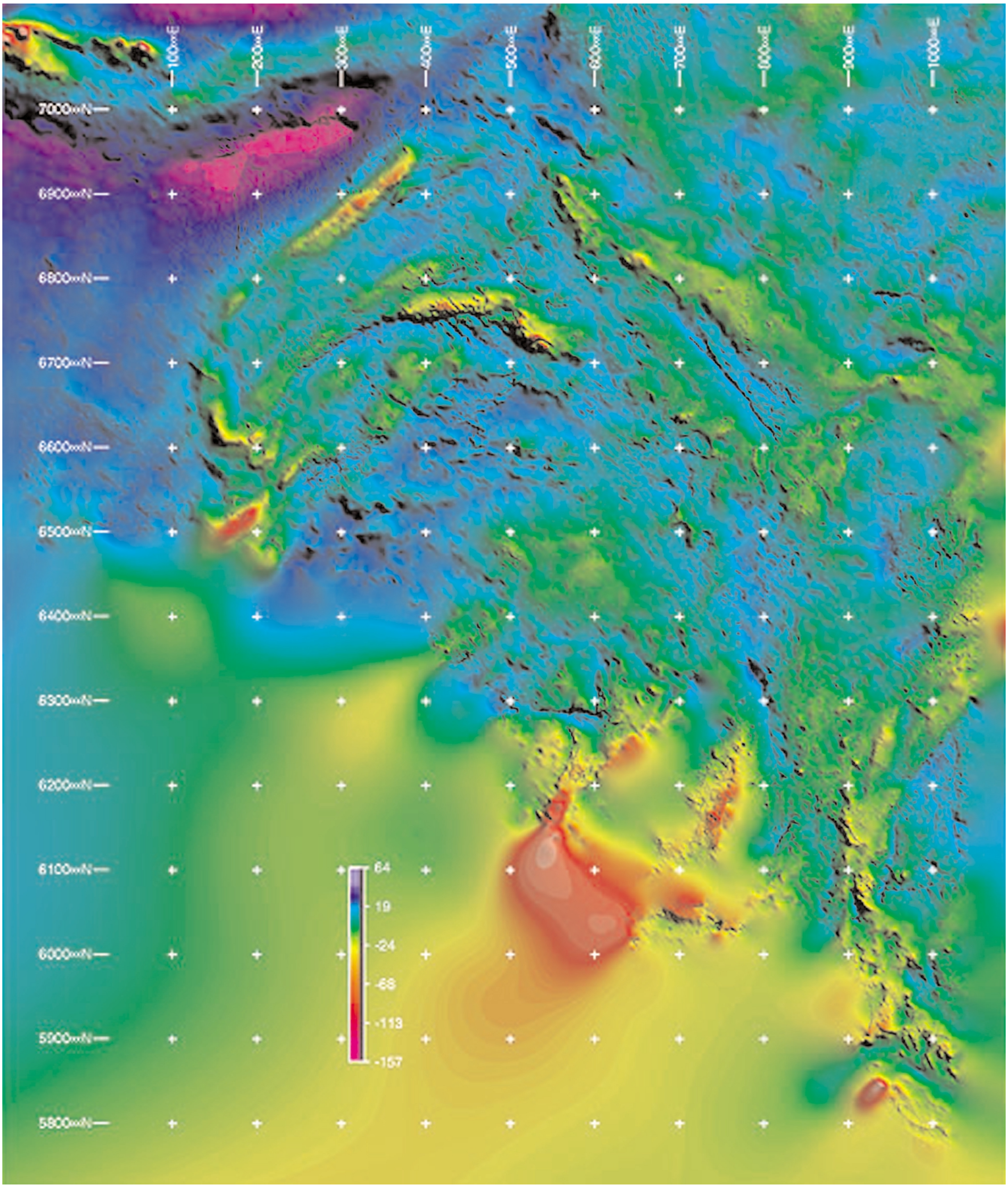

Figure 2. Gravimetric dataset of South Australia.

gOcad™ – Geological Objects Computer Aided Design

The gOcad™ modelling system is a data-based, three-dimensional modelling package that integrates external information through an object-oriented approach (Mallet, 1992). The three-dimensional modelling environment of gOcad™ allows representation and definition of sophisticated models that are topologically and geometrically consistent with many types of external geological information including, drillholes, level plans and cross-sections, seismic lines. The modelling framework allows for interactive manipulation, interpretation and visualisation of geological models comprising two basic model-types relevant to this investigation; (i) surface-type models representing geological and or structural boundaries; and (ii) grid-type models in which physical rock properties may be characterised in the defined model space. (**Click here to view gOcad™ model; VRML plugin available at http://www.parallelgraphics.com/**)

Upper Crustal-Level Models

Rock Type	Density (kg/m3)	Average Value
Adelaidean Fold Belt	2570-2670	2620
Archaean (Sleaford & Mulgathing Complex)	2530-2750	2740
Cariewerloo Basin	2600-2670	2635
Range Volcanic (felsic)	2560-2660	2610
Gawler Range Volcanic (mafic)	2600-2770	2685
Hiltaba Suite Granitoids	2480-2830	2655
Hutchison Group	2620-2870	2745
Ifould Complex	2530-2920	2725
Lincoln Complex	2600-2820	2710
Lower Crust	3000	3000
Mabel Creek Ridge	2600-2850	2725
Mafic Underplate	3100	3100
Moondrah Gneiss	2700-3100	2900
Mount Painter Inlier	2800	2800
Mount Woods Inlier	2690-2710	2700
Musgrave Block	2620-3050	2835
Officer Basin	2600-2760	2680
Peake & Denison Inlier	2700-2900	2800
Palaeoproterozoic Rocks (east of craton)	2700-2750	2725
St Peters Suite Granitoids	2750-2900	2825
Stuart Shelf	2540-2770	2655
Subcrustal Lithospheric Mantle (SCLM)	3300	3300
Shallow Crustal-Level Blocks	2510-2950	2730
Undifferntiated Precambrian Rocks	2700-3000	2850
Willyama Inlier	2670-2900	2785

Deeper Crustal Models

Rock Type	Density (kg/m3)	Average Value
Coorabie Block	2840-2880	2860
Deep Crustal-Level Block	3000-3100	3050
Gawler Cratonic Western Element	2740-2750	2745
Gawler Cratonic Eastern Element	2760	2760
Gawler Cratonic Basal Element	2795	2795
Karari Block	2790	2790
Lower Crust	3000	3000
Mafic Underplate	3050	30500
Musgrave Block	2700-2850	2775
Officer Block	2680	2680
Palaeoproterozoic Rocks (west of craton)	2750-2780	2765
Palaeoproterozoic Rocks (west of craton)	2760-2780	2770
Precambrian Block	2820-2850	2835
Subcrustal Lithospheric Mantle (SCLM)	3100	3100
Torrens Block	2740-2790	2765

Table 1. Rock density values of major crustal blocks of the Galwer Craton and surrounds (after Gow, 1997 & Betts, 1999).

Noddy™

The Noddy™ modelling system is a knowledge-based, three-dimensional kinematic forward modelling package that evolves on information of an a priori level of understanding (Jessell, 1997b). The system allows for construction of conceptual geological models and calculations of a geophysical response (Jessell et al., 1993). The Noddy™ package enables the development of complex structural histories. A three-dimensional model can be constructed through the superposition of a series of deformations on an initial layer-cake stratigraphy. The potential field response of the modelled three-dimensional geometry can be calculated (Jessell et al., 1993; Jessell, 1997a).

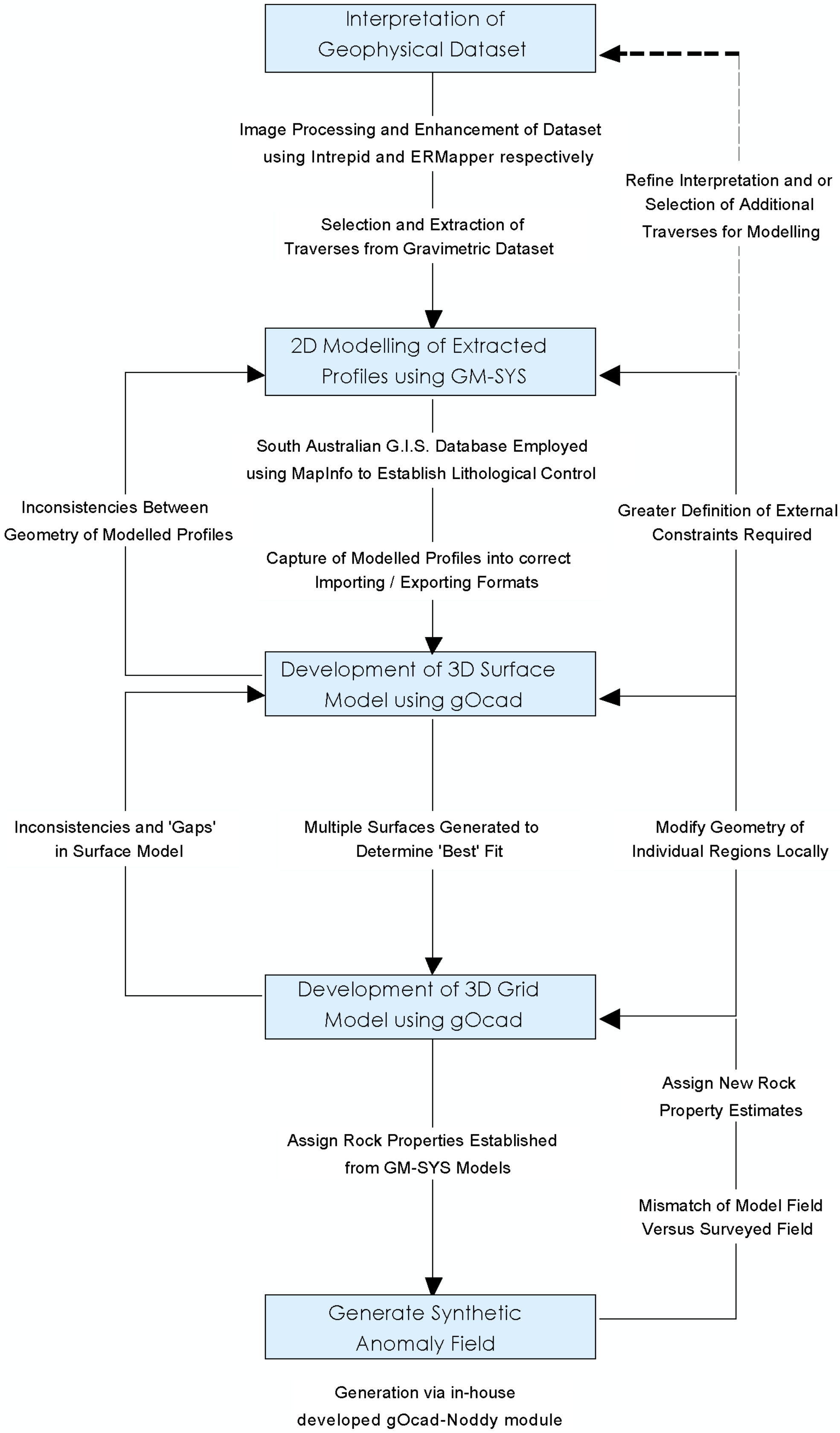

Figure 3. Schematic diagram showing the modelling operation used in this investigation.

Three-dimensional modelling procedure

The procedure for three-dimensional modelling of lithospheric-scale structures of South Australia in this investigation involves several stages. The modelling operation is depicted in Figure 3 and is briefly outlined below:

Stage 1 – 2 3/4D gravity modelling: The first activity of this stage involves extracting gravimetric profiles from the South Australian Bouguer gravity field map and importing them into the GM-SYS™ software. External constraints such as rock outcrop and drillhole information from the South Australian Geoscientific GIS dataset are then integrated to create a geological model for each profile.

Stage 2 – Surface modelling: GM-SYS™ models are exported into formats compatible with gOcad™. The next phase involves the creation of opened or closed surfaces from the finite set of points generated from the GM-SYS™ models. The creation of a surface is strongly influenced by the set of control points, in which case, multiple scenarios must be examined to determine the best fit to both the data and geological understanding. The resultant surface model is built up gradually through interpolation between each profile, the effect of which provides a self-consistency test of the two-dimensional interpretations.

Stage 3 – Grid modelling: This involves generation of a rectilinear grid model that encompasses the continuous volume of the gOcad™ surfaces. The volume elements within the grid model are directly analogous to the surface model and represent the in-fill volume of the generated polyhedra. From this three-dimensional model, a synthetic gravimetric field model is calculated through Noddy™ by assigning rock density values to the modelled regions.

Dominant Gravimetric Features

A number of relatively high gravimetric anomalies correspond to numerous crustal Palaeo- to Meso-proterozoic blocks (terranes) along the northern and western margins of the Archaean craton. These terranes have a distinctive gravimetric signature that can be mapped on the regional datasets and include the Mount Woods Inlier, the Peake and Denison Inlier, the Coober Pedy Ridge, the Mabel Creek Ridge and parts of the Ifould Complex (see Figure 2). A brief description and analysis of dominant gravimetric features of the Gawler Craton and its surrounds is given below.

Coober Pedy Ridge: The Coober Pedy Ridge is a large thrust-related, fault bounded elongated structural sliver of continental crustal that lies unexposed in the northern central Gawler Craton (see Figure 2). This geophysically distinct terrane is characterised by a relatively high gravimetric anomaly that trends east-west and is cut by the regional-scale Karari Fault Zone (Rankin et al., 1989). The source of this regional feature may be attributed to the high iron content of supracrustal sequences comprising this crustal block (Finley, 1993; Betts, 1999). The abrupt boundary truncations of this gravimetric domain are manifested towards the northern and southern margins where they are defined by several different generations of folded thrusts (Betts, 1999). The consistently high amplitudes and short frequencies of this gravimetric feature reflect a relatively shallow-level source of the anomaly.

Mount Woods Inlier: The Mount Woods Inlier forms a geophysically discrete crustal block to the southeast margin of the Coober Pedy Ridge. It is characterised by a relatively high gravimetric response predominantly in the western domain from which a gradual easterly decrease in intensity is apparent (see Figure 2). This is attributed to an increase in the burial depth of the crustal block towards the east. The north-western boundary of this block and the south-eastern boundary of the Coober Pedy Ridge are separated by the east-west trending Cairn Shear (Betts, 1999).

Mabel Creek Ridge: The Mabel Creek Ridge is a predominantly polygonal-shaped crustal block situated immediately north of the Coober Pedy Ridge and is separated by the Mabel Creek Fault (Betts, 1999). The gravimetric signature of the Mabel Creek Ridge is dominated by a relatively moderate to high elongated, northeast trending anomaly in the south-western quadrant along the boundary with the Coober Pedy Ridge (see Figure 2). Towards the central and northern regions, the response is relatively low and is comparable in intensity to that of the background response of the Mulgathing Complex of the Archaean nucleus.

Peake & Denison Inlier: The Peake and Denison Inlier form an arcuate wedge of exposed Palaeoproterozoic metasediments and metavolcanics immediately adjacent to the north-eastern margin of the Gawler Craton (Flint, 1993b) (see Figure 2). The relatively high, internally varying gravimetric expression trends northwest and appears to form the northern part of a distinct broad northwest-southeast trending regional gravity anomaly that intersects the Stuart Shelf and parts of the north-western region of the Adelaidean Fold Belt.

Adelaidean Fold Belt: The Adelaidean Fold Belt outlines a continuous expanse of thick Neoproterozoic and Early Cambrian sedimentary sequences that extends from the south-eastern to central-eastern parts of South Australia (Parker, 1993a). The regional gravimetric response of the fold belt varies from relatively high to very high in the south and eastern regions to relatively low to moderate intensities in the central and north-western corner (see Figure 2). The western margin of the Adelaidean Fold Belt is defined by the curvilinear north-south trending Torrens Hinge Zone (Thomson, 1970), which is interpreted to represent the eastern margin of the Gawler Craton. The eastern and north-eastern margins of the fold belt are in spatial relation with the Curnamona Craton (Thomson, 1975) and associated supracrustal sequences of the Willyama, Mount Painter and Mount Babbage Inliers.

Gawler Range Volcanic Province: The central Gawler Craton exhibits a relatively low intensity, long wavelength and massive regional gravimetric anomaly in close spatial association with the Gawler Range Volcanics (see Figure 2). This relatively deep-level feature is suggested to represent a mafic body associated with underplating during partial melting of the lower crust (Creaser & White, 1991) and subsequent emplacement of the Hiltaba Suite Granitoids.

Fowler Orogenic Belt: The Fowler Orogenic Belt encompasses a large region of the western-central Gawler Craton and is predominantly composed of multiphase plutons of the Ifould Complex.

South Australian two-dimensional Models

The structural and geophysical elements of the Gawler Craton reveal the protracted tectonic evolution of the Archaean nucleus and its Palaeo- to Meso-proterozoic orogenic complexes. The distribution of geometries and the distinct banding of anomalies in different orientations does not however, allow effective modelling of parallel traverses perpendicular to geological strike. A total of 9 E-W trending traverses were extracted for modelling. The gravimetric field response of the Gawler Craton generally reflects the entire crustal structure upon a superimposed component of the shallow-level geology. As a consequence, the focus of this exercise is two-fold and involves matching both; (i) the deeper-level crustal structures; and (ii) the shallow-level geology, both using constraints from the South Australian Geoscientific GIS database.

Upper crustal-level Profile Models: Of the 9 profiles extracted from the Bouguer Gravity Map of South Australia, 6 extend east-west from 50000mE to 1050000mE beginning at 7000000mN for every 100,000 metres south to 6500000mN on the Australian Map Grid (Figure 4). Another 2 profiles extend east-west from 350000mE to 1050000mE, one at 6400000mN and the other at 6300000mN. The last profile continues east-west from 450000mE to 1050000mE at a northing of 6200000mN.

Profile 6500000mN: This modelled geological cross-section provides insight into some of the major crustal structures of the South Australian lithosphere. The overall gravimetric response along this profile is dominated by a series of anomalies of relatively long wavelengths, reflecting the signature of the Archaean nucleus upon superposition of the shorter wavelength components of shallow-level sources (Figure 5).

The western half of the profile exhibits a marked range of values in comparison to the eastern half. The distribution of modelled blocks is consistent with geological maps and GIS datasets used.

Although continental crustal thicknesses in general vary from 35-45 km, and indication from seismic studies of the South Australian continent which supports a mean crustal thickness of ~38 km (Finlayson et al., 1974; Greenhalgh et al., 1989), a modelled horizontal thickness of ~32km appears to satisfy the gravity data along this profile. Seismic data suggests this depth marks an increase in the crustal velocity and therefore indicates transition into the lower crust.

The eastern margin of the Gawler Craton is interpreted as a shallow tapering, east-dipping wedge that extends into the lower crust and defines the boundary between Palaeoproterozoic supracrustal sequences in the east. This relatively planar, deeply penetrating structure extends to a depth of approximately 32km over a distance of ~300km and has been termed the Kimban Suture Zone (Betts, 1999) which developed during the Kimban Orogeny. The surface continuation of this suture zone is obscured beneath the Cariewerloo Basin and the Gawler Range Volcanics in the central Gawler Craton.

The gravity response of the centre of the profile is dominated by a broad smoothly varying, long wavelength regional anomaly, the source of which is modelled as a horizontal zone of high-density interpreted to represent a mafic body in the lower crust. This significantly wide approximately ~200km and ~7 km thick body lies directly beneath the Gawler Range Volcanics, suggesting a likely genetic link.

Short-wavelength gravity responses in the model reflect the distribution of near-surface sources. The western half of the profile shows the distribution of the Hiltaba Granitoids and associated plutons of the Ifould Complex. The marked change of intensity values across these bodies reflects the changing density properties across the craton. As such, the bodies are modelled as several discrete blocks. Towards the centre, modelled sill-like bodies of the Gawler Range Volcanics are depicted. Modelling of the gravity data suggests the Hiltaba Suite Granitoids, the Ifould Complex and bimodal associations of the Gawler Range Volcanics extend to depths of up to 10 km.

In the eastern half, polygons of the Cariewerloo Basin, the Adelaidean Fold Belt and the Willyama Inlier extend west-laterally from the cratonic boundary. It is noted that variations in the geometry and density values of these bodies do not significantly affect the calculated gravity response. The data suggests these bodies do not extend to a depth greater than several kilometres. A probable source of the anomaly is supracrustal sequences from shallow levels of up to ~10 km as modelled by Betts (1999). In the profile, alternating high and low density crustal blocks have been modelled to represent this.

Profile 6600000mN: In complete contrast to the gravity profile of 6500000mN, this profile is dominated by a succession of short wavelength, high-amplitude components, reflecting the influence of shallow-level sources superimposed against the Archaean nucleus (Figure 6).

The eastern half of the profile highlights the distribution of the Moondrah Gneiss, the Ifould Complex, the Hiltaba Suite Granitoids and the Gawler Range Volcanics across the craton. The regular 'rise and fall' gravity response of these units reveals the strong disparity of density values within individual complexes. In general, each discrete block exhibits a steep west dipping relationship of geometries that extend up to depths greater than ~5 kms. Contrasting punctuated highs and lows in the gravity response generally correspond to boundary contacts between the different units.

The western half of the traverse displays a very similar gravity profile, although exhibits smaller fluctuation of intensities in the data. The Kimban Suture Zone is of similar geometry to that modelled in profile 6500000mN.

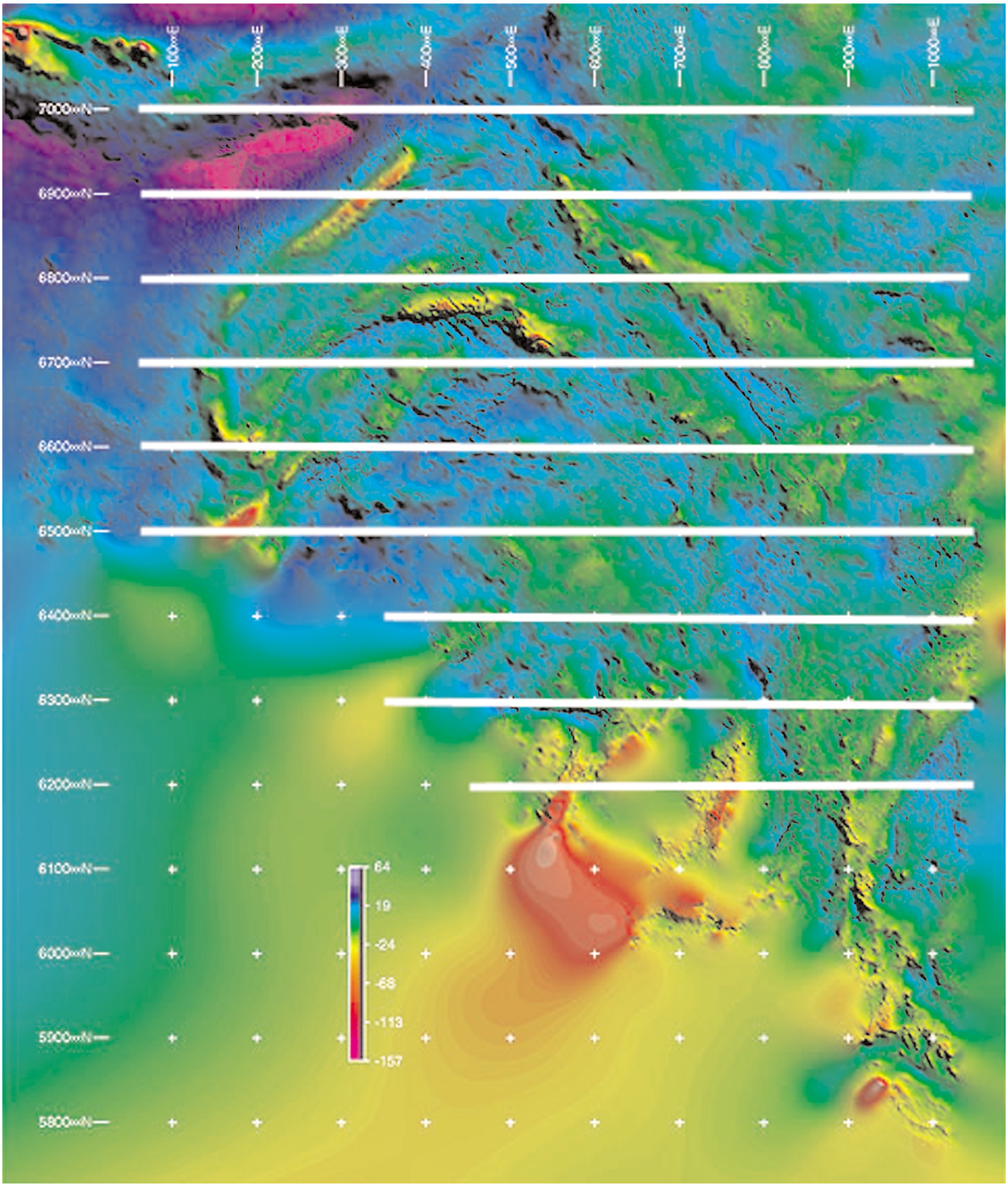

Figure 4. Location of Upper crustal-level Profile extracted from the Bouguer Gravity Map of South Australia.

The calculated response of the Cariewerloo Basin, the Stuart Shelf and Adelaidean Fold Belt once again show little affect against the gravity data without the introduction of several displaced high and low density crustal blocks beneath the Stuart Shelf.

Deeper Crustal-level Profile Models: Only 7 of the 9 profiles extracted from the South Australian Bouguer Gravity Map and one additional profile extracted from line 7100000mN was used to model the deeper-level crustal structures. The length of each profile also extends east to west from -100000mE to 1000000mE on the Australian Map Grid (Figure 7). No further traverses south of line 6500000mN were extracted for modelling because of the suspect gravity data in the coastal region.

Profile 6500000mN: The modelled profile differs greatly from that of the other 6500000mN modelled profile in that lithospheric-scale structures are modelled to match the longer regional wavelengths. The relatively shorter

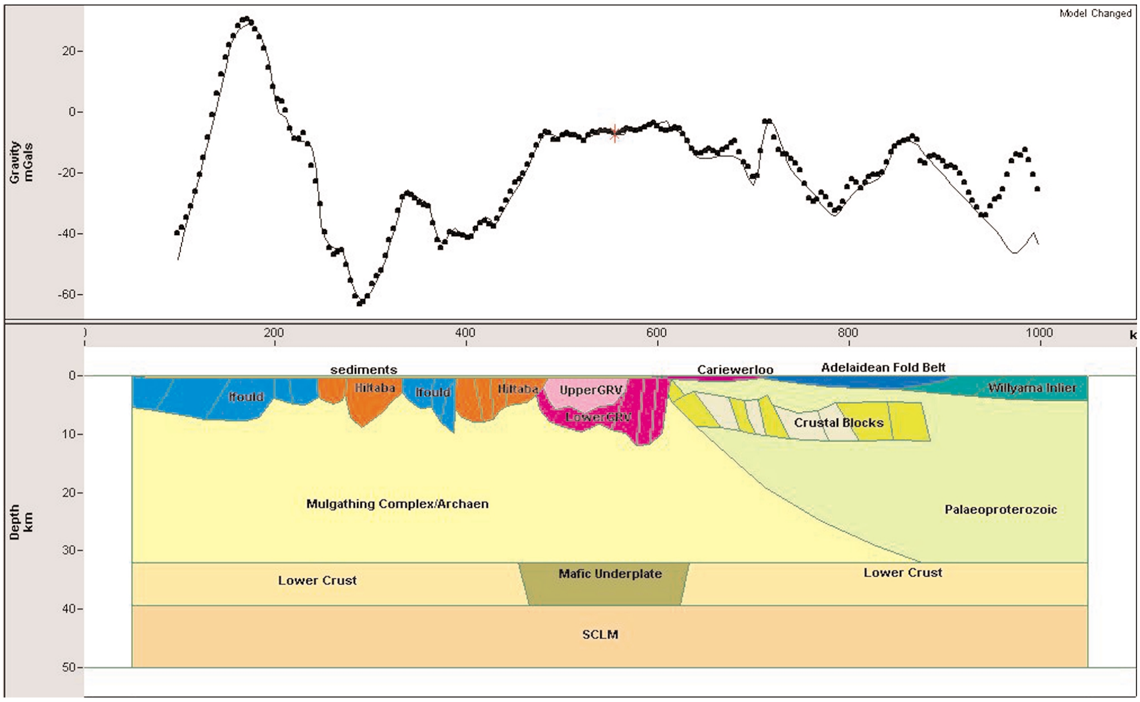

Figure 5. Shallow crustal-level profile modelling of traverse 6500000mN.

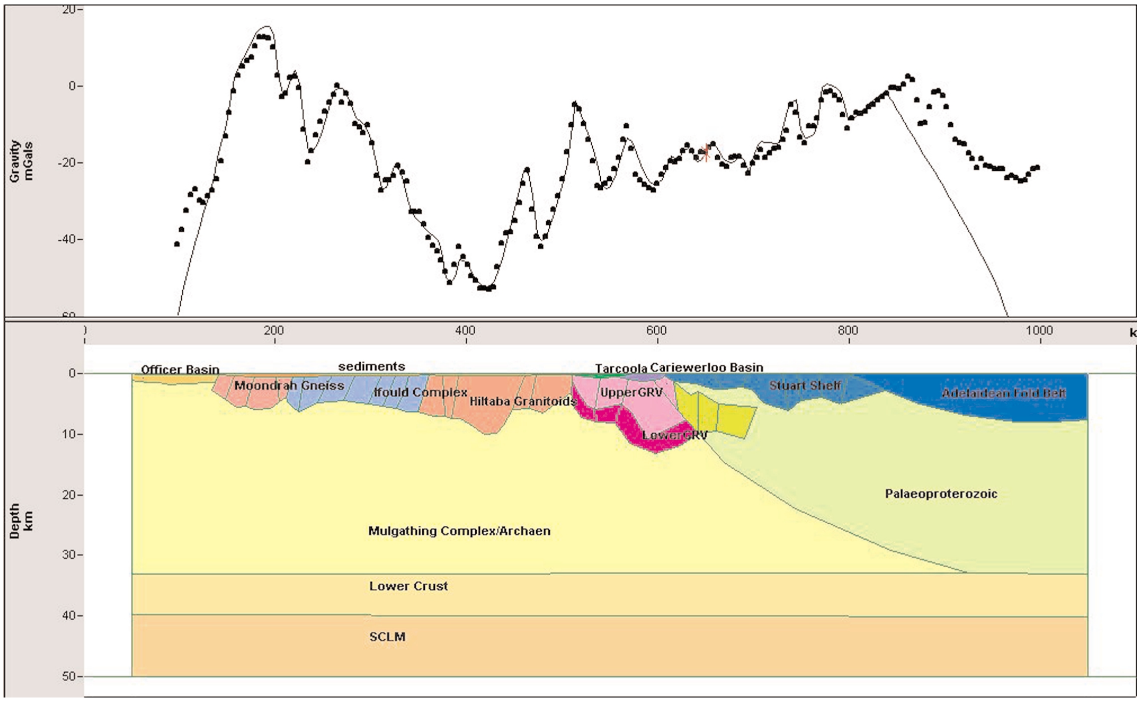

Figure 6. Shallow crustal-level profile modelling of traverse 6600000mN.

wavelength, high amplitude anomalies are essentially 'smoothed' out to show the overall broad varying response of deep-seated structures (Figure 8).

Variations in the geometry of the crust show a modelled thickness of ~38-40 km. This point of transition into the lower crust, and the geometry of the lower crust itself varies considerably across the substructure of the craton. The interpreted mafic underplate spatially associated with the magmatic province of the Gawler Range Volcanics essentially bisects the lower crust, demonstrating the thinning of the lower crust surrounding the region.

The eastern boundary of the Gawler Craton remains defined by the Kimban Suture Zone, moderately dipping to the east and separating Palaeoproterozoic supracrustal sequences from the east. The western boundary is defined by the steep gradient of the high amplitude anomaly in the west and modelled as a steeply west-dipping contact zone. Internally, the craton is divided into three cratonic elements

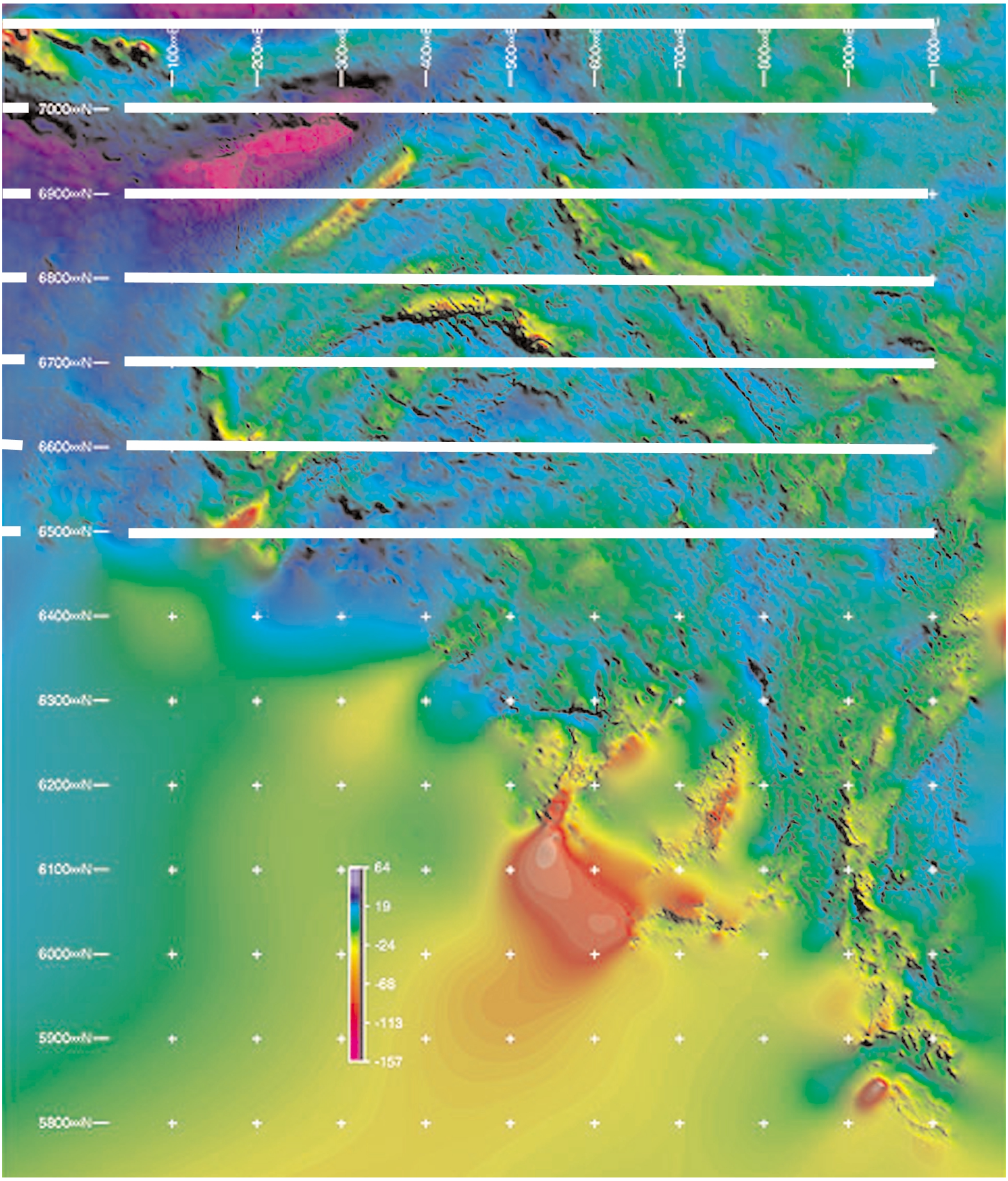

Figure 7. Location of deeper crustal-level profiles extracted from the South Australian Bouguer Gravity Map.

to essentially model differences in the Archaean Mulgathing and Sleaford Complexes.

The Officer Basin west of the craton is rather thick with depths ranging greater than ~5 kms. Although not modelled, mismatch of the data in the western end of the profile possibly reflects lateral density variations in the Coompana Block (Flint & Daly, 1993). The high amplitude, relatively long wavelength regional anomaly marking the western Gawler Craton boundary is characterised as the total response of accretionary complexes within the western regions of the Fowler Orogenic Belt. The magnitude of the response indicates this block may extend up to ~20 km in depth. Adjacent to the surface expression of the Kimban Suture Zone is a modelled 'reworked' region of the Torrens Hinge Zone defining the transitional zone between sediments of the Adelaidean Fold Belt and the Stuart Shelf.

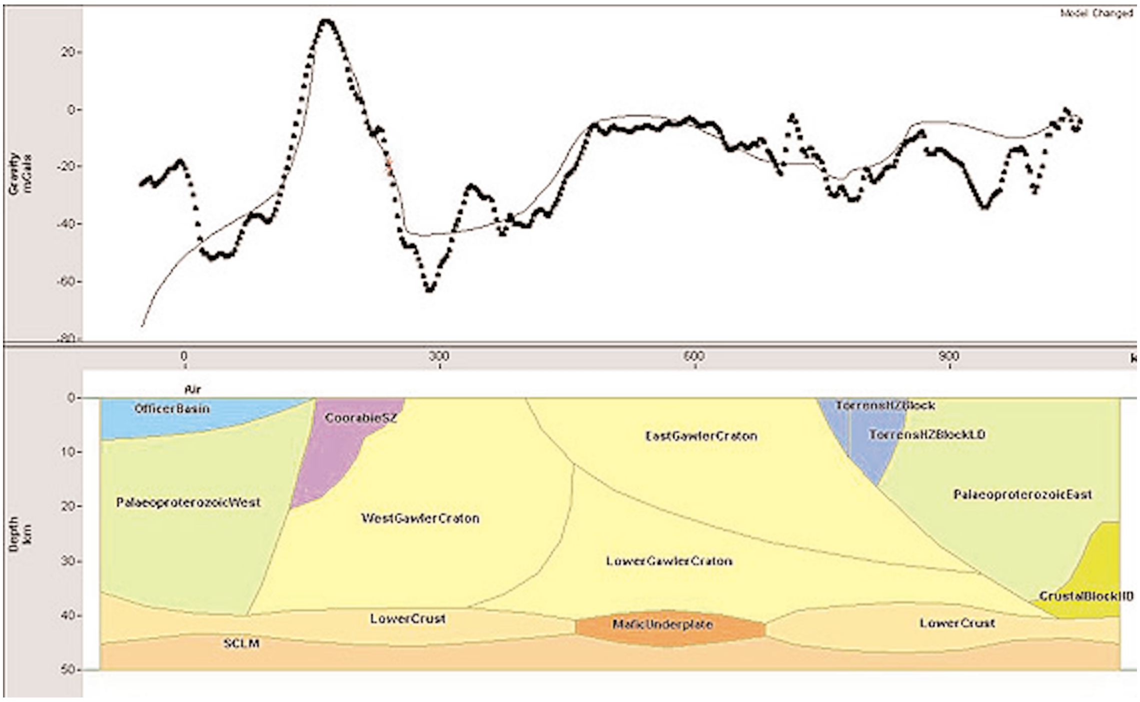

Figure 8. Deep crustal-level profile modelling of traverse 6500000mN.

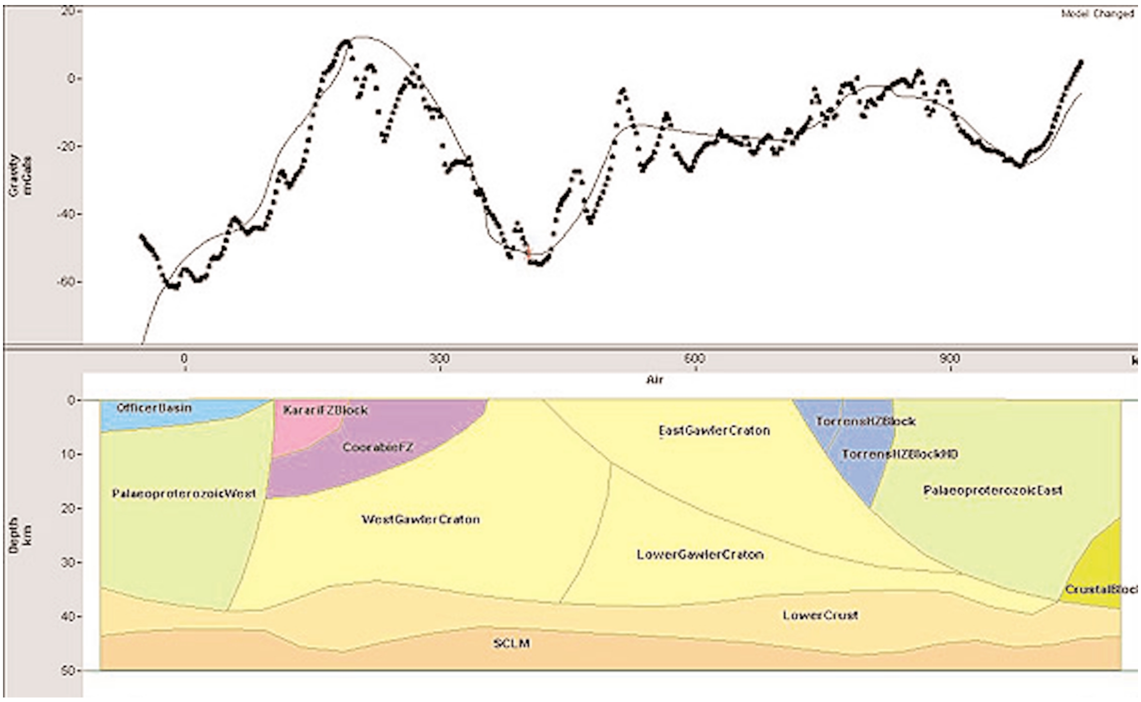

Figure 9. Deep crustal-level profile modelling of traverse 6600000mN.

Profile 6600000mN: The short wavelengths, shallow-level sources superimposed on the regional response of the craton are clearly demonstrated across this profile. Modelling of the longer wavelength, regional gravity sources across this traverse have ‘smoothed’ out spikes in the data (Figure 9).

The geometry of the lower crust is demonstrated to vary considerably in thickness, ranging from ~4 km to ~12 km. Thickness variations are observed to occur at the interpreted margins of the Gawler Craton where thickness of the lower crust is at its thinness. The greatest thicknesses occur where anomaly amplitudes are at it highest.

The eastern half of the profile is dominated by a large broadly varying anomaly and is highlighted by crustal blocks of the Fowler Orogenic Belt and crustal sequences north of the Karari Fault Zone. The Karari Fault zone is shown to initially dip steeply to the west (in east-west section) and then shallows off at ~ 8 km depth. The steep gradient of this anomaly leading into the extreme negative and gravity low of the profile coincides with the western cratonic margin and the southern region of the Officer

Basin. In the west, high-density blocks depicting the 'reworked' Torrens Hinge Zone extend to depths of up to ~20 kms. The introduction of a high-density crustal block adjoining the western cratonic margin at the lower crust is found to satisfy the profile across this area. Unlike the modelled crustal blocks in the upper-crustal level models, this block is much deeper (>20 km).

South Australian Three-dimensional Geological Models

Two, three-dimensional models were constructed, the first of which (upper crustal-level) occupies a spatial window on the Australian Map Grid orthogonal to (50000mE, 7000000mN) and (1000000mE, 6200000mN), the second model covering an area from (-100000mE, 7100000mN) to (1100000mE, 6400000mN).

South Australian Upper crustal-level Surface Model: All surfaces were created to honour the geological data, the ascribed delineation of gravimetric features and cross-sectional interpretations of the kind shown in figures 5 to 8. Lithological variations in the shallow-level geology were simplified into an assemblage of 18 units. These include;

- the lower boundaries of the Gawler Range Volcanics and comagmatic Hiltaba Suite Granitoids;
- the lower boundaries of the Cariewerloo Basin, Stuart Shelf and Adelaidean Fold Belt;
- the lower boundaries of the Willyama and Mount Painter Inliers;
- the lower boundaries of accretionary complexes of the Peake & Denison Inlier, the Mount Woods Inlier, the Mabel Creek Ridge, the Ifould Complex and the Lincoln Complex;
- the lower boundaries of the Hutchison Group, the St Peters Suite Granitoids and Moondrah Gneiss;
- the lower boundaries of the Musgrave Block and Undifferentiated Precambrian rocks.

Several additional features were created to define important lithospheric elements. These include:

- the boundaries of the Gawler craton;
- the lower boundaries of the sub-crustal lithospheric mantle (SCLM);
- the lower boundaries of the lower crust;
- the Kimban Suture Zone;
- a regional-scale mafic underplate;

The macroscopic nature of interpreted subsurface geological features of the Gawler Craton and surrounding environs are shown in figures 10 & 11.

These figures enable conceptual visualisation of the complex geometry of the Gawler Craton in which the following significant features are observable:

- the relatively large volume of rock occupied by the Gawler Range Volcanics;
- the widespread spatial distribution of the Hiltaba Suite Granitoids;
- the geometry of accretionary terranes and their relative orientations on the cratonic margins
- the geometry of the eastern cratonic margin.

South Australian Deeper crustal-level Surface Model: Lithospheric variations in the deeper-level geology were simplified into an assemblage of 13 blocks (Figures 12 & 13). These include;

- the boundaries of the Gawler Craton in the north and west and the Kimban Suture Zone defining the eastern margin;
- the boundaries of the eastern, western and lower cratonic elements;
- the lower boundaries of the Fowler Orogenic Belt as delineated by blocks defined by the Coorabie Fault, the Karari Fault Zone and units of undifferentiated Pre-Cambrian Rocks;
- the lower boundaries of the Musgrave Block and the Officer Basin;
- the lower boundaries of the 'reworked' Torrens Hinge Zone along the eastern margin of the Gawler Craton;
- the upper boundaries of a possible high-density displaced crustal block beneath the Adelaidean Fold Belt.

South Australian Geophysical Models: The surface model constructed provided the framework for three-dimensional geophysical modelling. This geophysical modelling approximation is based on a spatially consistent volumetric framework delimited from the surface objects.

The geophysical responses generated from the models represent anomaly responses and not the total potential field response (Jessell, 1997). These results attempt to reconcile the three-dimensional geological and geophysical inferences established from observations.

Three-dimensional Grid Models: The generated grid model consists of regions specific to each of the modelled block units. These regions comprise an assembly of volume elements that are defined for every point in the modelled block, and globally in the entire model space. The dimensions of individual volume elements for the upper and deeper crustal-level models were designed as 2 cubic kilometres and 5 cubic kilometres respectively.

South Australian Petrophysical Models: A composite grid model of 37 regions corresponding to 28 main lithological units and lithospheric structures was created for the upper crustal-level model. Similarly, a total of 15 regions was created for the deeper level-crustal scale model. These regions are illustrated in figures 14 to 17 and are directly analogous to the surface model representation shown in figures 10 to 13.

Upper crustal-level Gravimetric Model: This modelled gravimetric anomaly response demonstrates a poor level of correlation with the surveyed results (Figure 18). In areas where recognised gravity structures are interpreted in the observed dataset, corresponding regions in the model do not in general match in geometry or intensity. The synthetically generated field displays several distinct domains of anomalous mass distributions predominantly in the central regions of the Gawler Craton and on the eastern and northern provinces of the state. The relatively high gravity, polygonal-shaped anomaly in the central Gawler Craton is consistent with interpretation of the deep-seated, regional-scale gravity response of the mafic underplate, which occurs in close spatial association with the Gawler Range

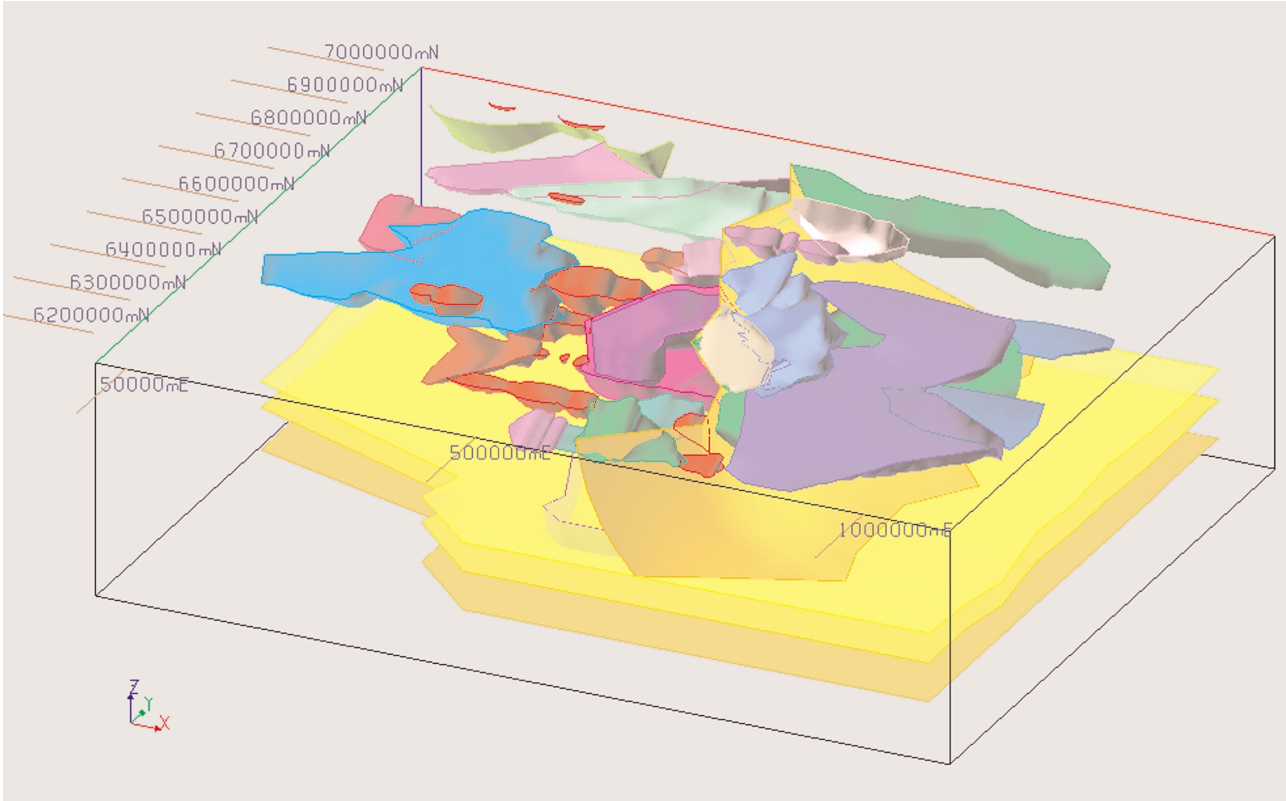

Figure 10. gOcad three-dimensional surface representation of upper crustal-level structures of the South Australian model. View is towards N335 at 25 degrees elevation. **(Click image to view gOcad™ model; VRML plugin available at http://www.parallelgraphics.com/)**

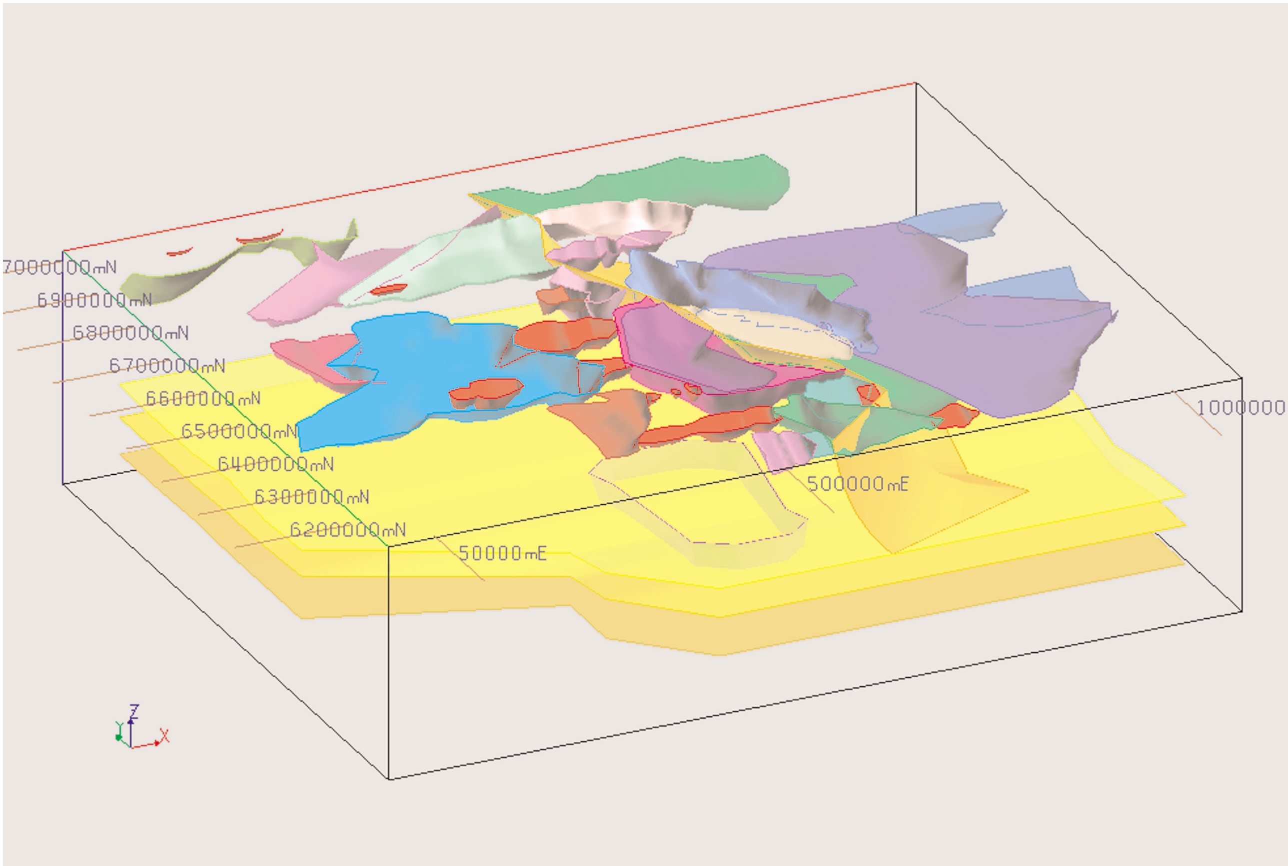

Figure 11. gOcad three-dimensional surface representation of upper crustal-level structures of the South Australian model. View is towards N025 at 25 degrees elevation.

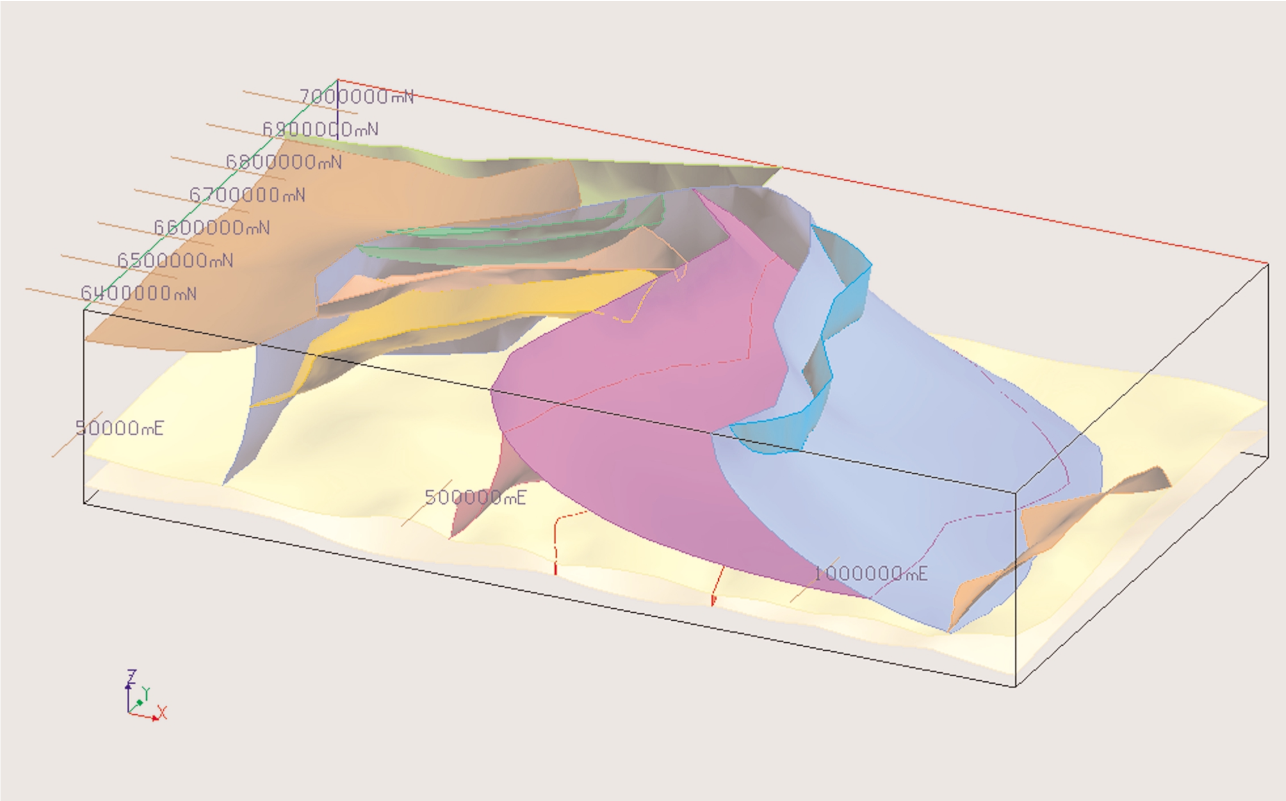

Figure 12. gOcad three-dimensional surface representation of the deeper crustal-level structures of the South Australian model. View is towards N335 at 25 degrees elevation.

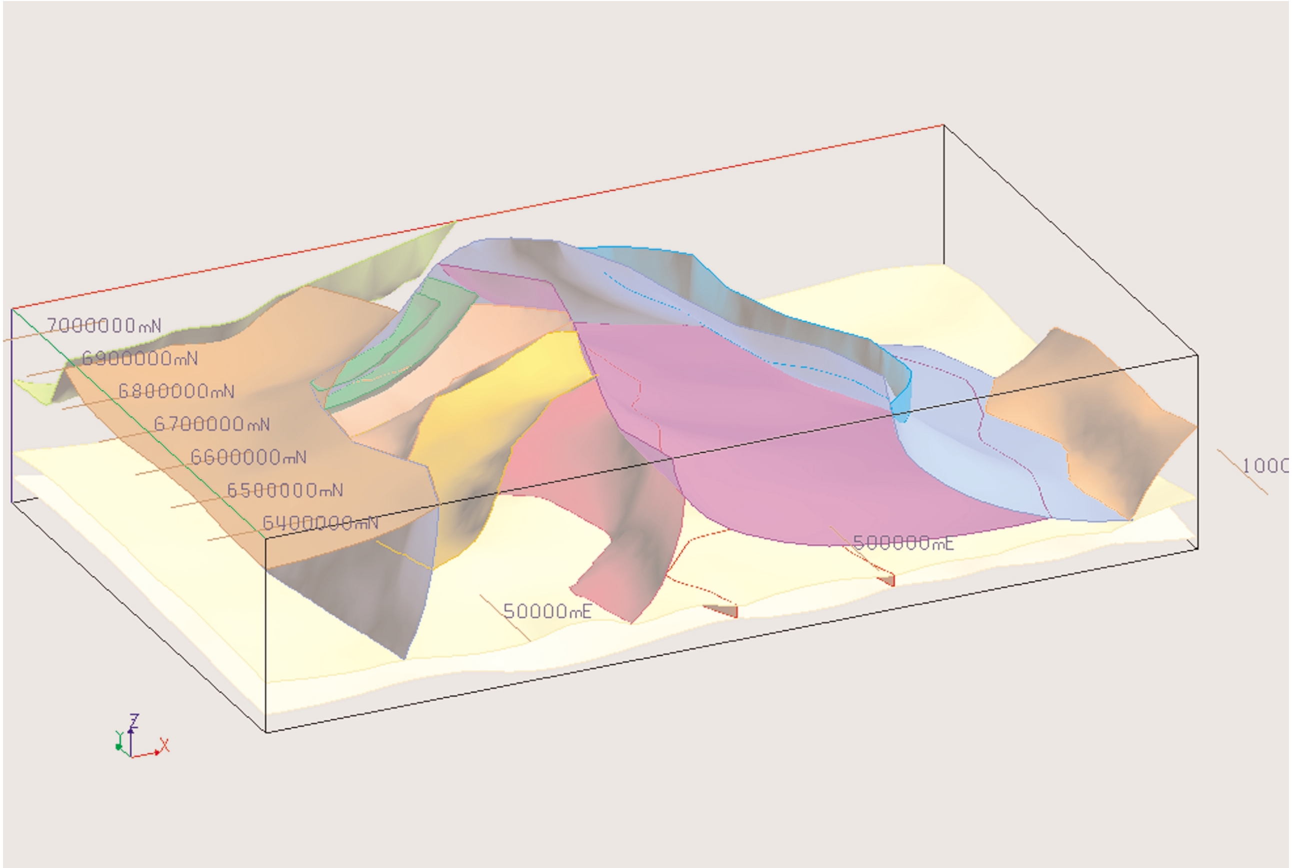

Figure 13. gOcad three-dimensional surface representation of the deeper crustal-level structures of the South Australian model. View is towards N025 at 25 degrees elevation.

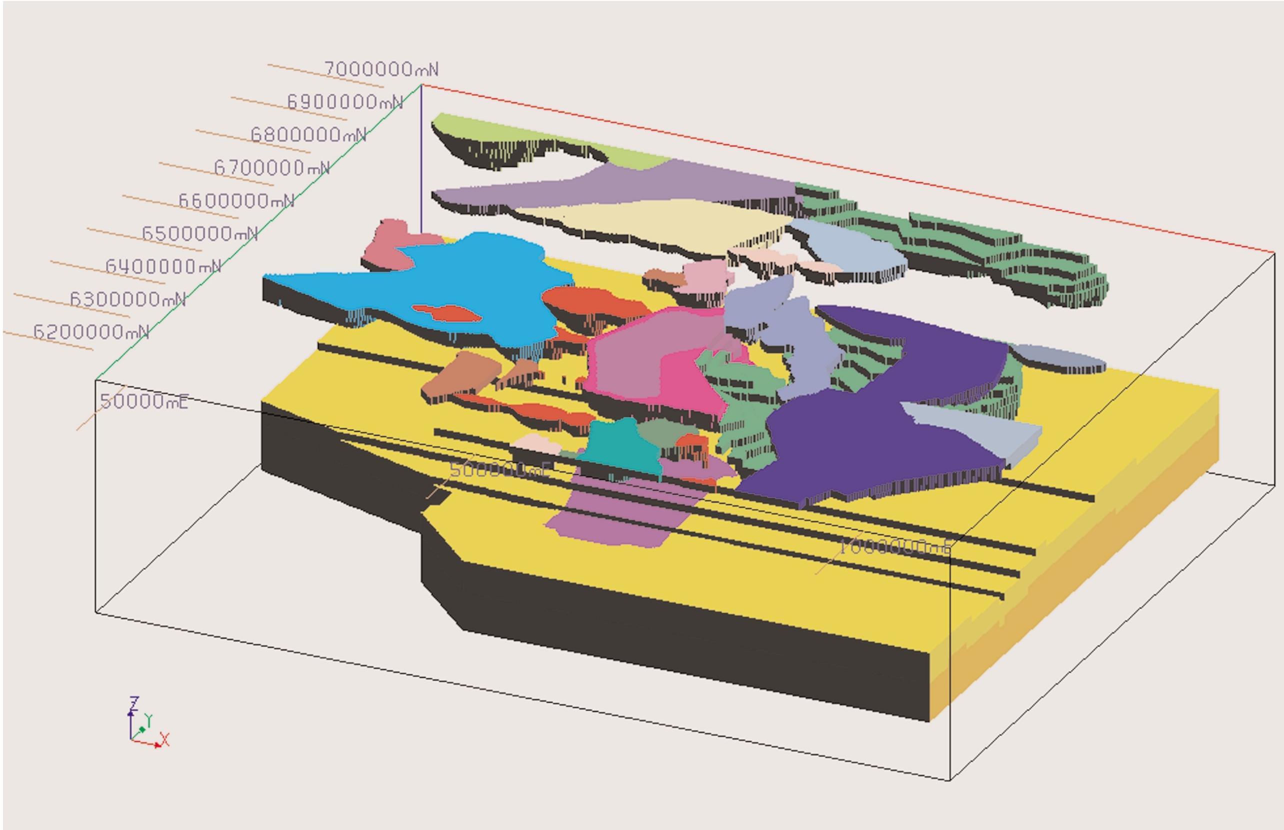

Figure 14. gOcad three-dimensional grid representation of the shallow crustal-level structures of the South Australian model. View is towards N335 at 25 degrees elevation.

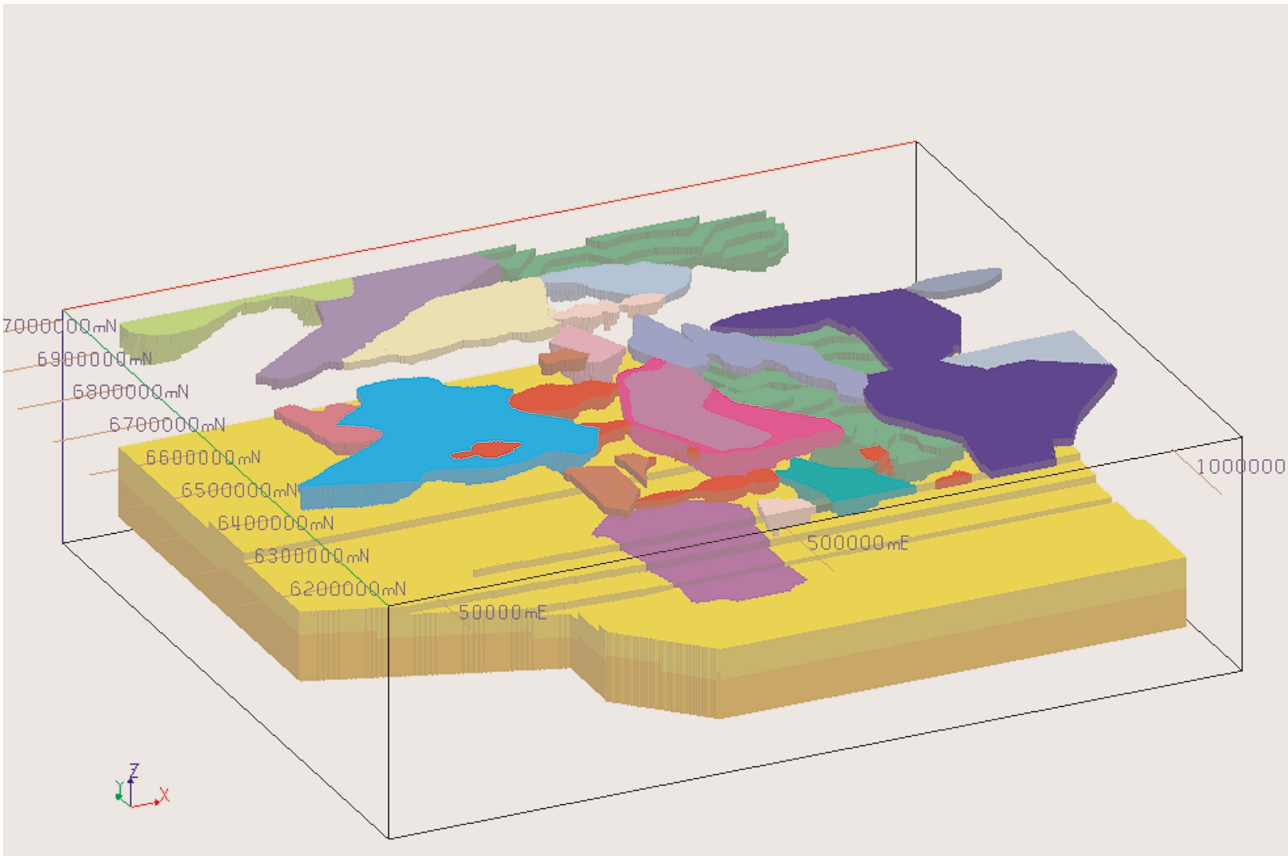

Figure 15. gOcad three-dimensional grid representation of the shallow crustal-level structures of the South Australian model. View is towards N025 at 25 degrees elevation.

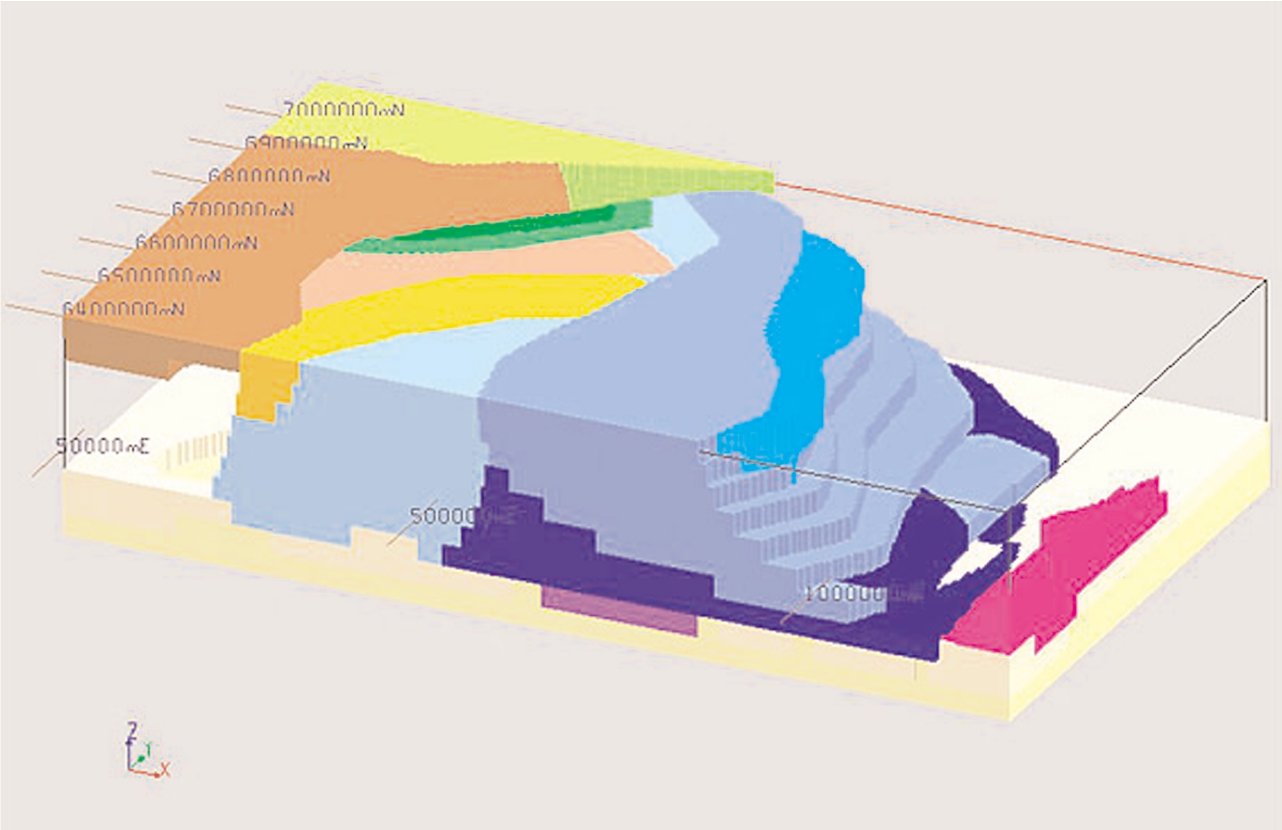

Figure 16. gOcad three-dimensional grid representation of the deeper crustal-level structures of the South Australian model. View is towards N335 at 25 degrees elevation.

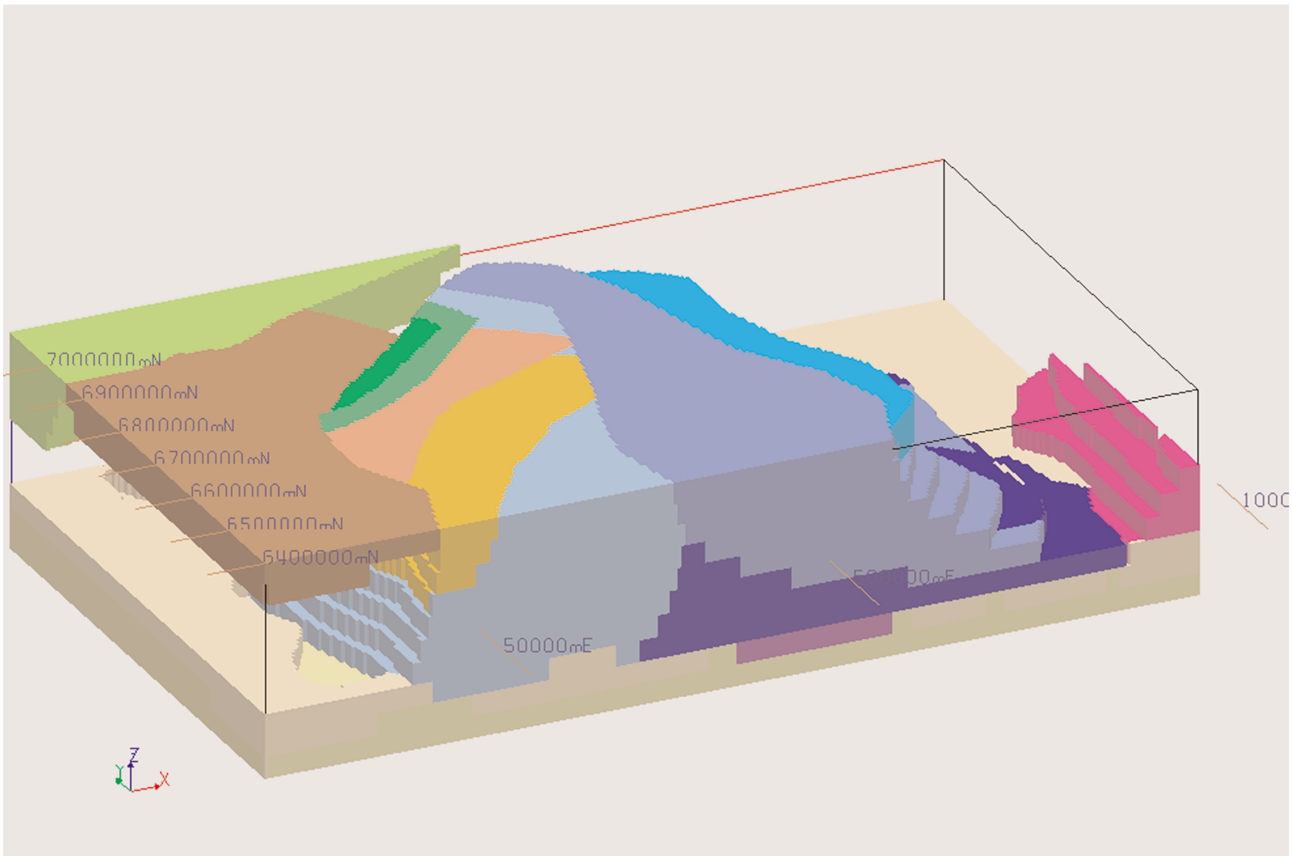

Figure 17. gOcad three-dimensional grid representation of the deeper crustal-level structures of the South Australian model. View is towards N025 at 25 degrees elevation.

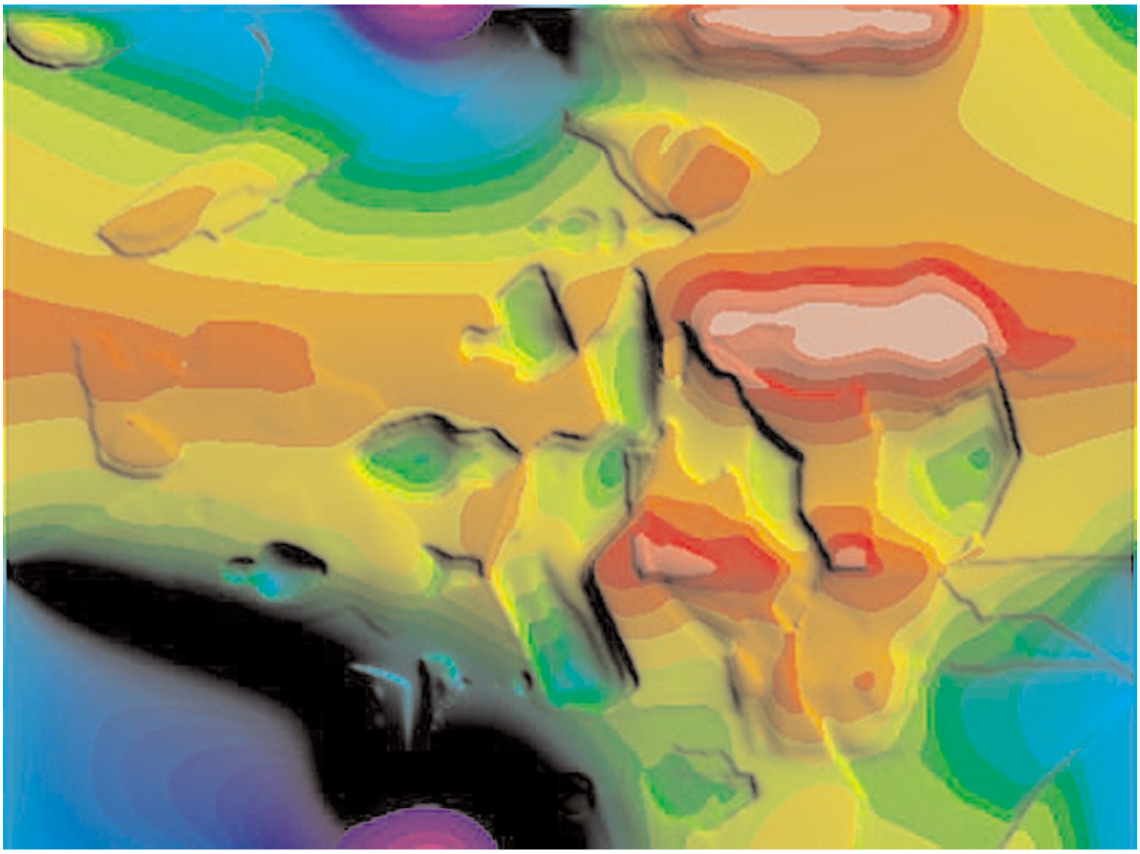

Figure 18. Synthetic gravimetric anomaly response of the shallow crustal-level model.

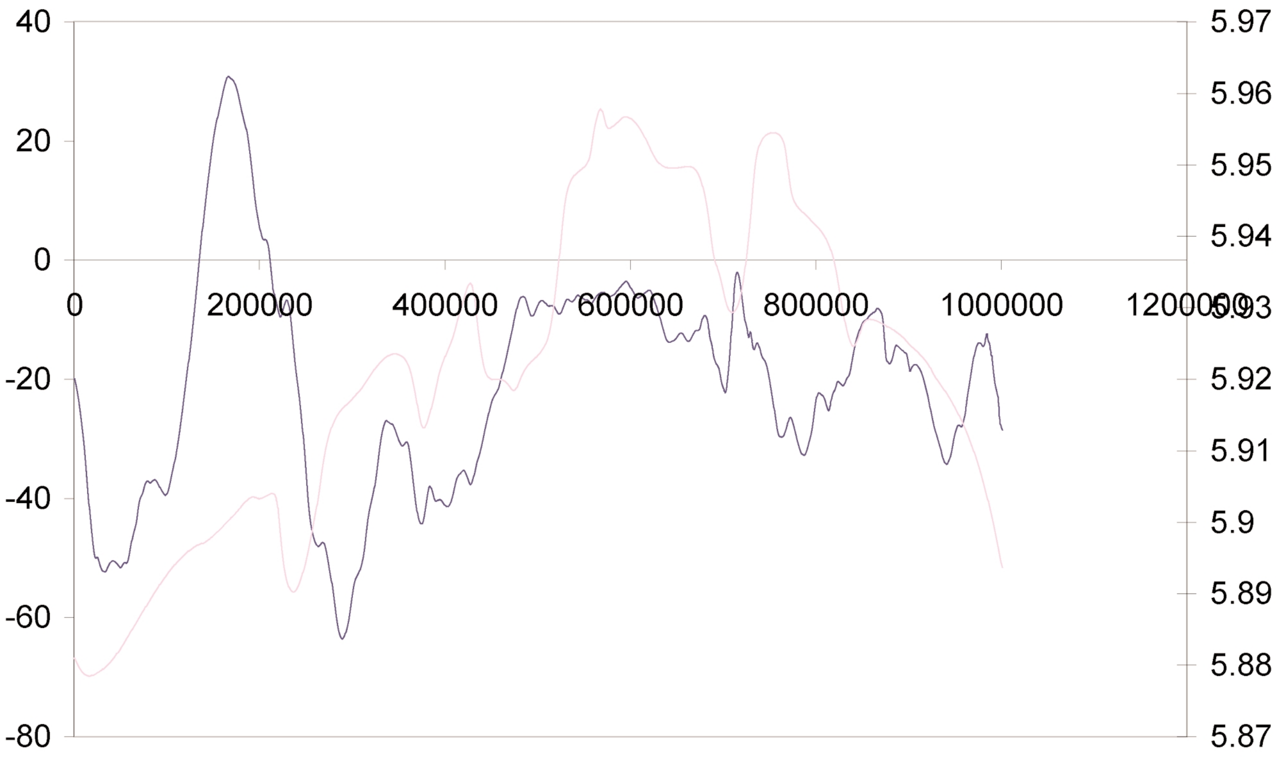

Figure 19. Comparison of traverses extracted across the line of 6500000mN from the shallow crustal-level model; (a) broken line represents response from the model; (b) unbroken line represents response as measured from the field.

Volcanics Province. Along the eastern cratonic margin, a number of strong east-west trending, relatively high gravity signatures are defined. These are the modelled response of displaced crustal blocks neighbouring the Kimban Suture Zone. Evidently, the geometry and/or rock properties of this series of crustal blocks are greatly inaccurate and may point to another source of the observed anomalies. Many of the shallow-level supracrustal sequences and accretionary terranes located on and around the cratonic margins do not have a relatively strong or characteristic modelled gravity response – with the exception of the Peake & Denison Inlier in the northwest of the craton. It is clear the response of most upper-scale geometries from the model represent distinct punctuated gravity lows superimposed upon the response of the regional structures. This is exemplified by relatively low gravity signatures from the Adelaidean Fold Belt, the Gawler Range Volcanics and the Stuart Shelf, the Mabel Creek Ridge and Mount Woods Inlier, the Lincoln and Ifould Complexes, the Hutchison Group and much of the Hiltaba Suite Granitoids.

The contrasting gravimetric signatures are further apparent in the traverses of figure 19. These profiles were extracted across the line of 6500000mN (AMG) from both images. There is visible disparity in the distribution of anomaly sources. The geometrical aspects of the anomaly waveforms are clearly dissimilar with obvious discrepancies in the anomaly amplitude and wavelength between the calculated and surveyed data. In addition, the gravimetric intensity values from the observed data is significantly greater than that calculated.

Deeper crustal-level Gravimetric Model: This modelled gravimetric anomaly response demonstrates a moderate level of correlation with the match-filtered gravimetric dataset (Figure 20). The lithospheric-scale model exhibits distinguishing structures in which the following features are comparable;

- the relatively high-gravity response and curvilinear geometry of the Musgrave Block;
- the relatively low-gravity response of the Officer Basin;
- the relatively high-gravity, northeast-southwest trend of the western and north-western domains of the Gawler Craton defining the western cratonic margin;
- the general low-gravity response of the central domain of the craton;

The synthetic gravity response however fails to account for an important part of the observed anomalies in the eastern and northern regions of the study area. The most significant disparity is the relatively high to extremely high, large gravity anomaly in which the model has calculated. Much of this area encompasses the Adelaidean Fold Belt, the Curnamona Craton and associated supracrustal rocks of the Willyama, Mount Painter and Mount Babbage inliers.

Nonetheless, the geometrical and petrophysical similarities are further demonstrated in their respective gravity profiles extracted across the line of 6500000mN (Figure 21). The geometrical aspect of their waveforms appears broadly similar, displaying duplicate gravity lows and highs in the west and central regions. However, there are obvious inconsistencies in the amplitudes and wavelengths between the two profiles further across to the west of the state. Apart from these apparent differences, the calculated gravity anomalies exhibit slightly higher average intensity values.

Discussion

The main contributions to this investigation involved rationalising the gravimetric field characteristics of lithospheric-scale substructures of South Australia. This section presents a brief discussion of significant elements of the interpretation of the datasets that were used to construct the three-dimensional models of the South Australian lithosphere in the context of two- and three-dimensional potential field modelling.

Geophysical boundaries of the Gawler Craton

Profile modelling of crustal level sources in the gravity data indicates that the geometry of the Archaean Gawler Craton at its margins varies significantly in the third dimension. The western margin is a markedly steep, west-dipping suture defined by an intense negative anomaly low. The structure of this boundary is curvilinear and marks an abrupt transition into Archaean and Palaeoproterozoic rocks in the west. Modelling of the northern cratonic margins indicate an analogous sub-vertical, north-dipping suture. The eastern margin, referred to by Betts (1999) as the Kimban Suture Zone, is in contrast a relatively shallow, east-dipping suture. Crustal thicknesses defining the basal contact between the cratonic margins and the lower crust are however comparable in depth.

Although unsubstantiated, division of the Gawler Craton into large elements to essentially characterise the different gravity signatures of the Archaean complexes has agreed somewhat with the measured gravity data. The modelled western cratonic element differentiates the Mulgathing Complex predominantly in the central and northern regions of the Gawler Craton from the Sleaford Complex found largely in the south and east of the Gawler Craton. The contacts of each cratonic element may represent possible ancient suture zones to protoliths of the Mulgathing and Sleaford complexes.

Origin of various anomalies

The source of the relatively moderate to high, polygonal shaped long wavelength, regional gravity anomaly in the central Gawler Craton has been ascribed to a mantle derived mafic underplate intruding the lower crust (Blissett et al., 1993). Modelling of this anomaly demonstrates the likelihood and existence of such a body. This high-density sheet-like mass is interpreted as the remnants of a possible mafic underplate.

Modelling of various regional-scale anomalies in the east and northern regions of the state adjacent to the eastern margin of the Gawler craton indicate the presence of relatively shallow to mid-crustal level dense bodies of unknown origins. The modelling of displaced crustal

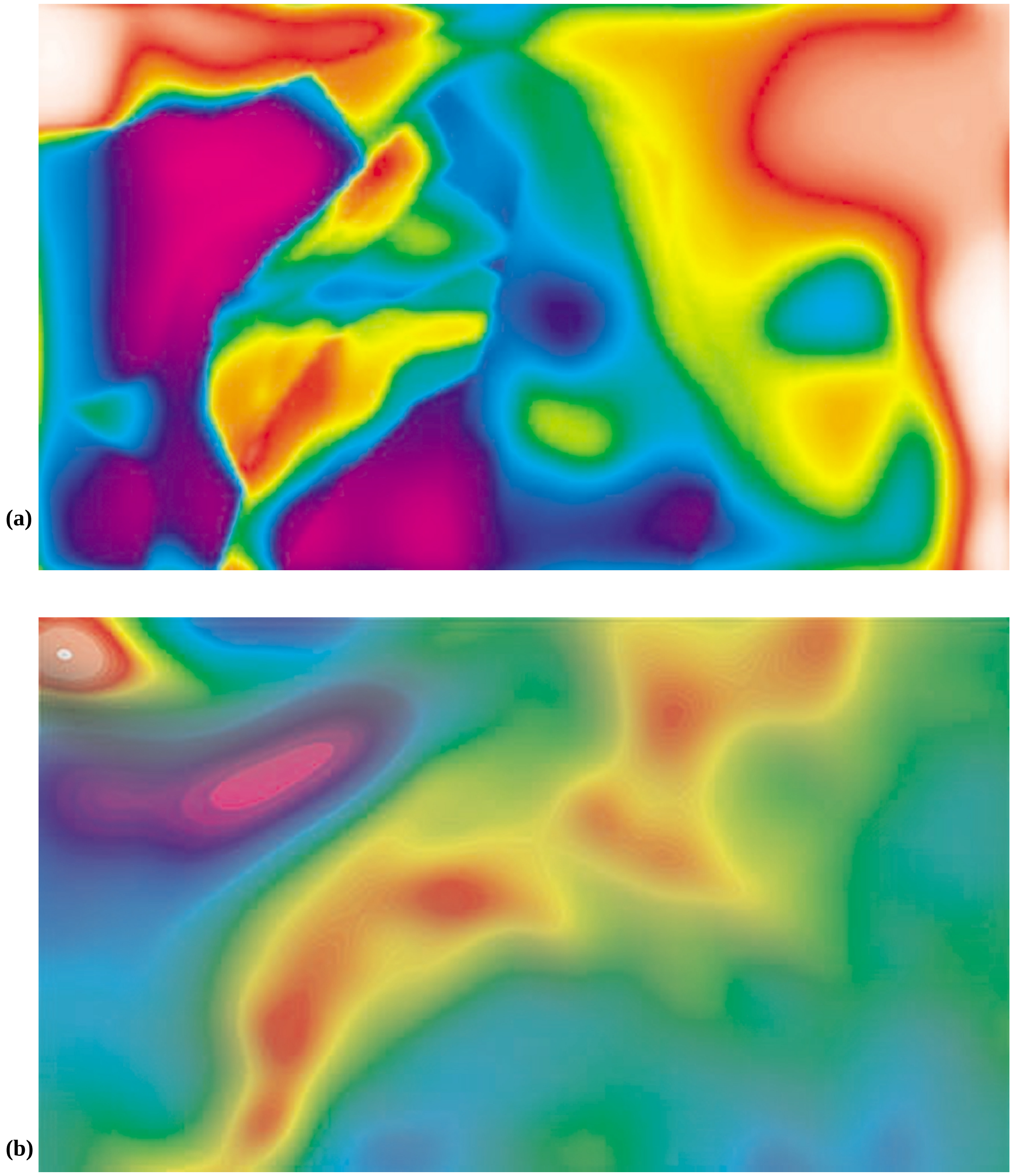

Figure 20. Comparison of the modelled gravimetric response with the match-filtered data; (a) synthetic gravimetric anomaly response generated from the deeper crustal-level model; and (b) match-filtered image of the surveyed gravimetric dataset of South Australia.

blocks beneath and further north of the Stuart Shelf cannot however, be directly correlated (in three-dimensions) from the calculated anomaly response. These bodies exhibit a much higher signature than indicated by the measured dataset and the nature of the source appears to emanate from relatively deeper crustal levels than modelled in the profiles. It is possible that these bodies represent shallow crustal-level plutons. The existence of such bodies however, remains speculative.

Petrophysical Characteristics

The forward modelling technique of calculating a gravity response from a geological model requires; (i) defining geometrical dimensions; and (ii) assigning homogeneous rock properties. The latter is an inherent assumption in both the two- and three-dimensional geophysical modelling undertaken in this investigation. The density values used in both forms of the modelling represent a first-order approximation on the three-dimensional distribution of anomalous cryutal blocks. Although the densities are not definitive of any one particular rock type, they do however

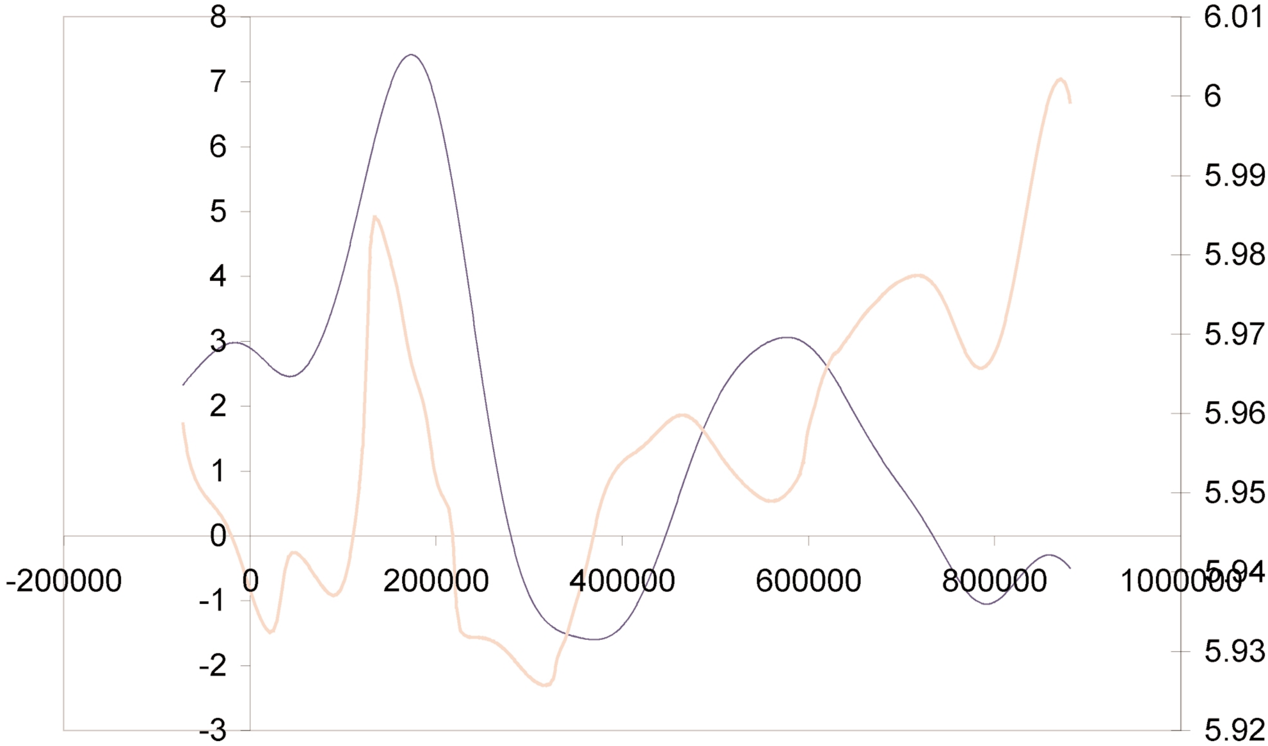

Figure 21. Comparison of traverses extracted across the line of 6500000mN in the deeper crustal-level model; (a) broken line represents response from the model; (b) unbroken line represents response as measured from the field.

provide a primary constraint on the crustal composition and also aid in defining contacts between rocks of similar characteristics.

Matching of the gravity signatures across the profiles reveal rocks of the Palaeo- and Mesoproterozoic exhibit an overlap of density values. Nonetheless, modelling of the Archaean crust indicate average values (2921 kg/m3) typically greater than rocks of the Palaeoproterozoic (2782 kg/ m3). Likewise density values of the Palaeoproterozoic are in general, greater on average than rocks of the Mesoproterozoic (2646 kg/ m3). The central Gawler Craton province of the Gawler Range Volcanics display very similar ranges of values between the Gawler Range Volcanics, Hiltaba Suite Granitoids and associated sediments. In addition, Neoproterozoic rocks of the Adelaidean Fold Belt, Stuart Shelf and the Officer Basin reflect comparable average modelled density values (2652 kg/ m3) to those of the Kararan Orogen.

Level of modelling

The upper crustal-level models show that geometrical sources of the high frequency domain modelled against the gravimetric profiles do not, in general, extend to depths greater than approximately 10 km. The profile modelling of crustal structures at depth cannot however, be viewed in isolation without an understanding of the level of information associated with the gravimetric dataset. The measured dataset provides information on the three-dimensional distribution of anomalous masses in the Earth's crust (Telford et al., 1995). Modelling of this field requires interpretation and or knowledge of the structures as it is progresses with depth. The image processing technique of depth-slicing (Berger & Reudavey, 1996), where a separation filter such as a matched filter is used to effectively isolate a cumulative ensemble of sources at a given depth, can facilitate better resolution of modelling and interpretation. Unfortunately, the matched filtering technique currently available (and employed in this investigation) does not provide a clean separation of frequencies for different depths (pers. comm. P.McInerney) and is at best a 'pseudo depth slicing'. For this reason, the two-dimensional profile modelling was not conducted on the matched filtered image because certain frequencies of the data, which was meant to have been removed, were reintroduced into the filtered dataset. Modelling and interpretation of the deeper crustal-level components was restricted to matching the broader and longer wavelength components of the profile. There are clear and obvious inaccuracies associated with this procedure, such as the unknown level at which the modelling is undertaken.

Conclusions

This study presents an example of the use of regional-scale geological and geophysical datasets for modelling geometrical and petrophysical properties in an area largely concealed beneath sedimentary cover. Two- and three-dimensional forward gravimetric modelling of lithospheric-scale structures of South Australian reveals geometrical and petrophysical differences in the crustal architecture between the Archaean Gawler Craton and interpreted margins of Palaeo- to Meso-proterozoic accretionary complexes immediately adjoining and surrounding the cratonic nucleus.

Profile modelling of the shallow crustal-level structures inherent in the high frequency domain of the South Australian gravimetric dataset indicate supracrustal sequences of the Kimban and Kararan Orogen do not extend to depths greater than ~10 km. The modelled geometry, size and crustal levels of these accretionary terranes reveal a marked change of crustal composition throughout particular rock types. This lateral change of rock property is reflected in discrete modelled blocks exhibiting predominantly sub-vertical contacts likely related to normal faulting.

Profile modelling of the deeper crustal-level structures of the gravimetric dataset indicates differences in the modelled geometry and crustal level response of the Archaean nucleus when compared to the modelled interpretation of the Gawler Craton and supracrustal sequences developed in the upper crustal-level models. This is apparent where each of the profiles is modelled to essentially match the relatively longer wavelength components of the gravimetric dataset.

The modelled profiles were subsequently integrated into a two three-dimensional geometrical models, which provided the framework for rock property modelling. This model demonstrates that the interpreted geophysical boundaries of the Archaean nucleus vary in geometry. The eastern cratonic margins dips shallowly to the east while the western and northern cratonic margins sub-vertically dip to the west and north respectively.

The generation of synthetic gravimetric anomaly responses from the three-dimensional models provided a test for comparison of the two- and three-dimensional interpretations against the measured dataset. The modelled anomaly response of the shallow crustal-level structures demonstrates a poor level of correlation with the measured dataset. Although the modelled profiles show a good match of the data, the transition to a three-dimensional model interpretation does not support a direct correlation of the most of the interpreted structures. The modelled gravimetric response of the deeper crustal-level sources demonstrates a moderate level of correlation with the match-filtered dataset. Despite the apparent discrepancies between the model response and target data, the generated field gives some confidence to the interpretation of the lithospheric-scale geometry.

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