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An interpretation of the granitoid rocks of eastern Tasmania

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Summary

This study was commissioned by Mineral Resources Tasmania to provide a current, revised view of granitoids in eastern Tasmania, including Flinders Island, which would permit creation of a comprehensive three-dimensional model. The work is essentially an update of Leaman *et al.* (1980) and Leaman and Richardson (1992, 2003). The report includes the first integrated assessment/compilation of gravity and magnetic data across Tasmania and Bass Strait.

The interpretation of the granitoids at such a regional scale has necessitated consideration of many other geological elements — including the contents of Bass Basin and the exposed Paleozoic and Precambrian rocks of the western side of Bass Strait. Granitoid rocks, alone, appear to form 'basement' only in the east.

This new interpretation differs radically from all previous assessments in that it is neither assumed, nor found, that the granitoids, whether individually or as batholithic complexes, are universally deeply-rooted plutons. The former view can only be maintained in western Tasmania where smallish, isolated bodies are present, and also with respect to exposed granite near Three Hummock Island or southern King Island (here considered one intrusion). In eastern Tasmania the intrusive bodies do not generally possess such deep roots (inferred up to 9–10 km in western Tasmania) and many appear terminated at relatively shallow depth (or may be termed detached in most cases, and certainly in bulk). This structural style was first inferred for the Housetop Granite in northwest Tasmania (Le Clerc, 1996) where a large magnetic anomaly associated with the exposed granite demanded a new solution. A detachment where ultramafic rocks underlie the granite was inferred at four to six kilometres depth. A similar character to the Housetop example appears to be general across eastern Bass Strait, northeast Tasmania and, perhaps, southern Victoria where both magnetic and density anomalies, inconsistent with deeply-rooted granitoids, are evident.

The termination implied, herein termed a detachment, is general and lies at a depth of four to seven kilometres. The termination structure is curved, upward to the west, and with splinters into other units in most areas. In Tasmania these splinters can be found near Beaconsfield and many locations in northwest Tasmania (see also Leaman and Webster, 2002). It is not clear just how far south, within Tasmania, this structural style persists but it may be as far as the south coast (e.g. Leaman, 1992).

Consideration of the apparent ages of granitoids which appear either to be terminated at shallow depth, or crustally penetrative (more deeply rooted), leads to a view that general detachment first occurred before the youngest intrusions were emplaced, or that some fortuitous juxtaposition has happened as a result of movement (unlikely). Smaller, penetrative plutons include, for example, south Ben Lomond, Bicheno, north St Helens/Eddystone and possibly some sites north of Flinders Island.

A similar situation involving deep plutons may apply south of Coles Bay/Freycinet along the coast but, as described, there are some concerns about data coverage near the eastern continental margin.

Modelling, although often ambiguous — especially in the gravity case, due to limited control of any sort — indicates massive displacement, or termination, of the batholiths. The integration with magnetic data across Bass Strait allows placement of limits on the structures involved and yields a coherent view of the general granitoid mix (proportions of granite/adamellite to granodiorite, and a basal surface). While the complexes may once have included discrete plutons, especially of granite/adamellite, these now appear wholly detached.

If the structure which appears to terminate, or slice, the batholiths is a true thrust/detachment then it involves slices or pods of material with the properties of ultramafic rocks. This is a view comparable to the current interpretation of the Housetop Granite (Le Clerc, 1996). Slivers of Cambrian ultramafic rocks can be traced from this structure into outcrops across northern Tasmania. As the granitoids are principally Devonian in age, while ultramafic rocks are nominally Cambrian in age, it must be presumed that the age of detachment and movement inferred is intra-Devonian, as not all granitoids are involved. The quality of the present interpretation, and also of the dates of the granitoids, does not permit any better estimate of the age of structuring than about 360 to 380 million years (Middle Devonian).

Introduction

This report provides a new interpretation of the general structural form of the granitoids of eastern Tasmania (including Flinders Island) and the islands of eastern Bass Strait. It marks a considerable evolution from previous studies such as Leaman *et al.* (1973, 1980) or Leaman and Richardson (1989*a*, *b*; 1992).

The analysis is regional and there remains much scope for detailed examination of individual plutons, as has been done for intrusions in western Tasmania (e.g. Leaman and Richardson, 1989*b*; Leaman, 2002 and various company reports for Pasminco and RGC Ltd, 1990–1994).

Some aspects of the regional geology have not been included due to scale of influence or the resolution of data as sampled. This means that some features of intrusions of Jurassic dolerite and Tertiary basalt, in particular, have not been considered.

More detailed study should not proceed until some of the inferences described here have been confirmed or reviewed, as some elements of the interpretation are novel and radical — and often unsupported by fact (such as drilling).

Other regional studies, such as that of Gunn *et al.* (1997), Teasdale *et al.* (2001) and Blevin *et al.* (2005), have described or inferred some major intra-crustal structures which must involve northeast Tasmania and its granites which also form the basement to the eastern side of the Bass Basin.

The data used for this review were gravity and magnetic compilations of the Tasmania region, assembled by Mineral Resources Tasmania from State, National and exploration surveys. Variable quality is to be expected in such compilations but it is considered that the poorest quality data (mainly in the region of Bass Strait) is more than adequate for a regional analysis of the type reported here. The compilations are presented as Figures 1 and 2. The gravity data, reduced at 2.67 t/m^3, has also been converted to a residual by the separation process defined by Leaman and Richardson (1989*a*) using the current guide model MANTLE09 (Leaman, 2009).

The gravity image (fig. 2) reveals several features which must be considered in analysis. Continental Tasmania is essentially Bouguer positive with some zones in northwest, southwest and central northern Tasmania strongly positive. Similar positive character persists across part of Flinders Island.

More strongly positive character has been observed north of Cape Grim towards Victoria via King Island. A clue to the origin of this response may be provided by the more constrained anomalies south of Macquarie Harbour where Cambrian mafic and volcano-sedimentary sequences are exposed.

Within this setting there are well-defined negative anomalies associated with some granitic intrusions, e.g. Heemskirk, Granite Tor, Meredith and Dolcoath in western Tasmania, and Ben Lomond, Bicheno and St Helens in eastern Tasmania (see also fig. 31). Comparable responses appear associated with the Three Hummock Island–south King Island intrusion and west of Cape Barren Island but broad regions of granitoids offer no significant negative response. This raises queries about the volume and depth extent of this material, or the proportion of granodiorite:granite-adamellite.

The reduction in gravity field intensity west of Cape Barren Island may be associated with the fill of the Durroon Sub-basin.

Figure 1 clearly shows intense features off the west and east coasts/continental margin. The western belt of anomalies extends continuously into Bass Strait from the south and may extend into Victoria east of Port Phillip Bay. There is a bifurcation in this trend at the southern end of King Island with the major section to the east. Other large anomalies may be observed in central Bass Strait, extending from near King Island to the northeast tip of Tasmania. Other structures of, perhaps, comparable origin and orientation may occur beneath the Gippsland Basin and stretch from beneath basement in Victoria eastward to the continental margin.

The fine texture of the magnetic field in Tasmania is mainly due to Jurassic dolerite or Tertiary basalt. A variably acquired and reduced magnetic compilation of the island should not be over-interpreted. More recent, and reliable, surveys provide better definition of sources of all types (e.g. Leaman and Webster, 2002).

On Figure 2, large positive gravity effects can be correlated (*cf.* fig. 1) with the western (and eastern side of King Island) magnetic belt off the coast. Large negative effects may be observed in the central Bass Basin (presumably due to Bass Basin sedimentary section) and off the east coast; the latter possibly due to inadequate data coverage. The heart of Bass Basin is apparent, as is the general NW–SE structuring of the basin.

An elongated N–S gravity gradient (strongly negative to the east) extending from Waterhouse to Port Arthur is colloquially known as 'the great granite wall'. This effect persists off the east coast where minimal coverage and depth of water may contribute to the effect.

Tasmania, as a whole, is generally Bouguer residual positive using the current mantle separation model (see text).

The magnetic coverage (fig. 1), although of variable quality (on and off shore as noted above), is more suggestive of general geological correlations and structural ties or of internal variations within units, than is the gravity. Many features extending across the north coast may be identified. These include Cambrian volcanic rocks at Smithton/Edith Creek; Arthur Lineament belt of altered/metamorphosed rocks; and extension of ultramafic rocks from Heazlewood, Penguin and Beaconsfield. Other large anomalies extending beneath northeast Tasmania have also been linked to ultramafic rocks (presumed Cambrian in age) (see Roach, 1994; Leaman, 2002).

Most of these features can be traced into, and indeed across, the very heart of the Bass Basin, albeit in variously modified

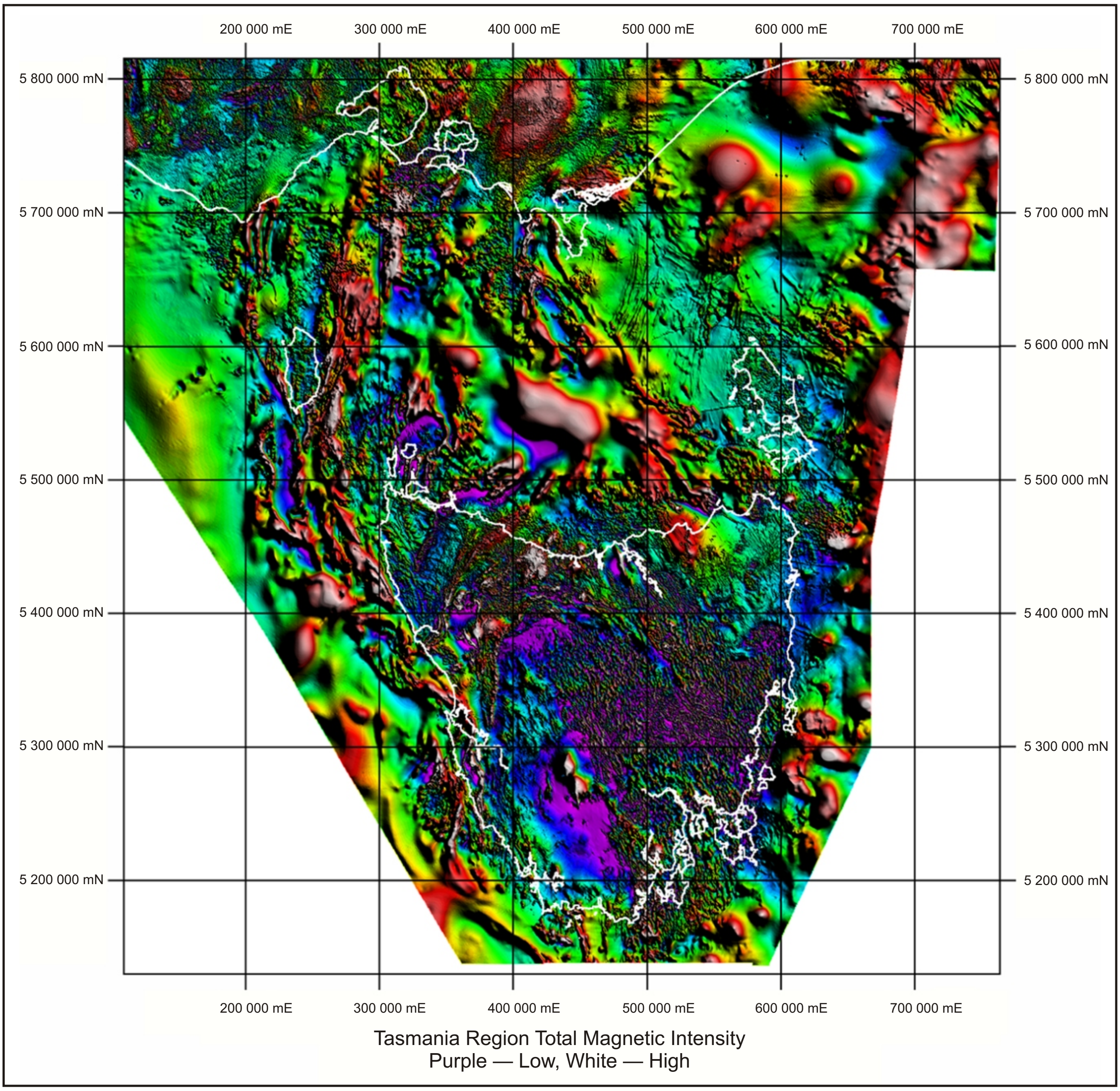


Figure 1

Compilation of aeromagnetic data. Compilation supplied by Minerals Resources Tasmania, 2011.

forms which can be associated with changes in dip, composition or depth. These propositions are tested and discussed below. An important issue raised by the magnetic field is the observation that many large anomalies, of a type that in the past has been associated with ultramafic rocks, occur across the 'granitoid' belt extending from northeast Tasmania via Flinders Island to southern Victoria. This factor has also been reviewed below.

Some of the most pronounced magnetic anomalies lie along the continental margins, both east and west, and force consideration as to whether some aspect of the margins is important or if some deep features have been sliced and exposed by the continental separations involved.

The questions already posed, or perhaps resident in the mind of the reader, present implications for theories about the origin of, or precise nature of, the Bass Basin as well as of the granitoids. It has been presumed that the basin is a failed rift related to a dextral shear couple, but the data already described merely suggest a quite narrow sunken belt extending NW–SE with major marginal structures of this trend, and no evidence for W–E shears either to the north or south (Gunn *et al*., 1997). To this uncertainty Gunn *et al.* (1997) do offer that some features appear to be traceable from Tasmania to Victoria; there may only be modest transfer faulting (also Etheridge *et al*., 1984), a mid crustal detachment and some deep igneous bodies. Note that consistent NW–SE trends occur right across Bass Strait to the Gippsland coast (see fig. 1). Other recent work, such as Teasdale *et al.* (2001) or Blevin *et al.* (2005), expands on these themes or suggests a major crustal interface between Kanmantoo/Lachlan Fold Belt styles which has been mobilised. Teasdale *et al.* (2001), in particular, link this to the concept of a Tamar Lineament in Tasmania. This 'structure' has been disputed. It may not exist, or exist where inferred (Leaman, 1994*b*; Reed *et al*., 2002).

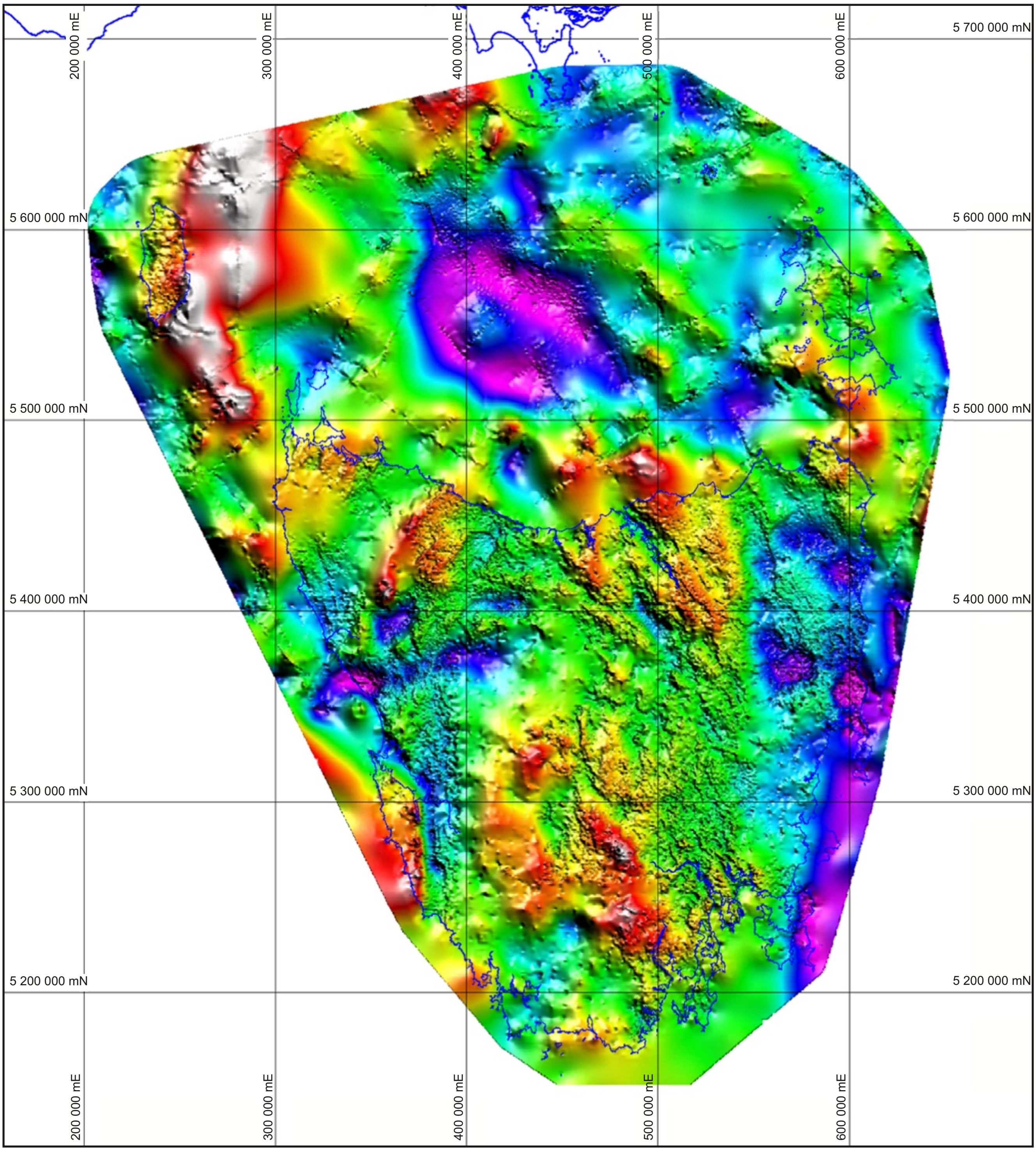


Figure 2

Residual Bouguer anomaly, density 2.67 t/m^3
Compilation supplied by Mineral Resources Tasmania, 2011.

It is clear that the new compilations require some comprehensive analysis and interpretation of many options and possibilities. It has not, previously, been possible to ask such questions or attempt answers and, it must be admitted, there might remain inadequate levels of constraint or control so as to render any conclusions invalid — although trends, or weight of consistency and assessment, may indicate the real nature of solutions while not providing a detailed quantification.

Further comment in expansion of qualitative implications follows in association with detailed extracts displayed in Figures 3, 4 and 5.

Interpretation and Discussion

The interpretation/discussion described in this report begins with consideration of the Bass Basin. This has been done as there is considerable uniformity in geophysical responses, both magnetic and gravity, between Mathinna–Scamander in the south (Tasmania) and Wilsons Promontory (Victoria) in the north, and this entire belt forms the eastern side of Bass Basin by providing a granitic 'basement'.

Within this region, so apparently dominated by granitoids, there are few suggestions of individual, discrete, deeply-rooted or contrasting plutons north of St Helens. While this may reflect data quality and coverage, at face value the only conclusion is that there is a high degree of structural homogenisation which must be explained. Similarly, the large magnetic anomalies of the central basin have previously been linked to volcanic piles deep in the basin or still deeper sources (e.g. Gunn *et al*., 1997).

It was noted in general comment above, and also by Gunn *et al*. (1997), that many magnetic units can be traced into, and perhaps from, the deep basin between Tasmania and Victoria. Volcanic mafic and ultramafic suites of probable Early Cambrian age appear to be involved — as inferred from onshore correlations in northern Tasmania. Changes in anomaly character can be assigned to factors of dip or depth of burial (review some sinuous trends and connections evident in Figure 1; also comments to figures 4 and 5).

Large magnetic anomalies occupy the central Bass Basin, but crucially also extend, in a patchy fashion, both to the northwest and southeast consistent with basin trends. Some elements of these features occur in regions where only granitoids outcrop. Roach (1994) and Leaman and Webster (2002) have associated such responses with detachments carrying ultramafic rocks; structures which have dislocated younger granitoids when rejuvenated.

One of the largest anomalies of this type occurs near Bridport. Any interpretation must deal with such options and evaluate them. The finding that the Housetop Granite in northwest Tasmania carries a similar association with underlying ultramafic rocks and a detachment (Le Clerc, 1996) makes this a live topic for eastern Tasmania.

In order to assess a range of observed geophysical features and ideas relating to origins and correlations, the review begins with the Bass Basin itself and the critical eastern margin apparently formed of granitoids.

The problem with such a starting point or reference is lack of control, but this problem is endemic in all granitoid areas and eastern Tasmania as a whole. The analysis has, therefore, sought to test hypotheses about structural options using available constraints, and to assess implications about physical properties and their consistency (using the methods of Leaman, 1994*a*), or to appraise ambiguities.

After testing this approach in the drilled parts of the Bass Basin an integrated view of basement geology can then be offered for eastern Tasmania.

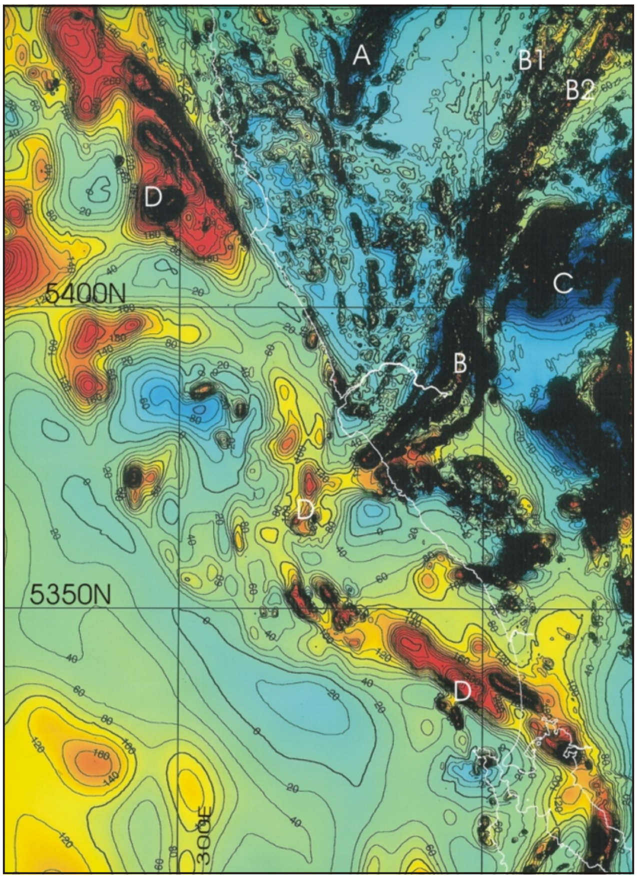


Figure 3

Detail of magnetic compilation, western Tasmania. Compilation supplied by Minerals Resources Tasmania, 2011.

Features in Figure 3 include the southern extension of the Cambrian mafic volcanic belt through Smithton and Edith Creek (A). Highly metamorphosed rocks of the southern Arthur Lineament near Savage River (B) extend northward before bifurcating as the north coast is approached (B1, B2), while east of (C) there is a large and often deep-seated magnetic source which is associated with ultramafic rocks at and adjacent to Heazlewood. Other strings of magnetic sources (D) extend along the west coast with some correlation with the continental margin and other parts which link with various onshore features. The pattern of anomalies and connections suggest multiple sources (of all the types implied above) for these features, especially in the region north and south of Macquarie Harbour.

This coastal zone continues to the coast of Victoria but splits around King Island (see Figure 1). There are also links to the mafic suites along the eastern side of King Island (e.g. near Grassy).

The belt of arcuate features between B and D, south of A, has been previously viewed as a piece of overthrust Precambrian rocks which incorporates the Balfour region (Leaman *et al*., 1994).

The data reveal a non-magnetic region about Three Hummock Island and its exposed granite (fig. 4). The anomalies suggest the scale and extent of the shallow

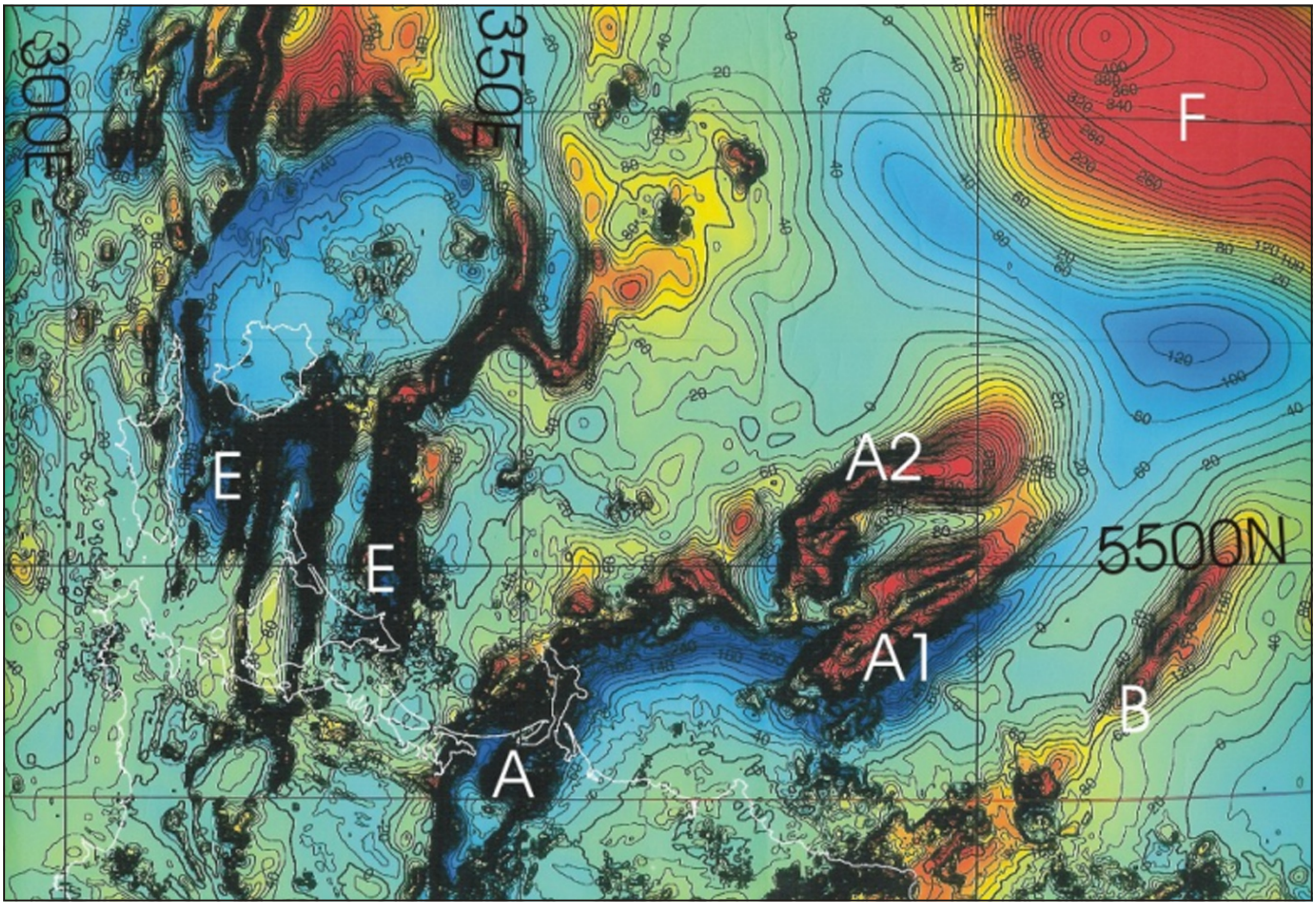


Figure 4

Detail of magnetic field near Three Hummock Island. Compilation supplied by Mineral Resources Tasmania, 2011.

distribution of this granitoid. Magnetic anomalies (E) ring this feature and may represent either volcanic rocks (within older rocks) or a metamorphic alteration halo (more likely). The Cambrian volcanic belt from Edith Creek and Smithton (A) is also evident, as is the change of trend off the coast. The features A1 and A2 define components of the volcanic suite and these are evident while at shallow depth. The feature B is an extension of the highly magnetic belt including the Arthur Lineament and nearby ultramafic rocks. This anomalous feature can be traced into the central basin anomaly (F) and beyond towards Victoria (see also Figure 1).

Downward continuation (fig. 4) results in a separation of effects (e.g. A1/A2) and that the Smithton volcanic belt (A1) not only changes in direction but shallows in dip such that individual units/members become apparent.

This treatment also distinguishes the two parts of the Arthur Lineament (or altered rocks of that zone) to reveal either termination or greater depth to source beneath the Rocky Cape Block (B1) while the belt B2 continues into Bass Strait, if patchily. The same character is noted for the ultramafic belt (C) which extends from Heazlewood. Features E are part of the alteration halo around the granite of Three Hummock Island. Some spiky effects on (A1/A2) are due to Tertiary basalt. The yellow colouring denotes outcropping Tertiary basalt and Jurassic dolerite, associated with high frequency character in the magnetic field. These features are localised, intense and beyond the scope of the present study.

In Figures 4 and 5, units B and C appear to terminate as the deeper parts of the Bass Basin are approached, but inspection of the features implies much greater cross-Strait continuity, much as suggested by Gunn *et al.* (1997).

Detailed examination of many units and their geophysical responses reveals many breaks in anomaly continuity — in rock properties if not in volume or geometry — and a 'podded' or 'lumpy' character is common. Review figures 1, 3, 4 and 5.

The interpretation given henceforth is described in two parts — north of Tasmania including Bass Strait, and continental Tasmania. This presentation reflects the nature of structures; such as domination of Bass Basin to the north, and the data available. Issues with respect to the data sets, gravity in particular, have arisen and these are considered as they present.

The northern coastline of Tasmania, and structures near it, has been used as reference to both parts of the discussion as this is the only region in which geological units and their variations, and much previous work (e.g. Leaman and Webster, 2002) are well-enough known to act as acceptable control upon modelling. The reference profiles are at 5 450 000 mN and 5 475 000 mN. Both offer complete transects of northern Tasmania.

This report includes samples of the ideas and models tested, each intended to suggest the nature of options or trends implied.

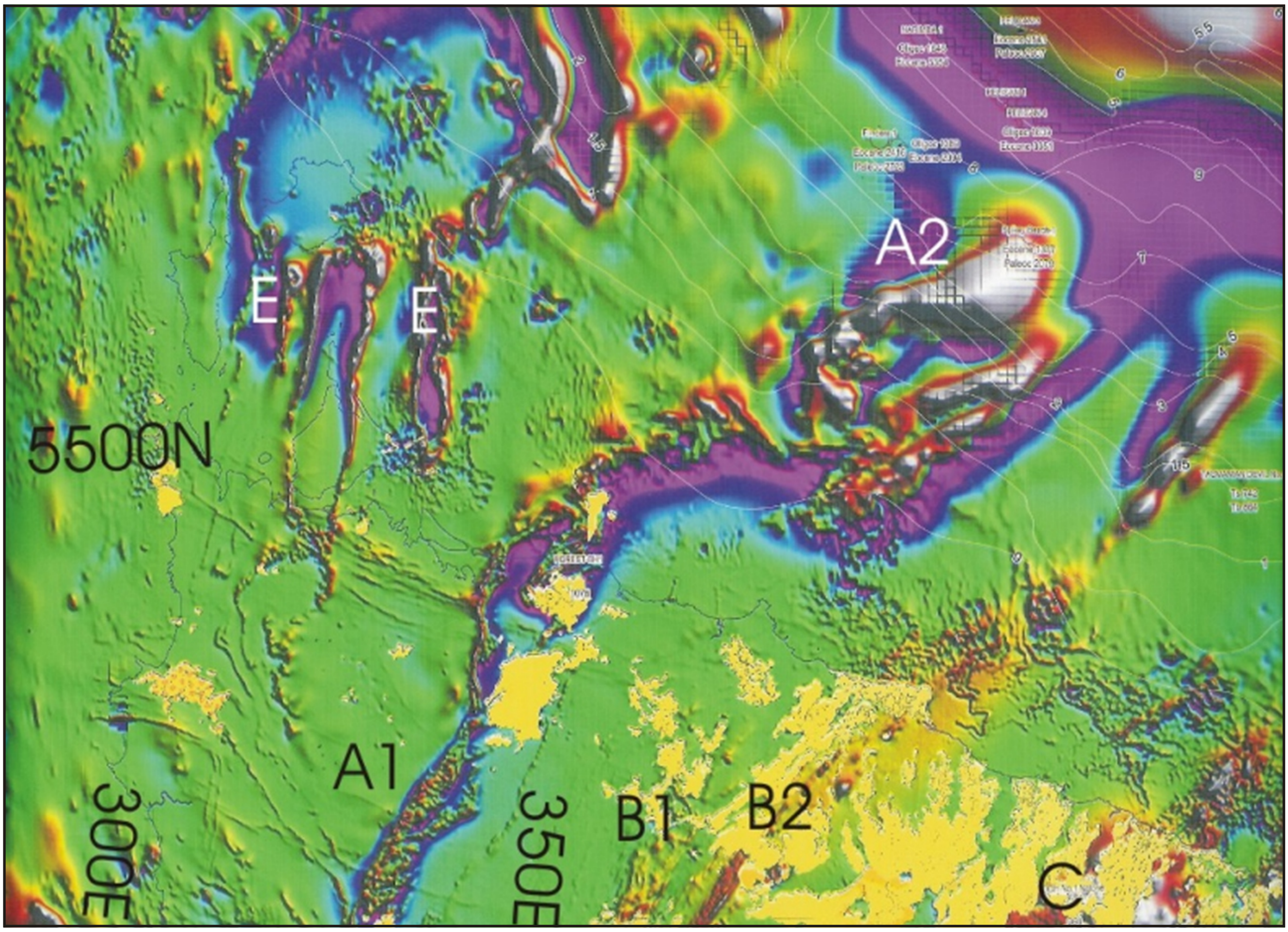


Figure 5

Detail of magnetic field near Three Hummock Island after variable range downward continuation.
Compilation supplied by Mineral Resources Tasmania, 2011.

Many sections have been modelled with up to one hundred variations and, clearly, it is not possible to present and discuss so many variations in a review report. The models actually presented here have been selected to allow assessment of critical elements.

Appendix 1 summarises the general ranges of unit properties, variants being discussed as they arise, while Appendix 2 indicates how to read and interpret the diagrams. **Appendix 2 should be understood before inspection of the many model diagrams**. The reader may also find it helpful to view this section in conjunction with a broad-scale regional geological map, such as the 1:500 000 scale *Geology of Tasmania* available from Mineral Resources Tasmania.

1. North of the Tasmanian coast

As the Bass Basin and its content plays a large part in any interpretation some comments are essential. An outline of basin concepts has been provided by Morrison and Davidson (1989), Gunn *et al.* (1997), Teasdale *et al.* (2001) and Blevin *et al.* (2005). The location of the basin structure is emergent within appraisal but the stratigraphy of the contents is another matter. For the purposes of this study, and to simplify rock property profiles, the section has been grouped as three assemblages: post Middle Miocene, Paleocene–Miocene and Cretaceous/Jurassic; with nominal bulk densities of 2.20, 2.30 and 2.40–2.45 t/m^3 (or less) respectively. No magnetic contrast has been assigned to these packages although there is some volcanic content which may be resolved with very detailed modelling, which is beyond the scope of the present treatment.

Nothing older than Upper Cretaceous equivalents of the Otway Group has been drilled or proven to exist in the basin. The oldest rocks in the Bass Basin, or its associates, are thought to occur in the Durroon Sub-basin — which extends onshore north of Gladstone where it was previously known as the Boobyalla Sub-basin — and which includes materials that are Lower Cretaceous in age. Post-Eocene sections may exceed 2500 m in thickness but there is some confusion about the total thickness of basin deposits. Morrison and Davidson (1989) apparently (possibly due to a drafting error) offer two estimates (compare their figures 9.6 and 9.12), implying either 12 000 feet or 12 000 metres. Later authors and company reports appear to have simply accepted the second of these estimates even though application of reasonable velocities to two-way seismic times would suggest a much shallower figure. This matter is considered by some of the models tested. Blevin *et al.* (2005) suggest a total maximum sediment section of eight kilometres.

PROFILE 5 475 000 mN (from 220 000 to 640 000 mE)

This profile (fig. 6) includes exposures in far northeast and northwest Tasmania and the shallow northern extension of structures west of Stanley, the Rocky Cape Block, the Arthur Lineament, the Burnie and Penguin blocks, structures near the mouth of the River Tamar and the northern continuation of the eastern batholiths east of Bridport. Findings and assessment at this northing are relevant to any evaluation of the Bass Basin or any units which may form part of its basement.

The magnetic and gravity models at this northing — as with those at 5 450 000 mN — were created to test property ranges where geological control exists and direct correlations with the potential fields are possible. Even so, a family of six structural styles was required for test, each of which included between three and seven variations.

The gravity model (upper part of fig. 6) has some obvious elements: the reduction in field due to water and shelf margin sedimentation at each end of the profile, or basin deposits internal to Bass Strait; and some unexpected features, such as the relatively more positive character of northeast Tasmania, which in places is comparable to background in far northwest Tasmania. This is an oddity given that granitoids are omnipresent in northeast Tasmania and many dense dolomitic suites are present in northwest Tasmania. It may be that the current mantle separation model is in some manner deficient.

These observations may have various interpretations, and as these matters arise regionally, they will be discussed here.

Many gravity profiles display highly negative ends near the continental shelf (as at 220 000–230 000 mE here) and, although these can be matched by model calculation — with various adjustments of either water depth, sediment drape thickness or density — the discrepancy may be due to lack of data coverage offshore.

This problem/uncertainty only applies to extremes of some models and does not apply to most of the profile/model.

The most serious issue arises with respect to the batholiths of northeast Tasmania. The residual gravity field is generally more positive east of the central basin accumulation where granitoids are exposed, as compared with northwest Tasmania where various, more dense rocks are exposed. This is clearly anomalous as, if it is assumed that the batholiths are deeply rooted — as has long been assumed — then the eastern half of the profile should be relatively negative, strongly so if granites/adamellites are dominant as these have a bulk density of 2.60–2.62 t/m^3 compared to siliceous Precambrian basement at 2.65–2.67 t/m^3 or the density of reduction at 2.67 t/m^3. A very large volume of granodiorite (at 2.69–2.71 t/m^3) can tip the balance slightly, but never account for the full difference even if nine kilometres or more thick. Yet the observations are real and widespread, dependent on different surveys and elements of the database.

This is why the presented model includes much granodiorite.

The most positive part of the profile is adjacent to a zone which has long lacked credible explanation (at and offshore west of Bridport, see Leaman *et al*., 1973). There is nothing known or likely in the near-surface with a density sufficient to generate the effect. Granodiorites, which are present and which are indicated as a solution in Figure 6, do not offer enough contrast regardless of depth or thickness.

The model shown, by its inclusion of much granodiorite, suggests the maximum, feasible thickness of any granitoid type one might insert or consider to be present. The existence of the positive gravity residuals forces this conclusion. No normal granite/adamellite can generate a positive anomaly.

Figure 6 may thus be termed the limiting case for any granitoid and not merely denser bodies.

Granodiorite, as shown, can only be part of a solution, if at all, and no component of the exposed Mathinna Supergroup can resolve this problem (concepts tested). Only a deep source of significant contrast and depth range can provide the necessary attraction. Such a solution is shown in the form of very dense Precambrian blocks (density >2.75, <2.82 t/m^3). This type of solution must be specific as the entire basement complex, taken as a whole, must be more siliceous (2.67–2.68 t/m^3 maximum) in order to account for conditions in northwest Tasmania.

Another issue is how much granitoid is present in the east, and at what depth does any interface with more dense basement occur, presuming there is a mass balance of the type suggested? This cannot be determined absolutely from gravity data alone; there are simply too many uncontrolled variables. Figure 6 presents the granitoid complex as predominantly granodiorite and this option slightly shallows estimates of the depth range. Similar resolution problems arise where basin sediments overlie either granitoids or basement, as the total basin depth is not established anywhere and densities vary within and across the sequence. Many options and structures can be juggled and results are ambiguous. Features shown in the presented model are representative only.

The ability to balance the effects of granite/adamellite or granodiorite components with underlying basement variants, or both, with adjustments of either thickness or density of sedimentary cover, is a fundamental problem.

The testing completed does imply that whatever is assumed about the sedimentary cover, or the precise nature of basement, the 'batholiths' are either bottomed or not in place, nor much thicker than four to five kilometres. Under the greatest density contrast differentials feasible the basal interface cannot be deeper than about six kilometres at the coast, and probably not more than 4.5–5 kilometres.

Magnetic data help somewhat. The large anomaly at about 290 + 220 000 mE (i.e. 510 000 mE; see explanation for calculation in Appendix 2) is crucial. This feature is an integration of many large features along the basin trend. The characteristics of these features demand a moderate depth range to source (typically 5–7 km) and properties which are normally only associated with ultramafic rocks (>0.1 SI). If it is presumed that such mafic rocks occur in podded form along some form of detachment, such as implied above, then

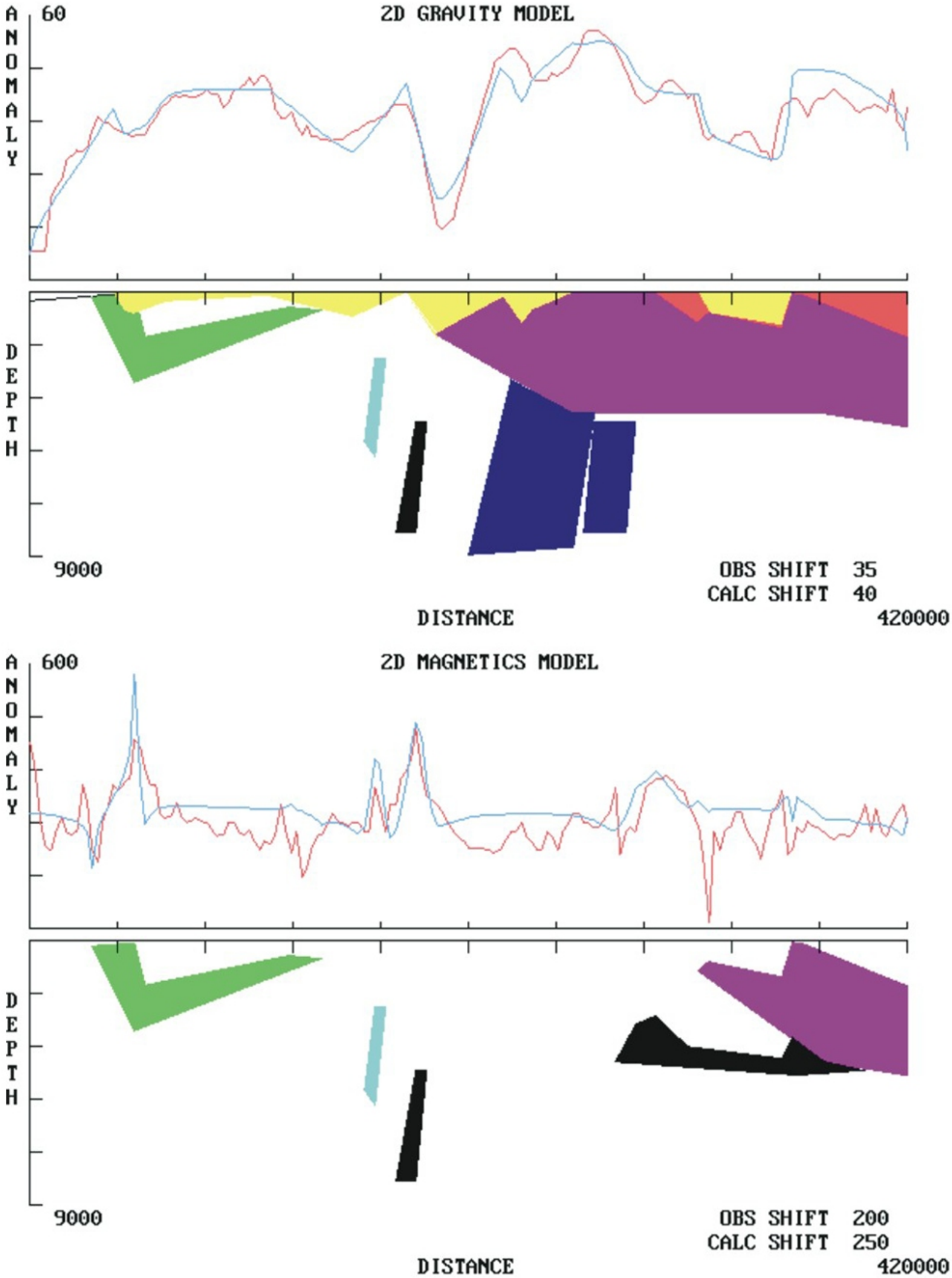


Figure 6

Line 5 475 000 mN (220 000 mE–640 000 mE) correlations with the gravity modelling indicate that a depth to that surface is at least 4.5 km, and this depth range is required to balance granitoids and basement responses (5.5 km if the granitoid is adamellitic).

Note that the elements interpreted as ultramafic pods are isolated but restricted to a trend zone and cannot be linked with anything shallow, i.e. they are not part of the basin sequence. Nor are they related to separate deep sources in the basement, as inferred and observed further west, although such sources might contribute to extensions of the observed anomaly elsewhere (not possible at this northing).

The mafic belts, within basement further west, may be parts of the Arthur Lineament (see also B, C in fig. 4 and 5). The mafic belt which wraps around King Island is shown as a folded sequence, shallowing to the east, but which cannot extend to any great depth with any credible contrast for mafic sequences (<0.05 SI). Gravity data support such a conclusion (the mafic rocks also being denser and thus imposing limits on bulk mass) provided the local basement is more dense than siliceous, or is dolomitic. This option appears in some other models/profiles.

Extensions of basin structures approach the coast near King Island and north of Stanley, but are onshore at Boobyalla where materials include Cretaceous sedimentation.

The magnetic model also indicates both the presence of granodiorite and some variation in its properties in order to account for minor excursions in the magnetic field on the eastern side of the Bass Basin. One of the ultramafic pods may be linked to these magnetic structures. Much of the minor variation in the field, not well sampled for this regional overview, is due to shallow sources (volcanic rocks within the Tertiary–Cretaceous section) and could be modelled (not shown here).

The curve-matching parameters of 200/250 nT (obs./calc.) for the magnetic field and the magnetic model is generally supportable throughout all modelling but a minor differential is possible between 200/220 and 200/250 nT. (See Appendix 2 for a full explanation of terminology and meaning. The "shift/match/or fit" value is the amount that any calculated value must be adjusted in order to equate with observations).

Similarly the gravity fit parameters appear sound and consistent in the north. Note that other gravity models do show the feasibility of more neutral model calculation/observed data matches (i.e. 35/35 obs./calc. mgal) whereas the calculation shift in Figure 6 is offset by 5 mgal (35/40). Were these to be 35/35 then this would imply more basement and less granitoids (about 1–2 km less), but the structural form would be unchanged. A deep batholithic mass is not possible under any such condition; a detachment/termination of the base of the granitoids is an essential element.

Models for profile 5 500 000 mN and 5 550 000 mN were selected to illustrate the range and nature of optional responses.

PROFILE 5 500 000 mN 220 000–640 000 mE

See Figure 7.

Comments as noted for profile 5 475 000 also apply at this northing, with two exceptions.

Part of the Precambrian basement near Cape Grim/King Island must be quite dense (at least 2.74/2.75 t/m^3) and the granitoid complex east of the basin (and near Flinders Island) must be predominantly granite/adamellite with only minor granodiorite (shown).

The Durroon Sub-basin offshore is deeper and this is also indicated. The detachment is at a depth of four to five kilometres.

Note that the gravity profile has strongly negative tails at line ends due either to inadequate correction or modelling.

The block of mafic volcanic rocks at 120 + 220 000 mE has a shallower dip (as discussed on page 10) and various constituent members produce discrete magnetic responses. No meaningful depth range can be deduced for any intra-basement features.

Rocks beneath the granitoids, and inferred detachment, can be imaged at this northing using both data sets. The magnetic data are less ambiguous as distinct anomalies have been observed which require a depth to source, and contrast, much greater than anything possible in the surface granitoids. Further ultramafic rocks, comparable to the Heazlewood Complex pod, must be implicit.

PROFILE 5 525 000 mN 220 000–640 000 mE

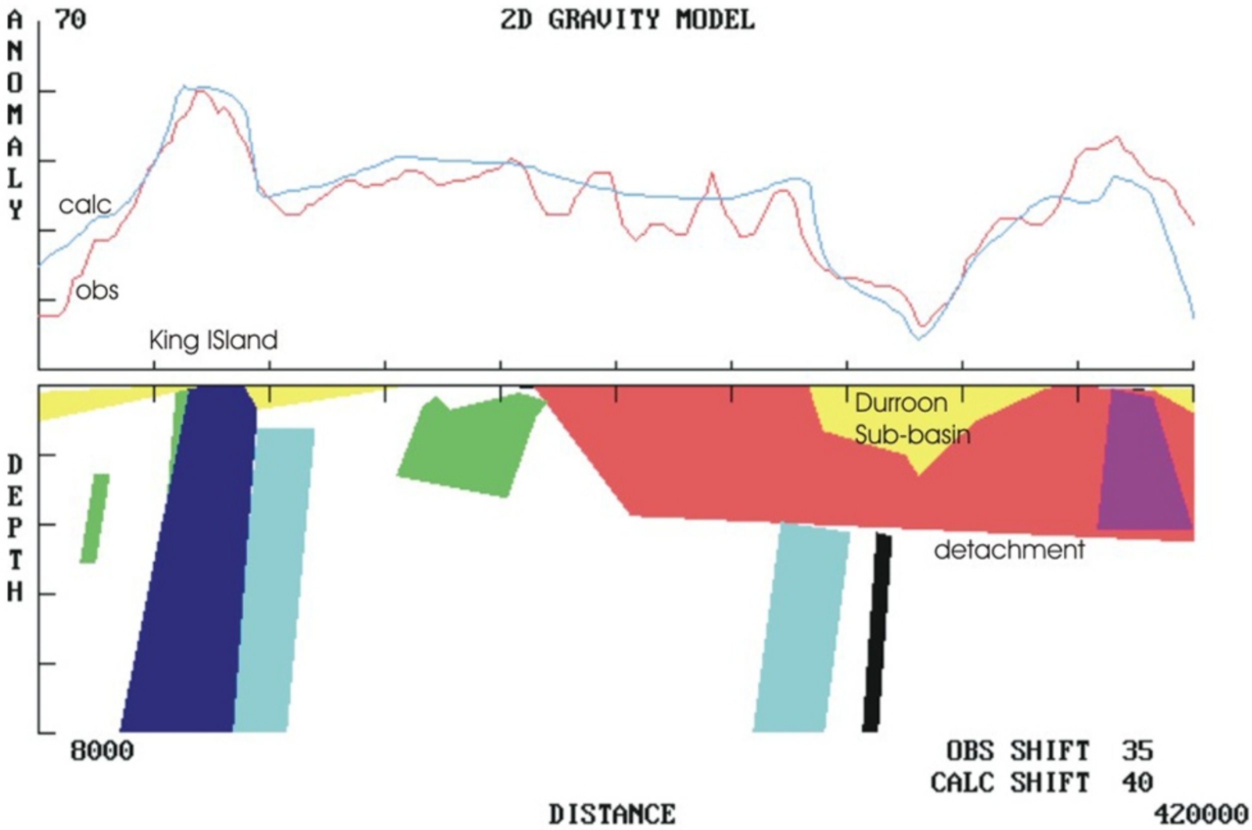
See Figure 8.

Comments given for lines 5475 and 5500 apply but more detail has been provided about the basin section and for sources underlying it.

This is the first section included which suggests the maximum thickness/depth of the basin material. With reasonable contrast assumptions, it cannot much exceed 5.5 to 6 km and can certainly not be 12 km as has been implied in some documents (see discussion, page 11).

The modelling undertaken indicates that inliers of Mathinna Supergroup rocks are limited in extent/scale and that granodiorite content (possible) is also minimal at this northing. The Three Hummock Island and King Island granites appear to coalesce to form a single deep pluton (although this conclusion may be an artefact of property integration) and magnetic anomalies near its roof are probably of halo-alteration origin as suggested by the pattern of responses (fig. 4, 5).

Mafic units are shown depth-limited but the actual depth range cannot be determined without further control. A large part of the basement suites must be non-siliceous, with a bulk density of the order of at least 2.73–2.75 t/m^3, a conclusion demanded further northward (fig. 9). This affects the eastern batholith balance and detachment/termination depth estimates to imply a range of four to six kilometres to the basal termination generally (4.5–5 km is considered most likely).



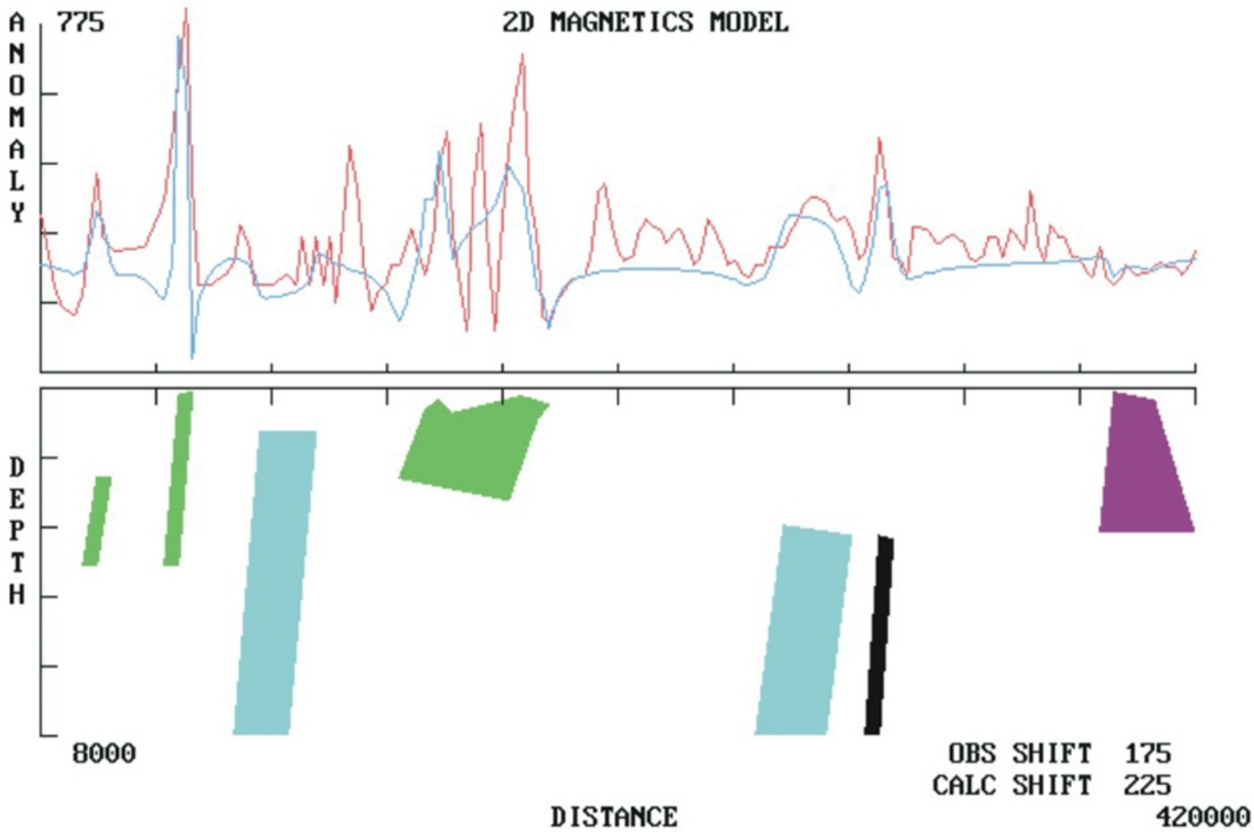


Figure 7

Line 5 500 000 mN (220 000–640 000 mE)

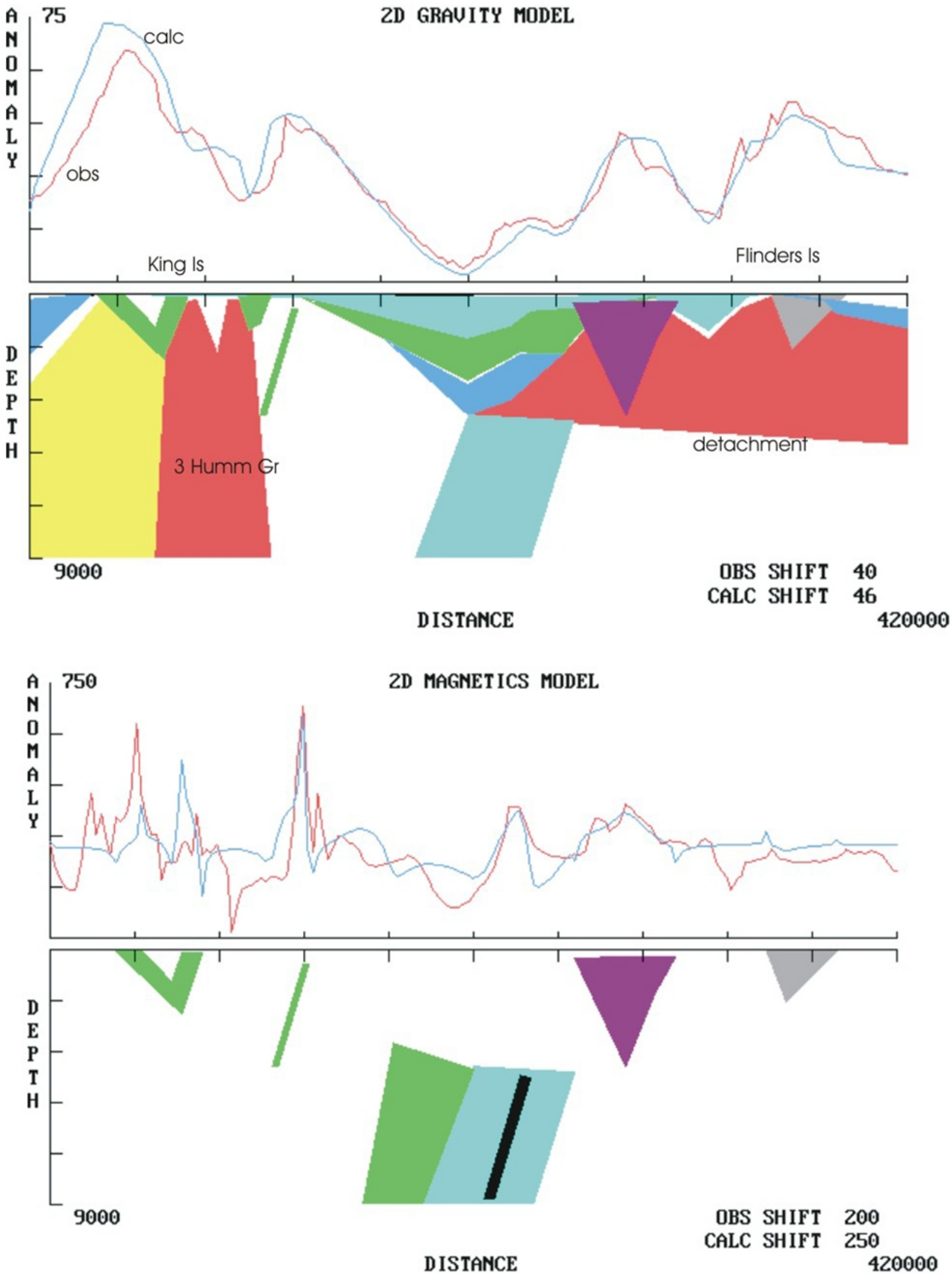


Figure 8

Line 5 525 000 mN (220 000–640 000 mE).

From this point in the text it will be presumed that the termination interface is, in fact, a major detachment — with all the implications such a term carries.

The complex, and generally denser, zone beneath the basin/detachment includes a slice of intensely magnetised material around 440 000 mE (presumed ultramafic rocks, an extension of the Heazlewood sequence).

PROFILE 5 550 000 mN 220 000–640 000 mE

Models (fig. 9, 10) indicate the maximum depth to the detachment (6500 m at the Tasmanian east coast). The estimate depends on a balance of granitoids with the Precambrian basement (at ~2.74 t/m^3) and the limitations imposed by some of the deeper magnetic sources, including the substantial mafic sheet trapped along the detachment. This sheet is not gravimetrically significant but is intensely magnetic (~0.18 SI) and is presumably, therefore, ultramafic in composition.

The granites of Three Hummock Island and King Island are separable and distinct plutons of West Tasmania style (relatively small, fully penetrative diapirs). Mafic units nearby are depth limited by these granites.

The gravity model presented further reviews the Tertiary–Cretaceous content of the Bass Basin to imply a maximum depth/thickness of about 5500 m using likely densities (maximum 2.47 t/m^3 for the deepest rocks). Note that Tasmanian Triassic/Lower Jurassic sedimentary rocks are of this order (2.45–2.48 t/m^3) and Permian rocks exceed 2.52 t/m^3.

The curve matching parameters of 200/250 nT (refer to Appendix 2) for the magnetics are generally supportable throughout all modelling, but a minor differential is possible (200/220 v 200/250 nT)). The gravity fit parameters of 35/40 mgal appear sound, but were these to be neutral at 35/35 then the result would imply more basement and less granitoids (some 1 to 2 km less). The structural form would be unchanged. Compare Figures 9 and 10 where the different curve-matching options are shown. A deep batholithic mass (below the modelled detachment level) would not be possible in any configuration or use of the data; the presence of a major detachment is not in dispute given the array of model concepts tested (23 concepts with up to nine variants in each case).

The basement complex, as modelled, provides for both dense and/or magnetic variations which represent elements of the Arthur Lineament and Burnie sequences. A neutral zone overlying these, which earlier work had indicated as overthrust portions of the Rocky Cape Block (see also Leaman *et al*., 1994; Leaman and Webster, 2002) is also included.

Note that models at this northing have introduced some familiar onshore elements not discussed on other sections. All sections/concepts have been tested and consistent patterns emerge, suggesting that structural continuity is feasible just as implied on inspection of magnetic data (fig. 1, 4, 5).

Figures 9 and 10 also illustrate the effect of small curve-matching shifts, in this case 5 mgal.

PROFILE 5 560 000 mN 220 000–640 000 mE

This profile (fig. 11) further tests the depth range to the regional detachment (now a maximum of 7500 m at the east coast of Tasmania).

Basin fill is slightly shallower/thinner, at perhaps 4800 m, and the roof of the King Island/Three Hummock Island granite a little deeper (top at 1500–1800 m).

An inlier of Mathinna Supergroup is also indicated to the east (Flinders Island), but a slightly greater volume of granodiorite is feasible and, given current mapping knowledge, more likely. If this is the case then the depth of detachment might be reduced to only 6000 metres.

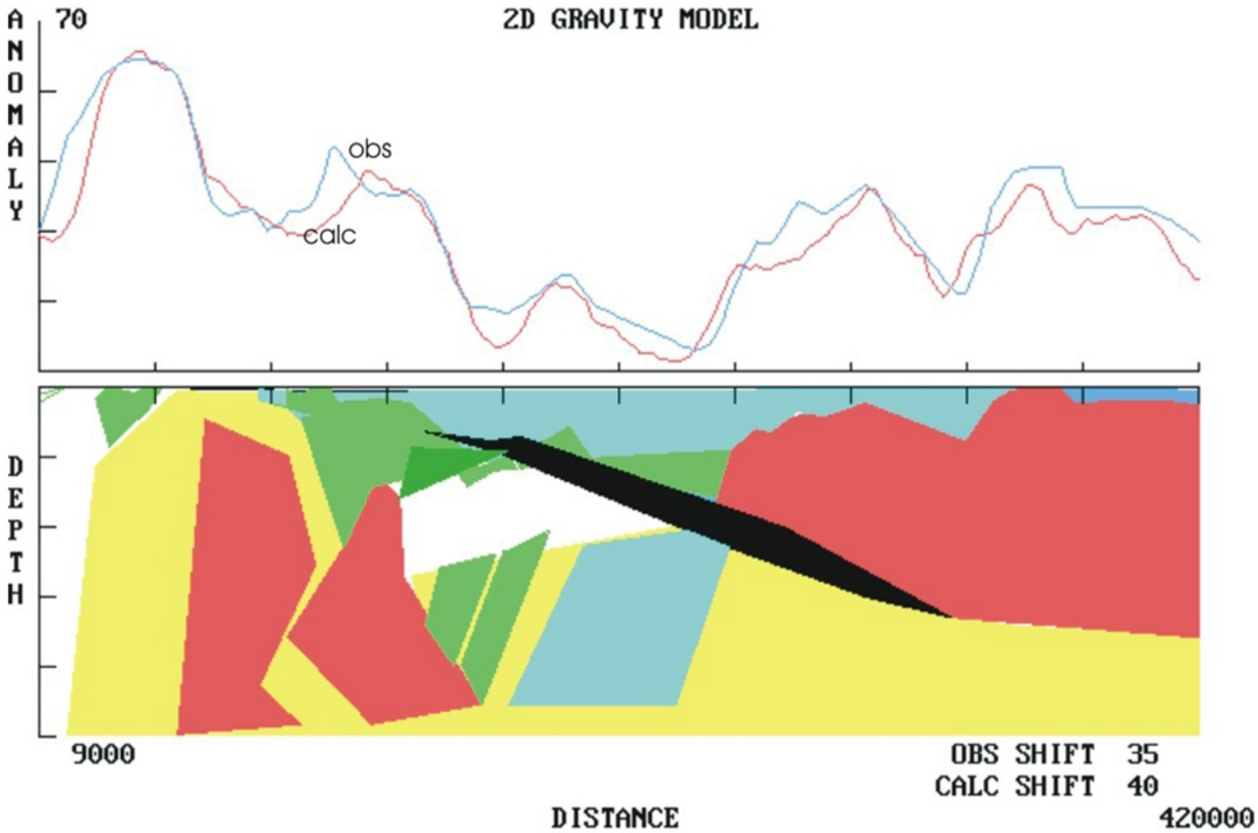
The complex nature of the basement is also suggested. The variable magnetic character of contained units is consistent with other profiles and is traceable onshore. Most significant is the extent of the ultramafic sheet which is virtually continuous along the detachment, even as the batholithic western limit to the basin reaches away from exposures (by up to 200 km!). This deep source style fully accounts for the magnetic field variation along the strike of the basin/trough — as well as 'beneath' the exposed rocks of northeast Tasmania.

COMMENT

An important aspect of modelling north of the Tasmanian coast is the issue of the three-dimensional form of the detachment implied. There seems little doubt that this surface curls (see summary in Figure 32) and shallows upward to the west beneath the basin/centre of Bass Strait, which thus appears to be a pull-apart structure with this as the active element. Crudely E–W extension is implied but principal stresses could be plus or minus 45 degrees from this ordinate. This might mean that the mafic rocks around (but not those in) the basin, inferred to be at least Early Cambrian in age, could have been shifted and structured anytime between the Jurassic and the present. This comment is based on the known age of ultramafic rocks in both Victoria and Tasmania and it is simpler to presume remobilisation of these than to invoke some other-age material for which no evidence exists. Structuring and remobilisation involving any such ultramafic rocks is certainly later than Silurian, as Devonian–Carboniferous granitoids have somehow been engaged. There may, of course, have been several stages in this process. The implied detachment surface appears to dip east and, if the combined implications of gravity/magnetic interpretations are accepted, then this surface also deepens northward into the centre of Bass Strait.

No analysis has yet been completed north of 5 560 000 mN although it may be suggested qualitatively that anomaly sources rise from the basin depths and extend onshore in Victoria (e.g. fig. 1).

The gross style of the detachment is comparable to that shown in Figures 55 and 60 of Leaman and Webster (2002) for north–northeast Tasmania, but its presentation onshore



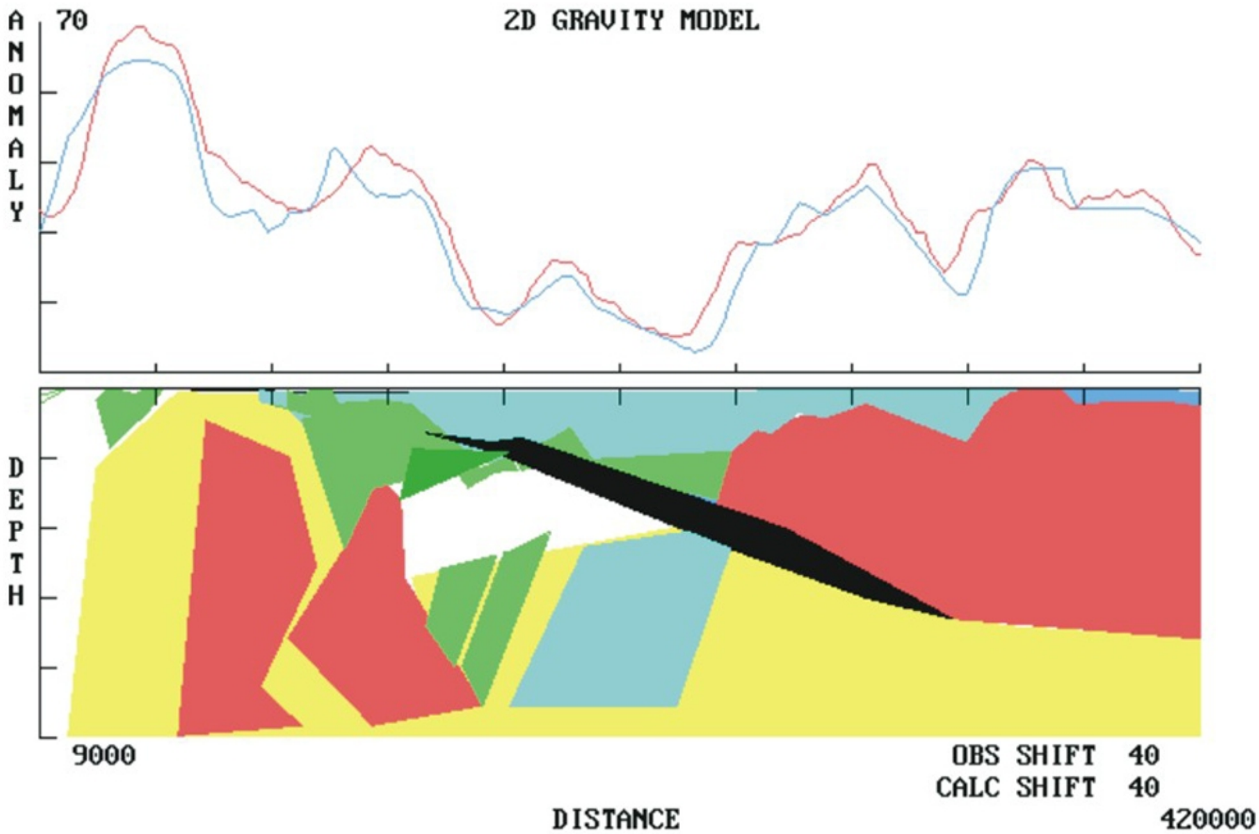


Figure 9

Line 5 550 000 mN (220 000–640 000 mE)
(gravity shift comparisons)

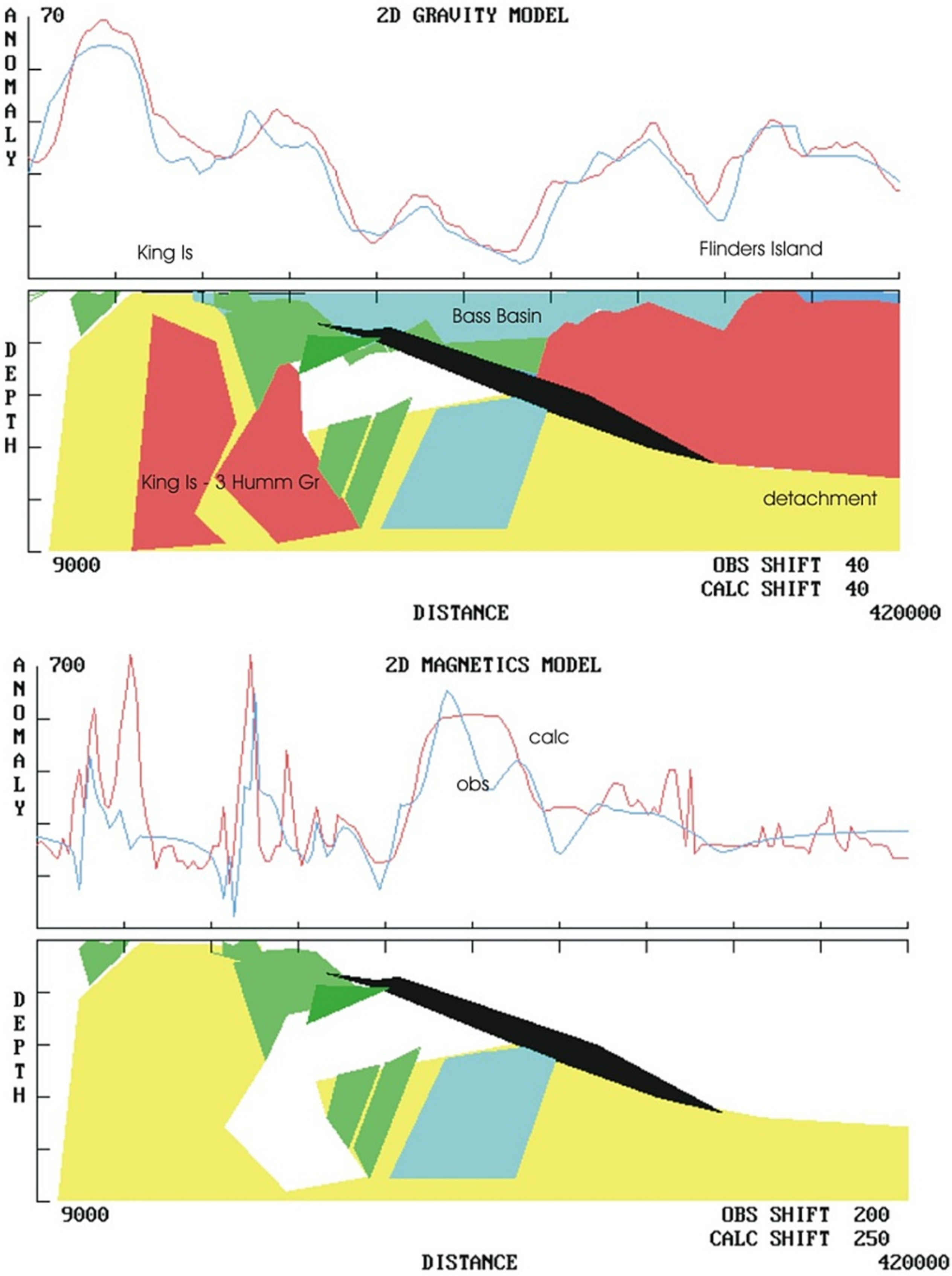


Figure 10

Line 5 550 000 mN (220 000–640 000 mE)
(using neutral gravity shift — see Figure 9 and Appendix 2).

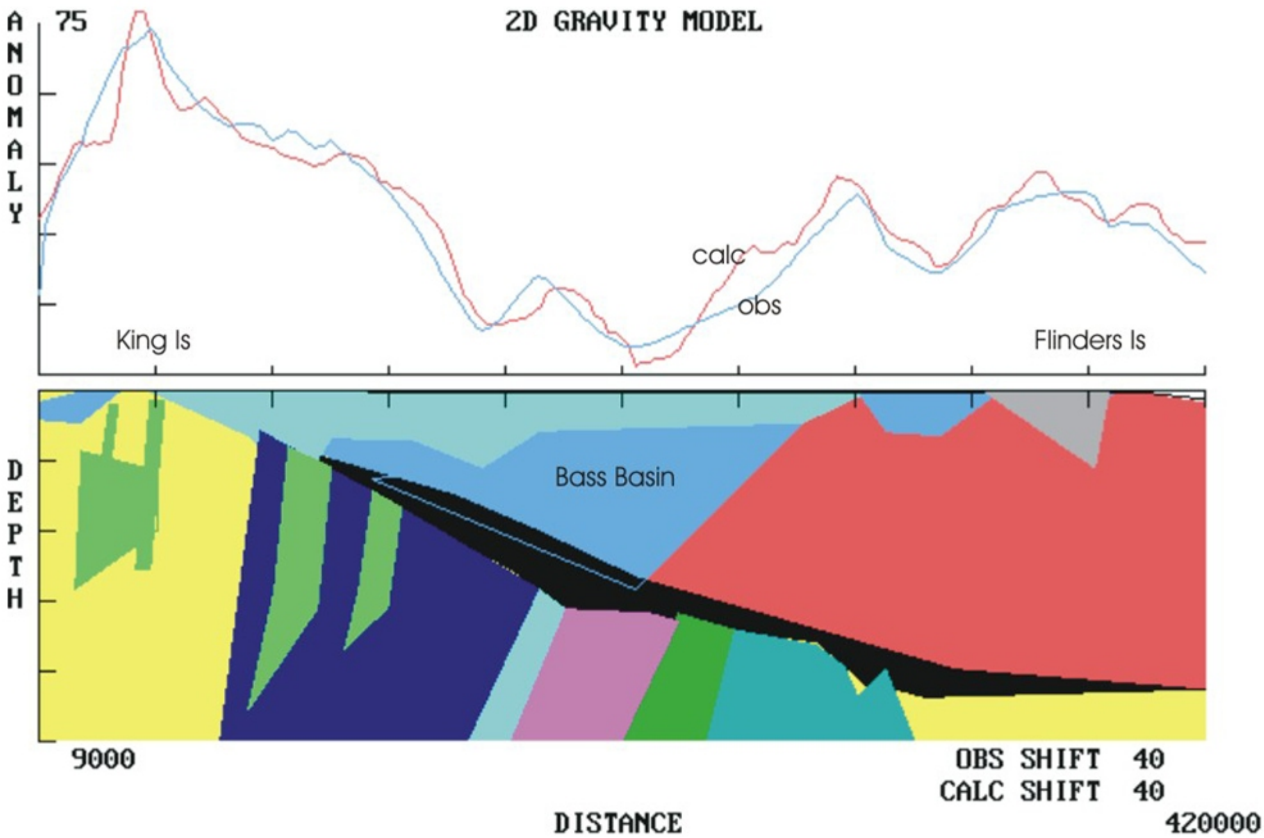


Figure 11

Gravity model, line 5 560 000 mN (220 000–640 000 mE).

may be confused by the remobilisation and exposure of discrete bodies of ultramafic rocks (discussed further at Profile 5 450 000 mN below).

Structures along the River Tamar, or the ultramafic connections eastward from Beaconsfield (as in Roach, 1994; Leaman and Webster, 2002) may be part of the dispersion of this structure and materials associated with it towards surface onshore in Tasmania.

The structural pattern inferred north of Tasmania, beneath Bass Strait and its surrounds, has been illustrated above but there is basis for some ambiguity, especially in terms of actual depths or details. These difficulties arise due to lack of control, or exposure, but the implications are clear within the limitations of the data sets/compilations: the eastern granites are not in place, while the western granitoids (as near Three Hummock Island) are. Plutons and compositional/intrusional variants are present, but dislocation post-dates all such primary factors. Much older ultramafic suites may have been caught up in the dislocating structures. The well known basement complexes exposed in western and northern Tasmania underlie all surface/shallow materials.

These propositions, developed in the splendid isolation and poor control pertaining in and around Bass Strait, will now be tested, or developed, within continental Tasmania where there is much other information and history of investigation.

The discussion is in two parts: north of 5 400 000 mN where granitoids are exposed (the Scottsdale and Blue Tier batholiths); and the region to the south where the bulk of the area is covered by Permo-Triassic sequences intruded by Jurassic dolerite, with granitoids only exposed in a minor manner along the east coast. In the latter case, considerable scope for ambiguity or uncertainty persists.

2. CONTINENTAL TASMANIA

The discussion begins with a comprehensive analysis of Profile 5 450 000 mN, which samples both northwest and northeast Tasmania (fig. 12). After a comparison of this long line solution with those further north (above, especially 5 475 000 mN and in Bass Strait), short line and more detailed versions are provided for the area east of the River Tamar (fig. 13–28). This has been done in order to give confidence about the consistency and value of other profile solutions where surface control is absent.

All models south of 5 450 000 mN are of short profiles (with an origin at 500 000 mE, rather than 220 000 mE, see also Appendix 2). Only gravity models are provided south of 5 440 000 mN due to uncertainties about the consistency and specification of magnetic surveys in this region.

PROFILE 5 450 000 mN 220 000–640 000 mE,

This diagram (fig. 12) should be compared and contrasted with Figure 6 for 5 475 000 mN. Many comments made on that section apply to this one. While these models infer much about 'basement' rocks, emphasis ultimately returns to the granitoids which were the raison-d'être of this study. This discussion, therefore, focuses on the character and distribution of the granitoids.

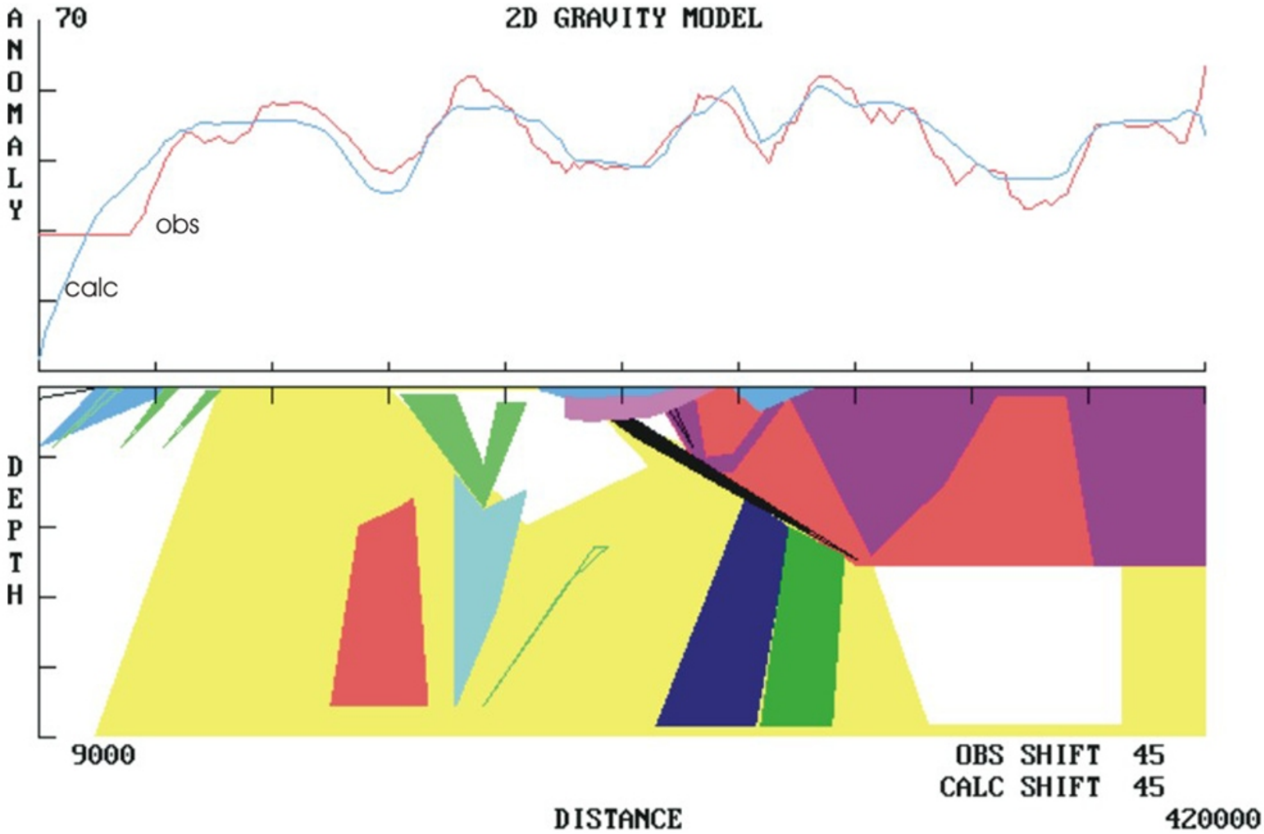


Figure 12

Gravity model, line 5 450 000 mN (220 000–640 000 mE).

The models for 5475 and 5450 are comparable, sampling similar transects of Tasmanian geology, but some additional detail can now be supplied. The model shown is the eighth concept series, version 5 and, like all others, is designed to illustrate findings rather than final conclusions.

No attempt has been made to create tight fits with the data near the continental margins/shelves due to rapid changes in bathymetry, lack of data and lack of knowledge about drape materials. The curve matching parameters (Appendix 2) are essentially neutral for the gravity model and offset by up to 50 nT magnetically. These values are consistent with estimates for profiles in Bass Strait.

The model examines the magnetic sources off the west coast to suggest at least three volcanic units (at ~0.025–0.05 SI). Although these are shown dipping west and fingering with depth, neither depth range nor dip can be determined unambiguously at this scale. Tests with east-dipping or vertical members showed that such other options are possible. The situation onshore, near Balfour, is much clearer (~370 000 mE), where a synform/syncline is indicated at the southern end of the Smithton–Edith Creek volcanics belt. Elements of the Arthur Lineament, the Heazlewood ultramafic rocks, Burnie Formation and other Neoproterozoic to Cambrian sequences with interbedded mafic components are all represented. Much more detail about these disparate elements is provided by Leaman (*in* Leaman and Webster, 2002).

Problems with the interpretation provided are evident where the Scottsdale and Blue Tier batholith assemblages are exposed. Granite/adamellite is displayed near surface when, in fact, these lithologies outcrop. At issue here is presentation versus calculation.

Similar comments apply to basement where a stringer of colour links blocks of material. Such connections are artefacts of display but they conceal a more serious difficulty.

The gradients associated with the Blue Tier granitoids (~585 000 mE) cannot be explained with any known bedrock density distribution, and extending the mass in depth offers little help with the amplitude of effect or the gradients. The only feasible solid rock solution to these problems is to suggest that the granodiorite component and volume is over-stated, that it is present only as a relatively thin sheet above Mathinna Supergroup country rock — which can offer an expanded density contrast with the granites. Reduction of the basement complex locally to a siliceous type (as shown) is not a realistic or useful option.

There are other possibilities. A variable, and quite thin weathered profile on granite can easily account for the amplitudes and gradients observed. This option has been included in the final presentation. It presumes an altered profile with densities ranging from 2.00 t/m^3 to rock density of 2.62 t/m^3 with essentially no significant equivalent weathering profile on Mathinna Supergroup rocks.

The 'detachment' surface is limited to about 4500 m near the coast and 4000–4500 m where basement members offer some control on the section. These estimates are based on very limited alteration profiles at surface to fit the observed data.

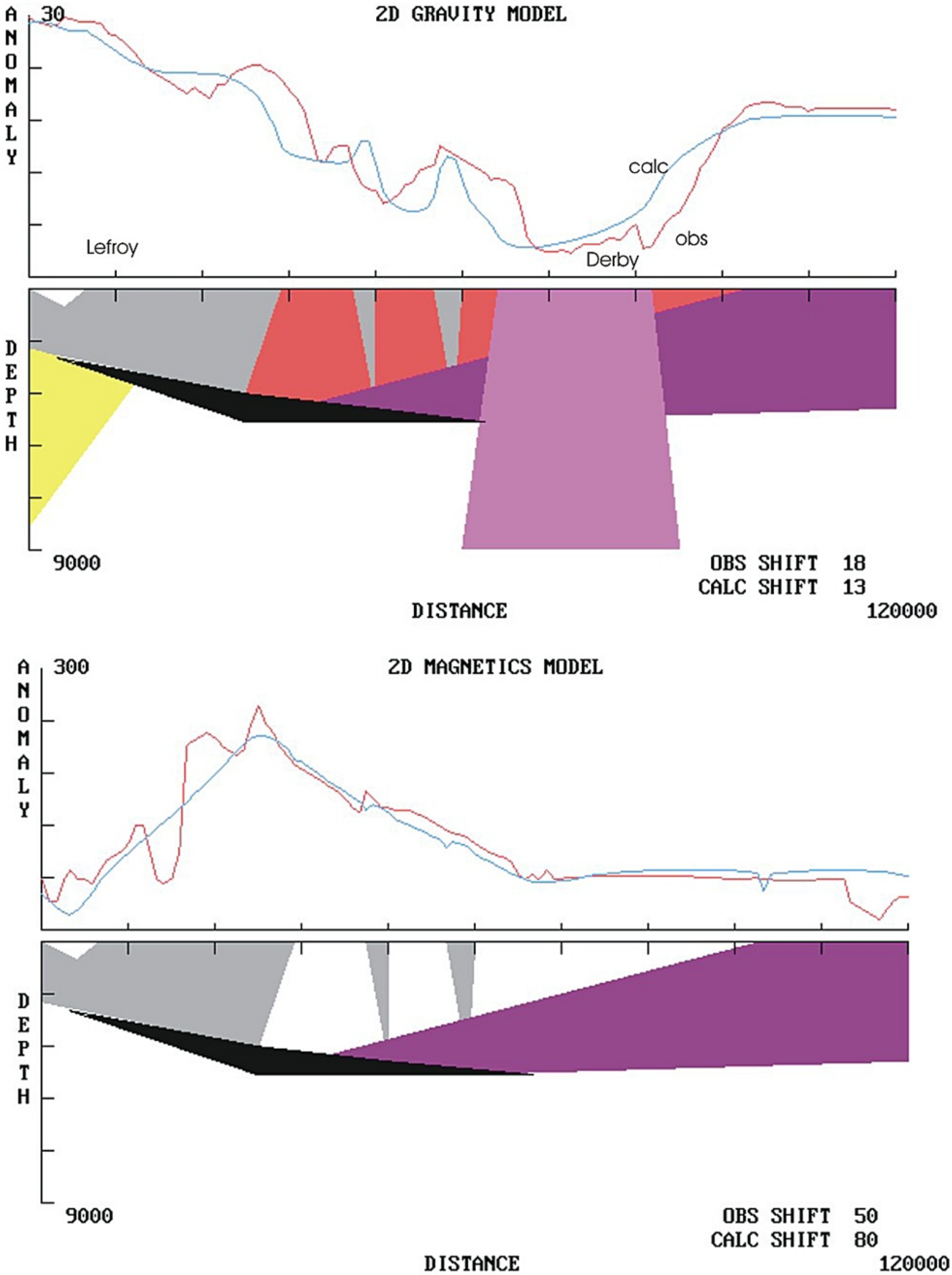


Figure 13

Line 5 450 000 mN (500 000–620 000 mE).

Some of these issues may be considered in more detail in discussion of the short form of the profile (below).

LINE 5 450 000 mN 500 000–620 000 mE

Both gravity and magnetic profiles (fig. 13) can be accounted for approximately using normal properties and exposure limits, but fine details are more elusive. At this level three-dimensional effects are important and not properly estimated by 2D models. This is the reason for the erratic gravity match between 524 000 mE and 560 000 mE and for the trend match accepted in the magnetic model between 510 000 mE and 536 000 mE.

The negative magnetic anomaly off the coast (617 000 mE) may be due to the edge of the continental shelf, return to granite or comparable boundary effects. All can provide the observed amplitude with normal properties and geometry. The granodiorite is shown as a wedge in order to give a compromise effect (2D/3D) as the section lies near and parallel to a contact between granitoids.

The gravity model requires a denser belt of basement rocks beneath the Tamar axis — as also shown in the regional model — but the problem of the Blue Tier granitoids is here resolved with a young penetrative pluton (near Derby). If the properties assigned to this body were those of the Mt Paris or Lottah intrusions (2.59–2.61 t/m^3) and not 2.63–2.64 t/m^3, then the gradients are more readily fitted and the body need not penetrate the detachment. The apparent misfit of surface distribution and anomaly near Derby may also reflect the 3D shape of the intrusions. This solution style does resolve concerns for the relatively positive gravity field north of Nabowla, west of Bridport, and off the north coast. Note also that maintenance of normal granite densities (~2.62 t/m^3) and a modest weathering profile can also satisfy the observed field.

The magnetic field is decisive in its contribution to understanding, or defining the geometry of, the detachment which here projects to exposure near Beaconsfield (see also Leaman and Webster, 2002). The extended nature of the observed anomaly demonstrates continuity of ultramafic rocks up to 30 km east of the first exposure of the granitoids of the Scottsdale Batholith.

Refinements of the model to account for the specifics of the observed field across the region between Lefroy and Derby, using variations in granite and Mathinna Supergroup geometries and volumes (at ~548 000 mE or 560 000 mE) can make the model look good but not necessarily more truthful. The style remains unchanged.

LINE 5 460 000 mN 500 000–620 000 mE

The magnetic field indicates larger volumes, rather than slivers, of Mathinna Supergroup between 514 000 mE and 556 000 mE. The most magnetic Mathinna Supergroup units are towards the west (fig. 14).

The gravity model is a reasonable fit with neutral parameters and observed densities where most deviations are minor and can be fully accounted for with insertion of thin weathering profiles, except near 516 000 mE to 520 000 mE where Tertiary materials up to 50 m thick are indicated (along Little Pipers River).

No known exposed materials east of the River Tamar (just west of the line origin) can produce the total positive effect, and a block of denser, older basement — as inferred on longer profiles — has been inserted. The placement of this block defines the general location of any possible detachment but no precise depth can be provided gravimetrically.

The granitoids exposed near the coast at Eddystone Point cannot readily satisfy the observed field unless the coastal pluton is both more dense than the bulk of the Blue Tier Batholith (but may not exceed 2.64 t/m^3) and also extends to considerable depth, much deeper than other granitoids in the section, i.e. it must penetrate any detachment. Other options may involve more granodiorite or Mathinna Supergroup in the region.

Similar issues may arise at and west of Bridport, where granodiorite is exposed or occurs at shallow depth. This option was tested but is not included in Figure 14. It can explain the relatively positive feature at approximately 530 000 mE (west of Bridport).

The magnetic model provides some limits on location, depth and thickness of any ultramafic rocks emplaced at the implied detachment beneath the batholith. The depth is approximately 3500 metres. Three dimensional, and irregular shape effects, distort the form of the observed anomaly east of the Tamar axis.

The model mismatch east of 572 000 mE is also due to three-dimensional effects related to the juxtaposition of intruded Mathinna Supergroup, granodiorite and granite.

LINE 5 440 000 mN 500 000–620 000 mE

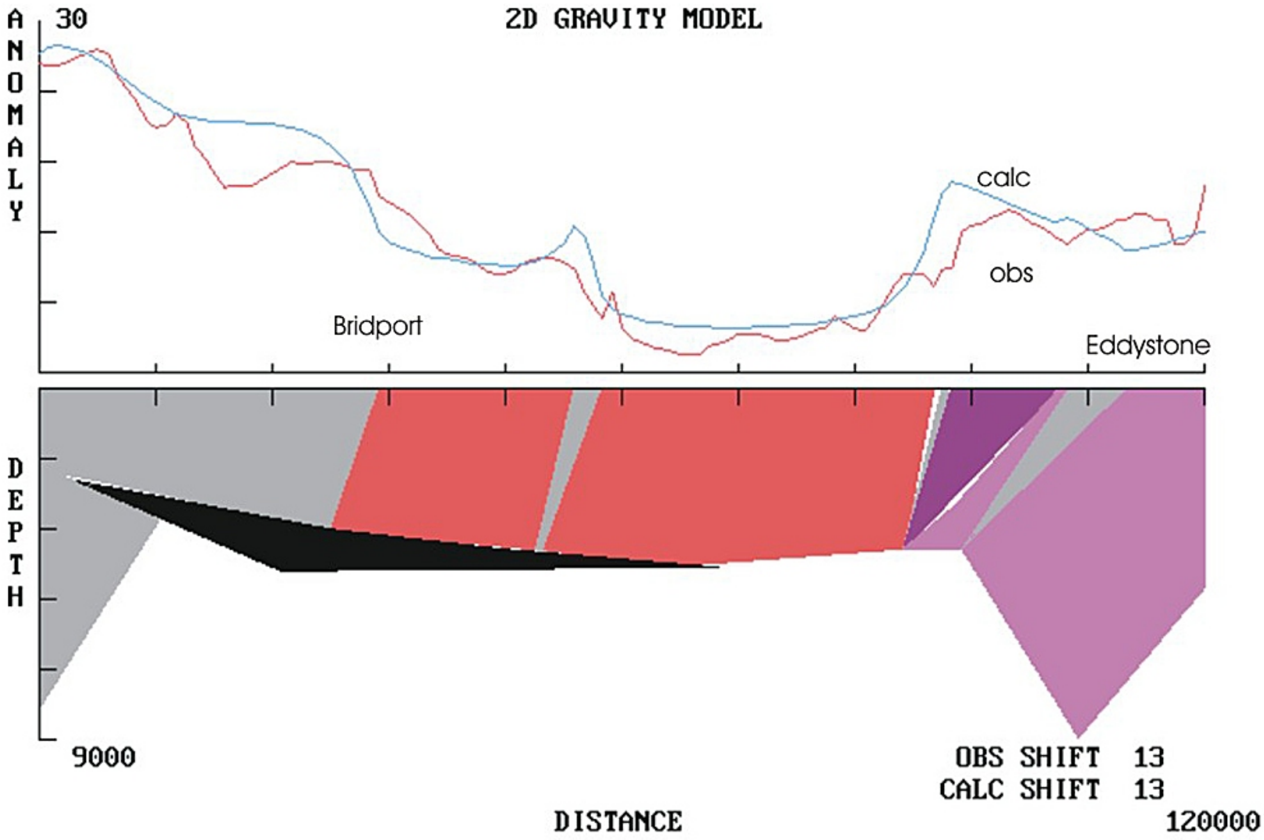
Most of the geological elements described on other profiles may be recognised here (fig. 15). This is a critical model as it marks a boundary between modelling assumptions and the residual field used as observed reference.

The shift match differential is no longer neutral, or even possibly neutral, using established rock densities. The observed field is too negative to be explained by any granitoid density in excess of 2.58–2.59 t/m^3. A fit, with revised depth ranges for 2.62–2.64 t/m^3 batholithic material, is only possible with the indicated shift offset.

This problem is endemic (see following models), and is discussed in the *Conclusions* section.

The model does demonstrate that the batholiths of northeast Tasmania are generally not deeply rooted, but that some members of them are.

Minor deviations in the profile, as at 500, 516, 538 and 596 000 mE, can all be explained with weathering profiles or younger cover, and such materials are exposed near these eastings.



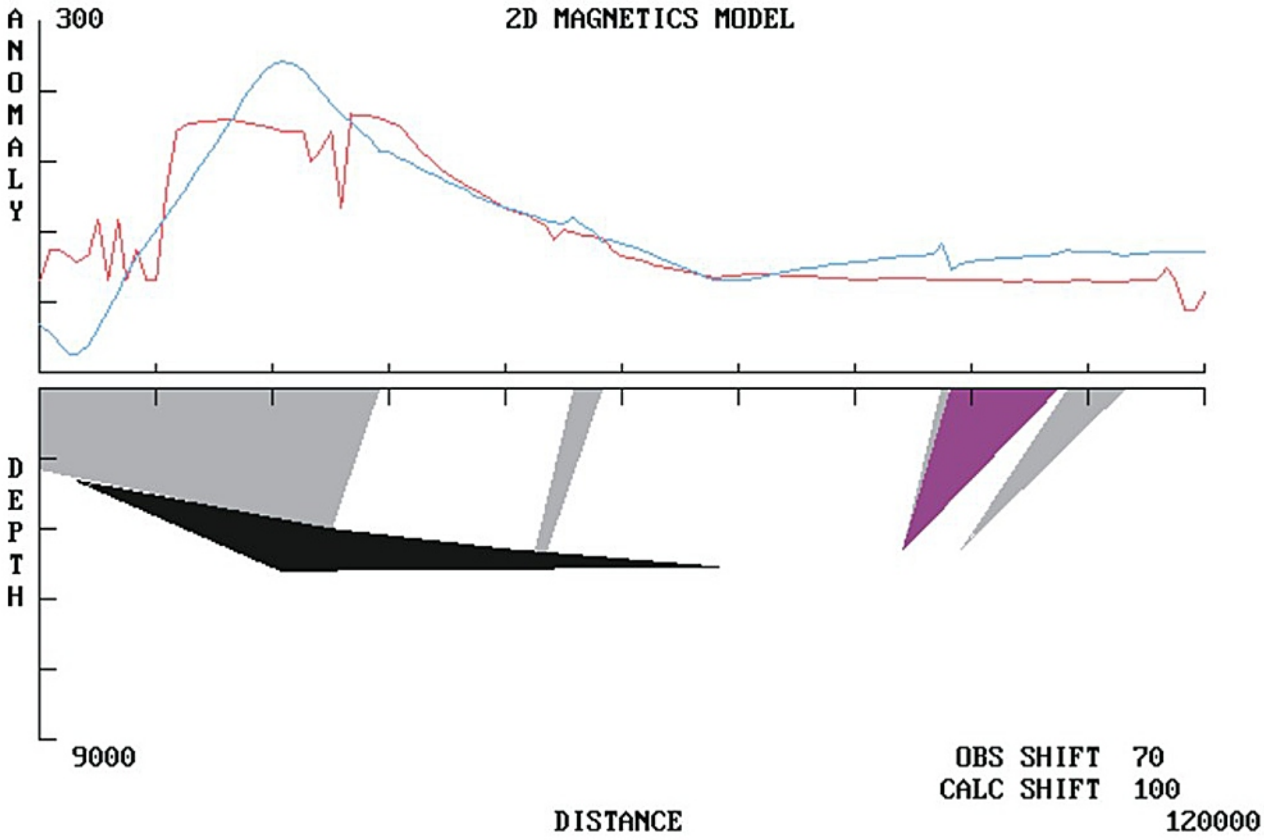


Figure 14

Line 5 460 000 mN (500 000–620 000 mE)

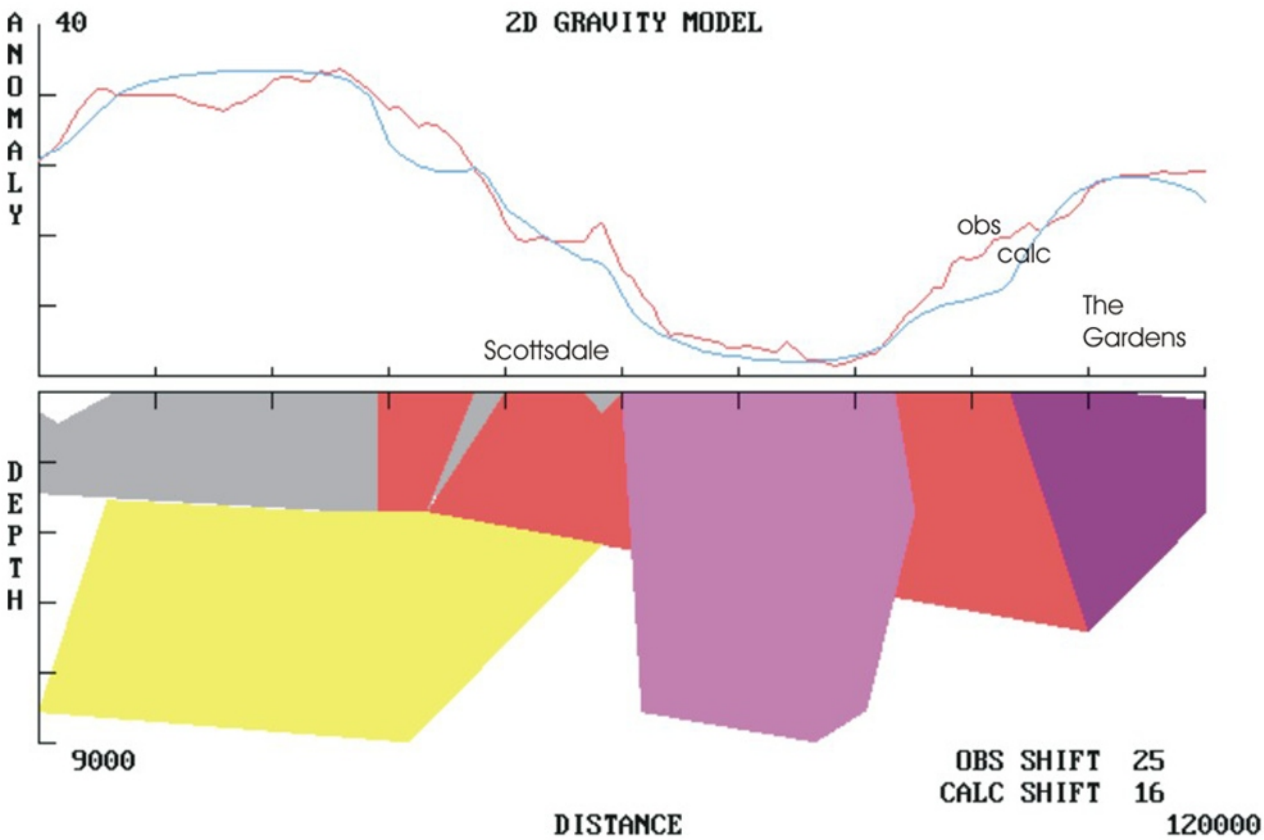


Figure 15

Line 5 440 000 mN (500 000–620 000 mE).

The following models, south of northeast Tasmania, do not include fine detail, such as the structures related to Tertiary volcanic rocks and Jurassic dolerite. Some gravity responses may be associated with these materials but the present review has attempted to maintain a crustal or regional aspect rather than assess near-surface detail.

LINE 5 430 000 mN 500 000–620 000 mE

The problems noted at 5440 000 mN are amplified at this northing (fig. 16). The same shift offset is shown and is a reasonable mean for the model. More mass is required near 535 000 mE but much less mass is required across the Blue Tier Batholith. A modest thickening has been incorporated but no such pattern can be used for the entire assembly and still retain a neutral shift for a bulk batholith density of 2.62–2.64 t/m^3. Further, at this northing, it is not possible to insert any simple penetrative porphyritic or adamellitic pluton, yet the deviation, assuming the curve matching parameters used here, does imply a deeper root for the core of the batholith.

The minor negative excursions shown from the nominal fit can all be explained simply. Narrow rift fills with Permo-Triassic rocks near Lilydale are implied at 515 to 524 000 mE. These may have a total thickness of fill in excess of 800 metres. The reduction in field intensity near the origin (500 000 mE) is due to the combined effects of Tertiary, Triassic and Permian rocks along the Tamar half graben. Other deviations at 555 and 596 to 620 000 mE may be due to weathering profiles on the granite and some Tertiary cover, but can also be explained with additional granite/adamellite.

LINE 5 420 000 mN 500 000–620 000 mE

The model provided (fig. 17) is a concept composite, with shallow and deep geology shown in a separated form, as though detached. Few exposed units can be extended much beyond 2000–2500 metres. These elements make little difference to the solution but this problem, and the inability to resolve it, leads to some confusion when an assembly or integration is offered (as in Figure 30).

The crucial items occur at depth: a block of denser basement to the west (consistent with inferences further north), and a projection of the south end of the Blue Tier Batholith (granite-adamellite component) in depth. Only the very crest of the roof of this body is exposed at this northing. The density implied is 2.61 t/m^3 (the lowest credible bulk value).

A similar property has been assumed for a concealed adamellitic/porphyritic portion of the Ben Lomond massif which is not exposed at this northing.

LINE 5 410 000 mN 500 000–620 000 mE

The model (fig. 18) provided is comparable to that at 5 420 000 mN above.

Mass deficiencies may be noted at each end of the profile. Water and the continental margin create the loss at the

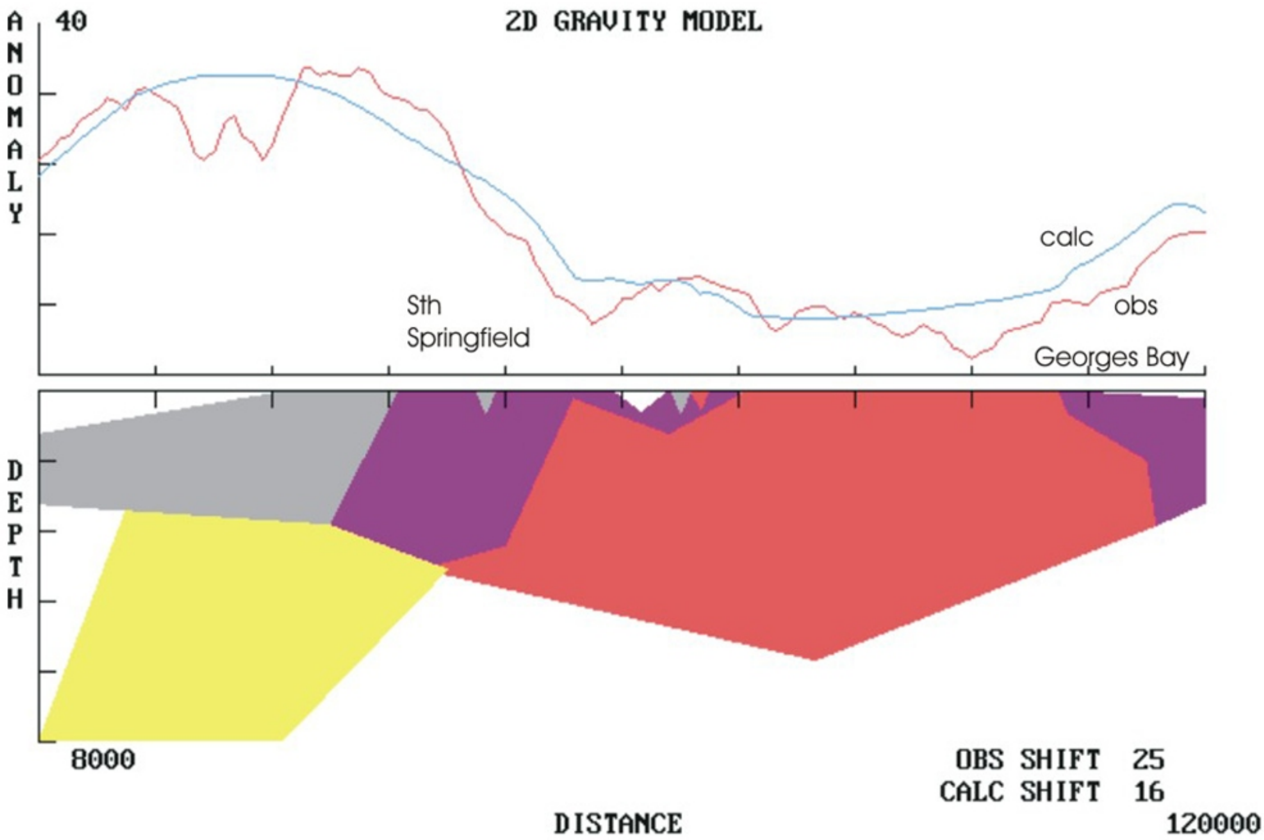


Figure 16

Line 5 430 000 mN (500 000–620 000 mE).

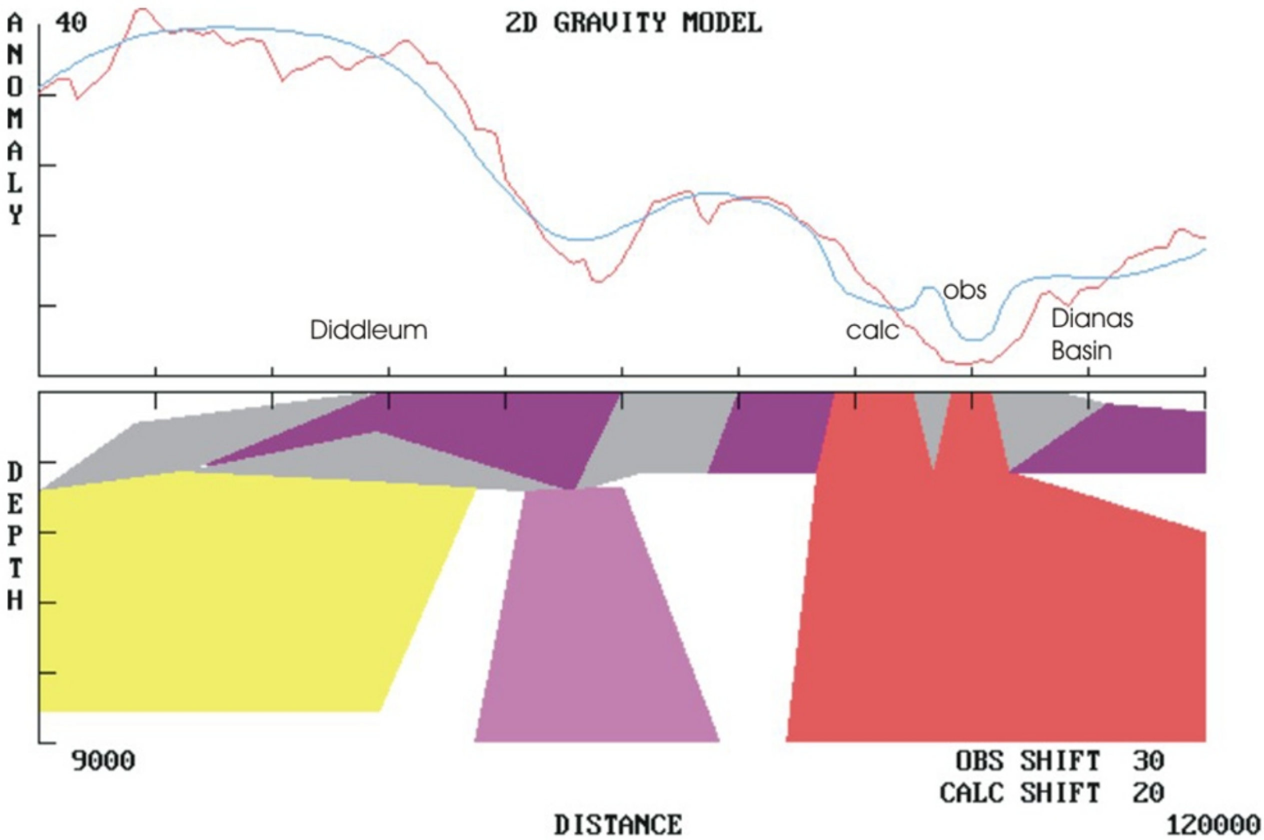


Figure 17

Line 5 420 000 mN (500 000–620 000 mE)

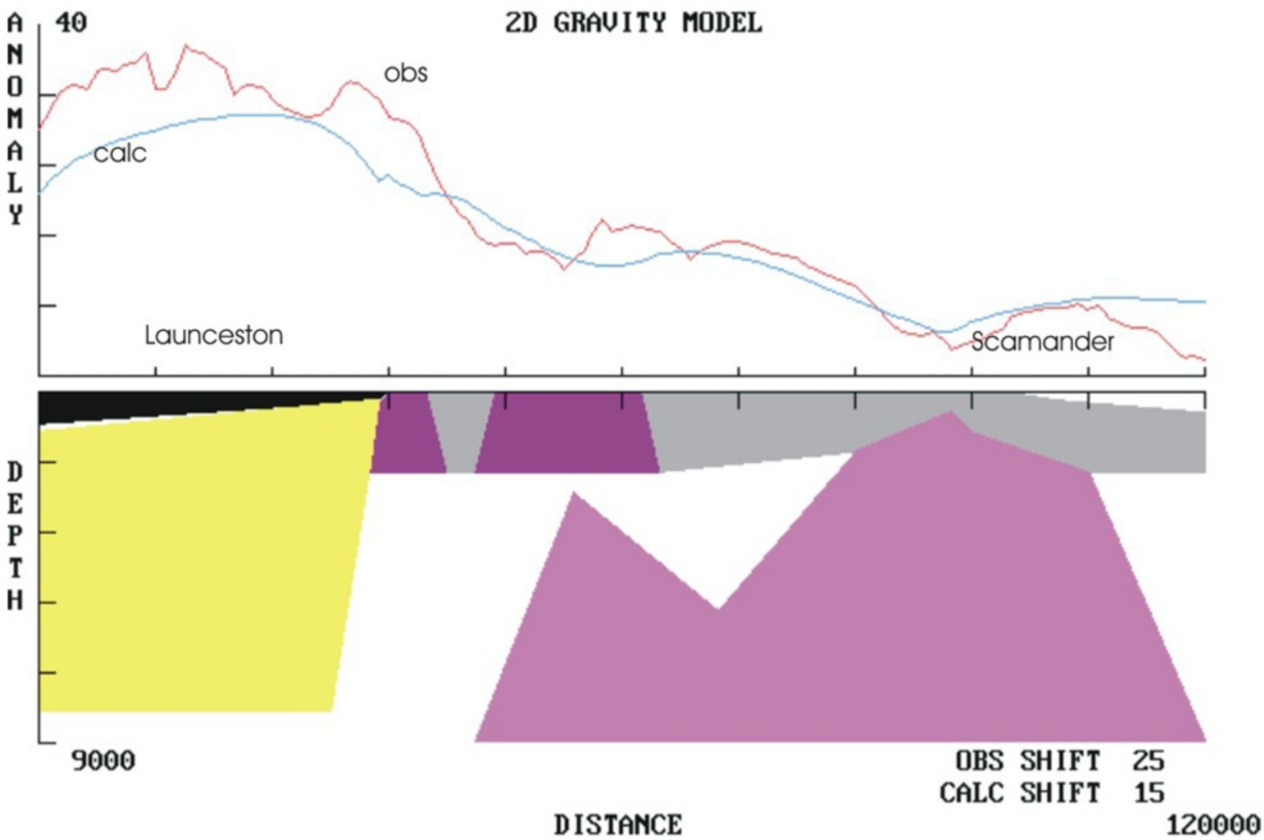


Figure 18

Line 5 410 000 mN (500 000–620 000 mE).

eastern (coastal) end of the profile but the major difference between the origin and 540 000 mE is due either to invalid assumption concerning either the drape cover or the thickness/density of the basement.

The 'drape' has, in these models, been treated as a single entity and not subdivided (Permian, Triassic, Jurassic dolerite), and the bulk density used presumes much Triassic and little dolerite. Inversion of this assumption resolves the difficulty.

LINE 5 400 000 mN 500 000–620 000 mE

The model offered (fig. 19) is a partial solution but all the critical elements are included: the denser basement block in the west, and the great mass of quite low-density concealed granitoid (2.61–2.63 t/m^3). The western projection of this mass is exposed south of Ben Lomond (near Rossarden); the rest is an extension of the Blue Tier Batholith. Granodiorite, part of the Scottsdale Batholith, near surface is a relatively thin veneer which cannot extend to depths in excess of 3000 metres.

The minor deficiency in the model near the east coast can be explained with less batholith (or deeper roof) and more water, or the effect of the St Marys Porphyry (which is a little denser than the bulk granitoids). All options have been tested but the porphyry may not be thicker than 500–600 m if it is the cause.

LINE 5 375 000 mN 500 000–620 000 mE

This section (fig. 20) considers the southernmost sizeable exposures of the rocks of northeast Tasmania, near Avoca and Royal George.

The model incorporates shallow granitoid protrusions near Avoca and at the coast, and offers a thrust slice style for intruded rocks. This style presumes Mathinna Supergroup, but various lithologies are possible at depth.

There is no suggestion of any significant detachment which might involve the granitoids; these must extend to great depth. Any attempt to thin the granitoid demands unsupportable density assumptions, as well as worsening the curve fit difference (see discussions above and Appendix 2).

All interpretation south of 5 370 000 mN must, by necessity, be uncontrolled (other than along the east coast) because of concealment of granitoids and intruded rocks by post-Permian cover.

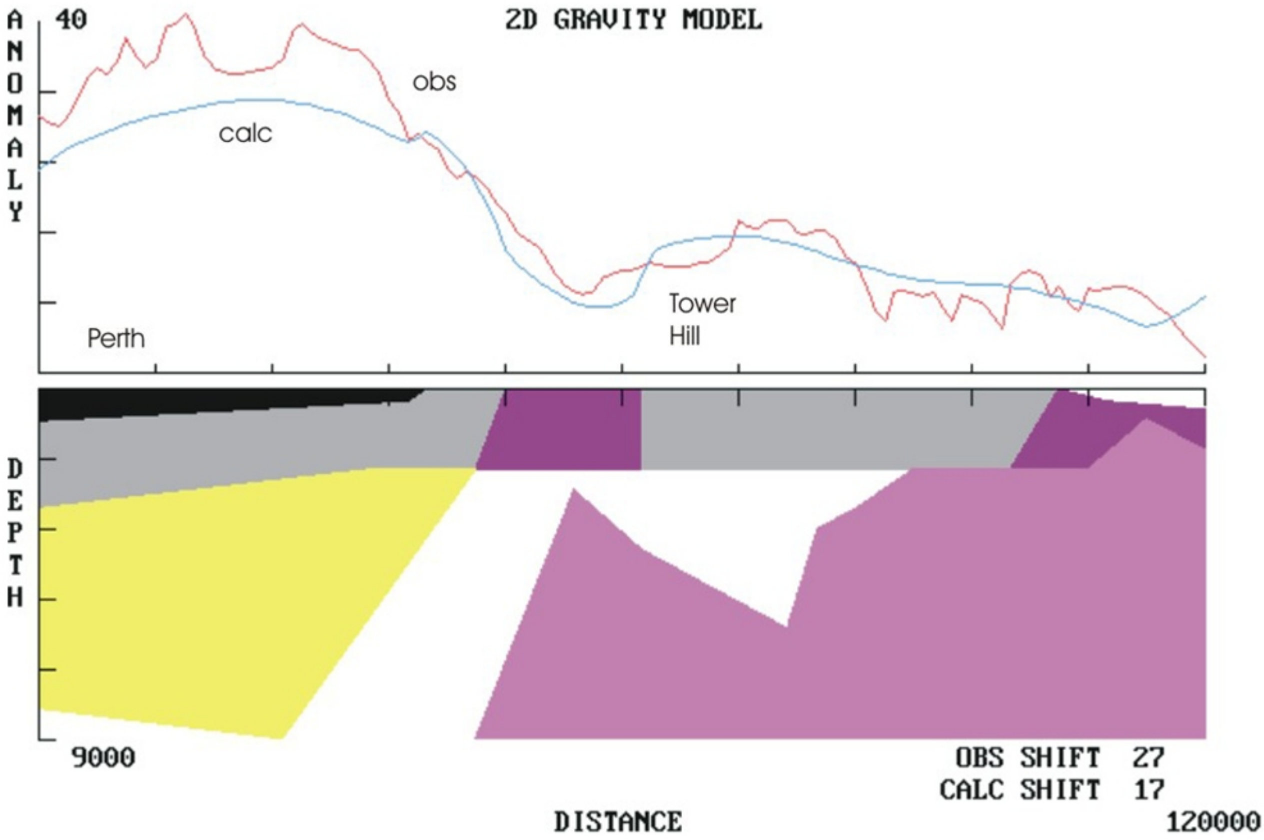


Figure 19

Line 5 400 000 mN (500 000–620 000 mE).

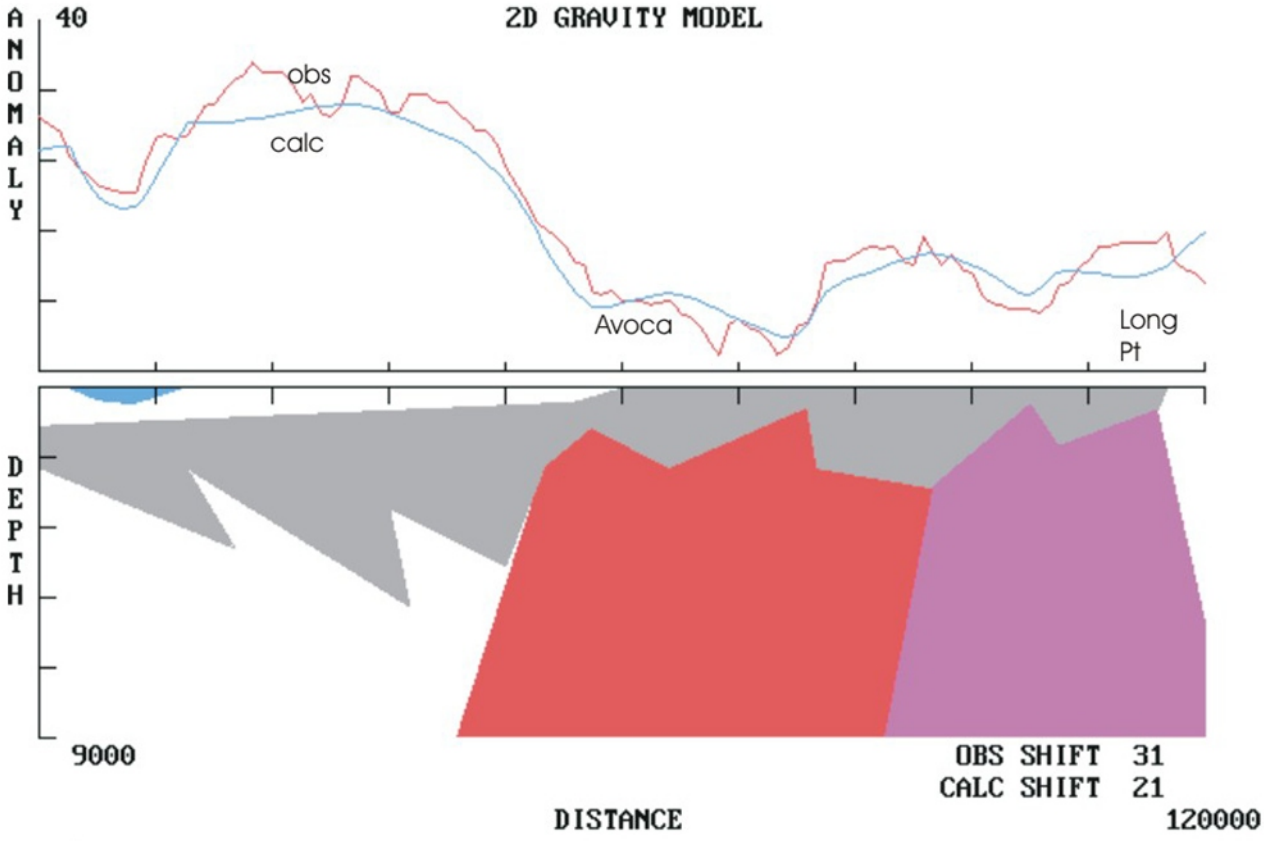


Figure 20

Line 5 375 000 mN (500 000–620 000 mE).

LINE 5 360 000 mN
500 000–620 000 mE

This model (fig. 21) has a generic style (that of 5 375 000 mN), and portrays a dislocated basement section (either Mathinna Supergroup or non-siliceous Precambrian rocks) and two granitoid extensions (Scottsdale–Ben Lomond to the west, Blue Tier to the east).

The coastal exposure of some granitoids is critical and determines absolute limits on rock properties and model fit parameters. Even with exposure and a depth range of nine or ten kilometres, the Blue Tier Batholith has an inferred bulk density of 2.61 t/m^3, which must be regarded as an absolute, realistic minimum. This also shows, as in other sections to follow, that the curve fit offset for calculated/model data (Appendix 2) is -10 mgal for this data set.

A very crude concept only is possible in the absence of control inland. The raised roof of the western batholith near 560 000 mE must involve granite-adamellite or an equivalent composition/density.

LINE 5 340 000 mN
500 000–620 000 mE

The implication at this northing is that the bulk of the batholith/compound granitoid complex is of moderate to low density (2.61–2.63 t/m^3), which would imply a very small proportion of diorite/granodiorite (fig. 22).

LINE 5 325 000 mN
500 000–620 000 mE, .

See Figure 23.

Comments provided for lines 5340 and 5360 apply.

LINE 5 300 000 mN
500 000–620 000 mE

See Figure 24.

Comments provided for lines 5340 and 5360 apply.

This section fully exposes many of the possible ambiguities described for other sections (5360 for example), especially at the western end of the section/batholith.

LINE 5 275 000 mN
500 000–610 000 mE

See Figure 25.

LINE 5 250 000 mN
500 000–620 000 mE

See Figure 26.

LINE 5 225 000 mN
500 000–600 000 mE.

See Figure 27.

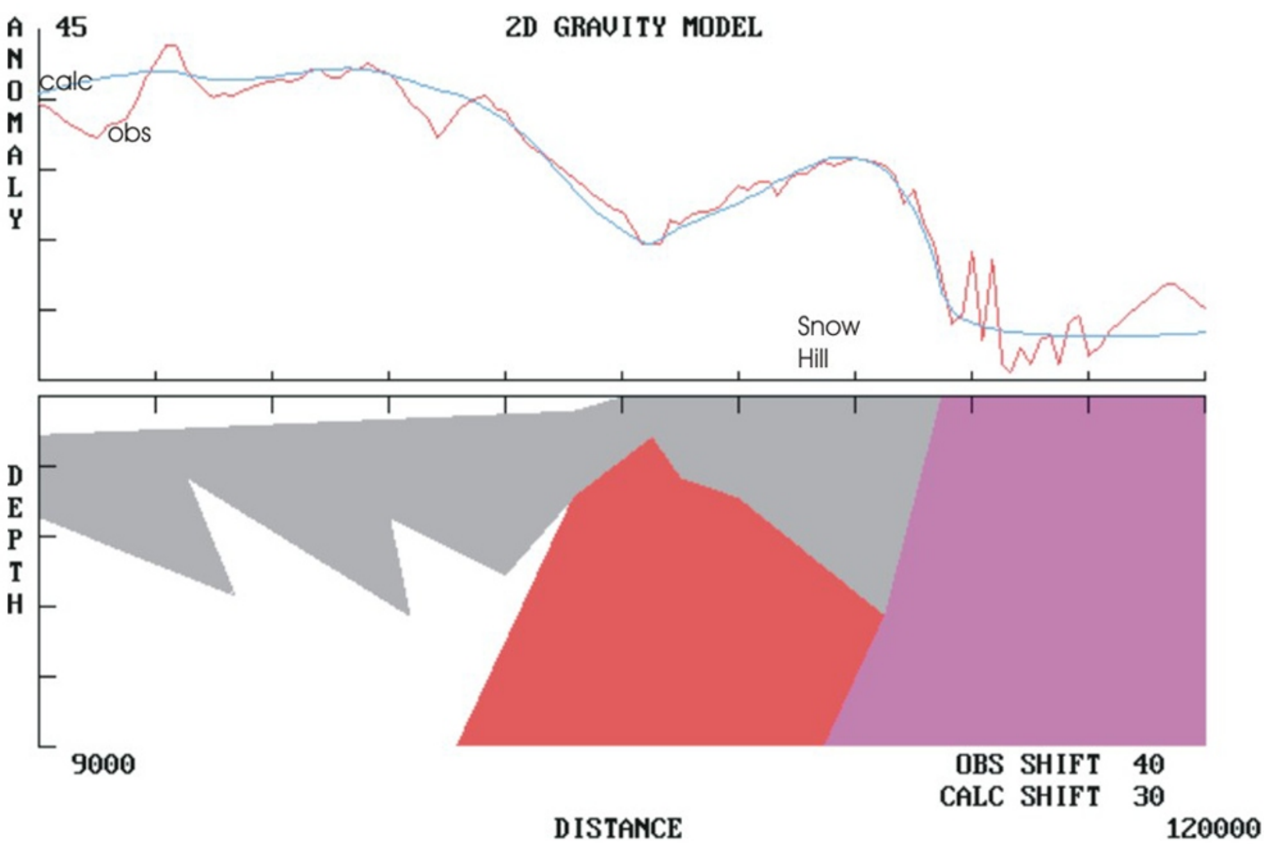


Figure 21

Line 5 360 000 mN (500 000–620 000 mE).

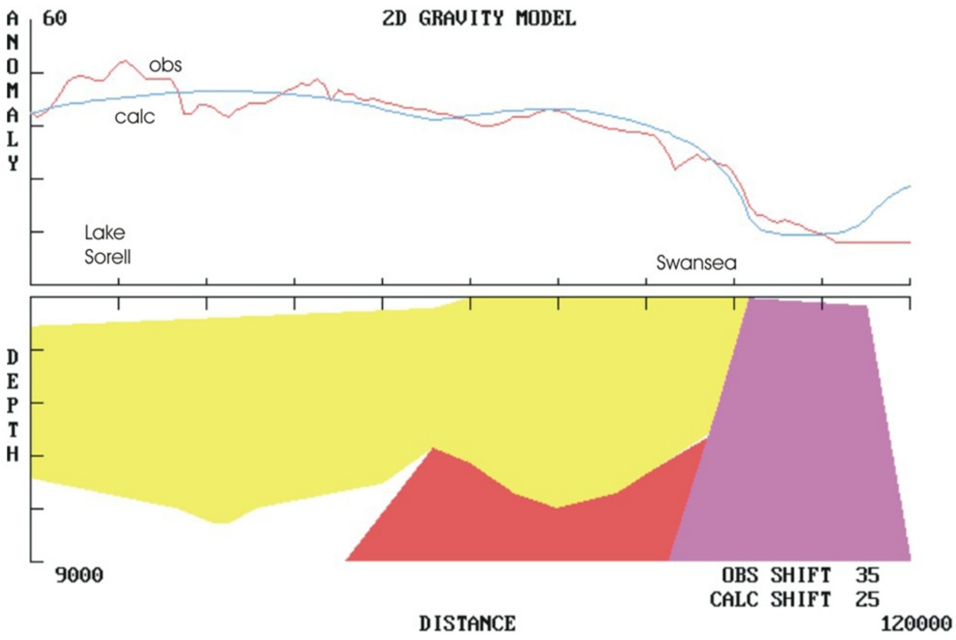


Figure 22

Line 5 340 000 mN (500 000–620 000 mE)

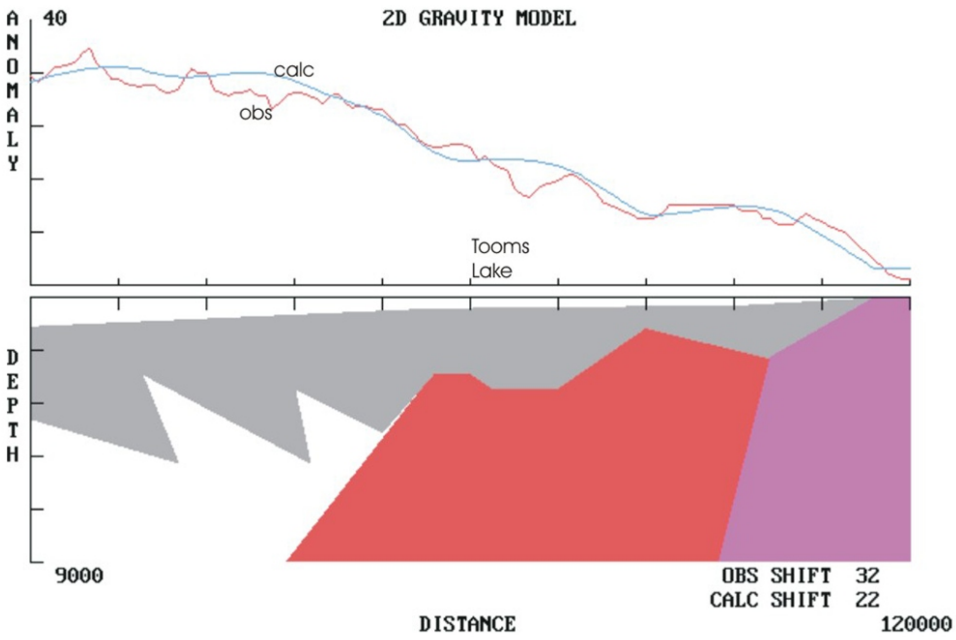


Figure 23

Line 5 325 000 mN (500 000–620 000 mE)

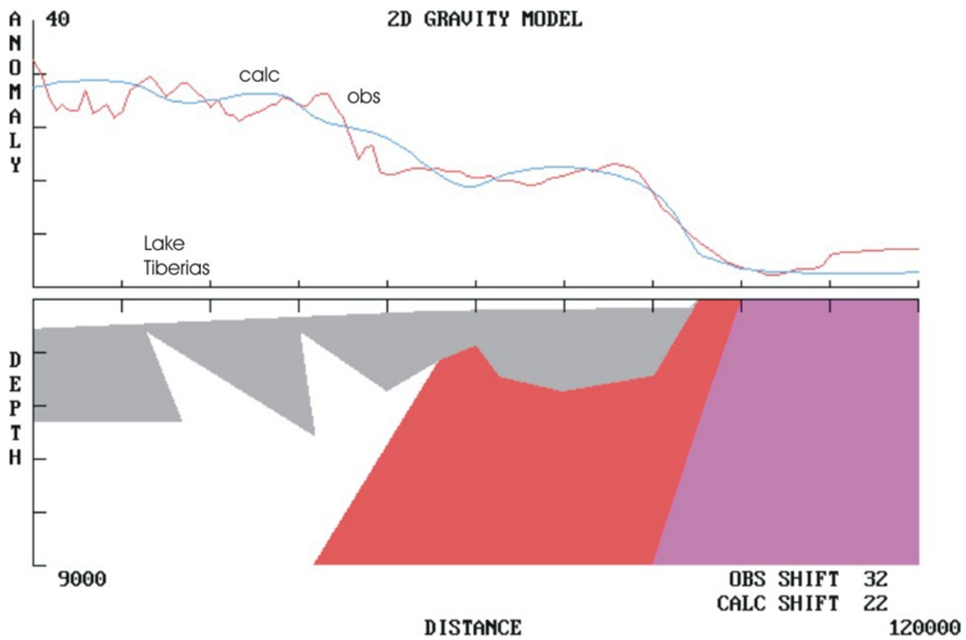


Figure 24

Line 5 300 000 mN (500 000–620 000 mE)

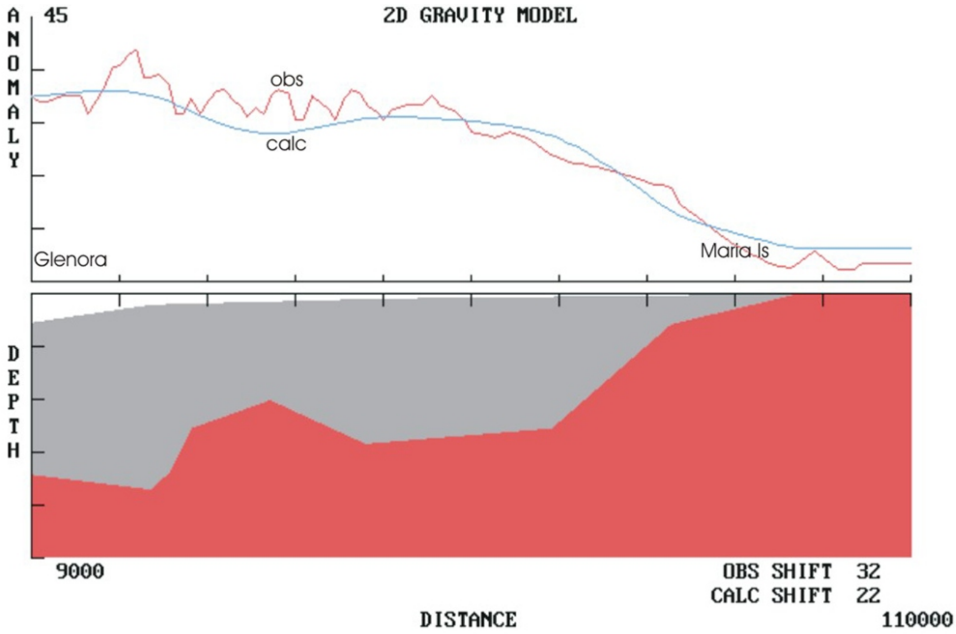


Figure 25

Line 5 275 000 mN (500 000–610 000 mE)

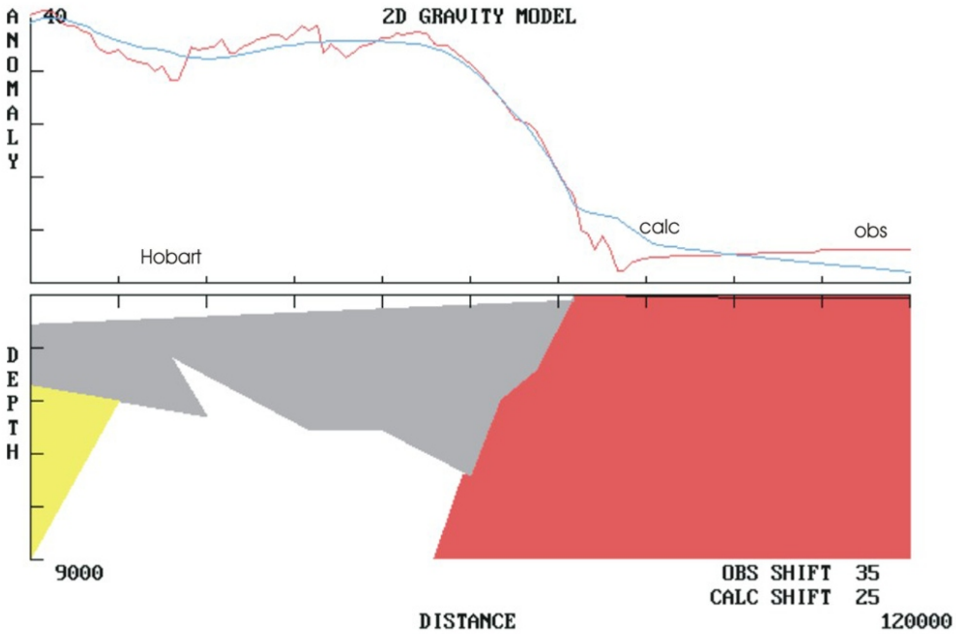


Figure 26

Line 5 250 000 mN (500 000–620 000 mE)

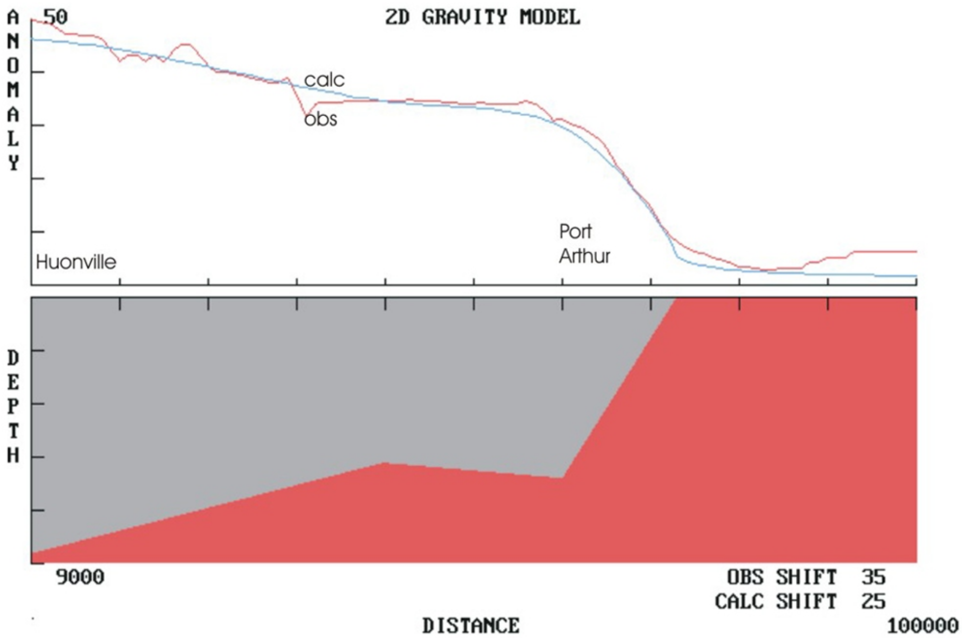


Figure 27

Line 5 225 000 mN (500 000–600 000 mE)

LINE 5 200 000 mN
500 000–600 000 mE

See Figure 28.

These sections (5400–5200 km N) reproduce the inferred structural style and do imply that lower density granitoids occur at depth to the west as well as along the coast. The entire pattern is suggestive of northeast Tasmania in terms of a pair of batholiths, but a substantial slab of material suggested tailing to the west is unproven. This volume could be granodioritic in composition, and shallower than shown.

Note that less contribution from overlying basement (above granitoid; whether Mathinna Supergroup or Precambrian) is then required. These ambiguities cannot be resolved with existing data. Such variation in intruded material is suggested in figures 21 and 22 for example.

The concept of paired batholiths leads to the idea that these are extensions of the Scottsdale and Blue Tier batholiths, with possibly similar proportions of granitoid types. If this is the case a higher proportion of granodiorite may be present to the western side but this cannot be confirmed.

Line 5 250 000 mN reproduces many of the elements inferred near the north coast, including a block of dense basement, although this is the last model in this collection to illustrate this. The options noted have all been tested and it is possible to introduce similar elements on the remaining profiles. This interpretation is supported by many xenoliths carried upward by Tertiary volcanoes (Everard, 2001).

In all cases the granitoid complex must be deeply rooted; the tie to reality and requirement is set by the coastal exposures in terms of composition, density contrast and observed gravity. Any reduction in granitoid volume or bulk density (not credible) cannot be supported, as this would worsen the curve fit parameters (refer to Appendix 2). Were the granitoid to be terminated at any moderate depth, and underlain by any form of Precambrian basement, then no fit would be possible with this data set.

If there are any detachments then they must occur within the batholiths.

Regional magnetic data do suggest that such structures extend south of the latitude of Launceston, and may involve ultramafic rocks, but adequate examination will require an improvement in the magnetics data base (see extracts in Leaman, 1992).

Note that several models have been constructed to include a saw-tooth shape implying thrusting within basement. This is merely to suggest consistency with the structural style presented in Leaman and Webster (2002) and Leaman (2008). Any equivalent mass distribution would produce similar results. The form illustrated should not necessarily be accepted as a demonstration of reality — although it might be.

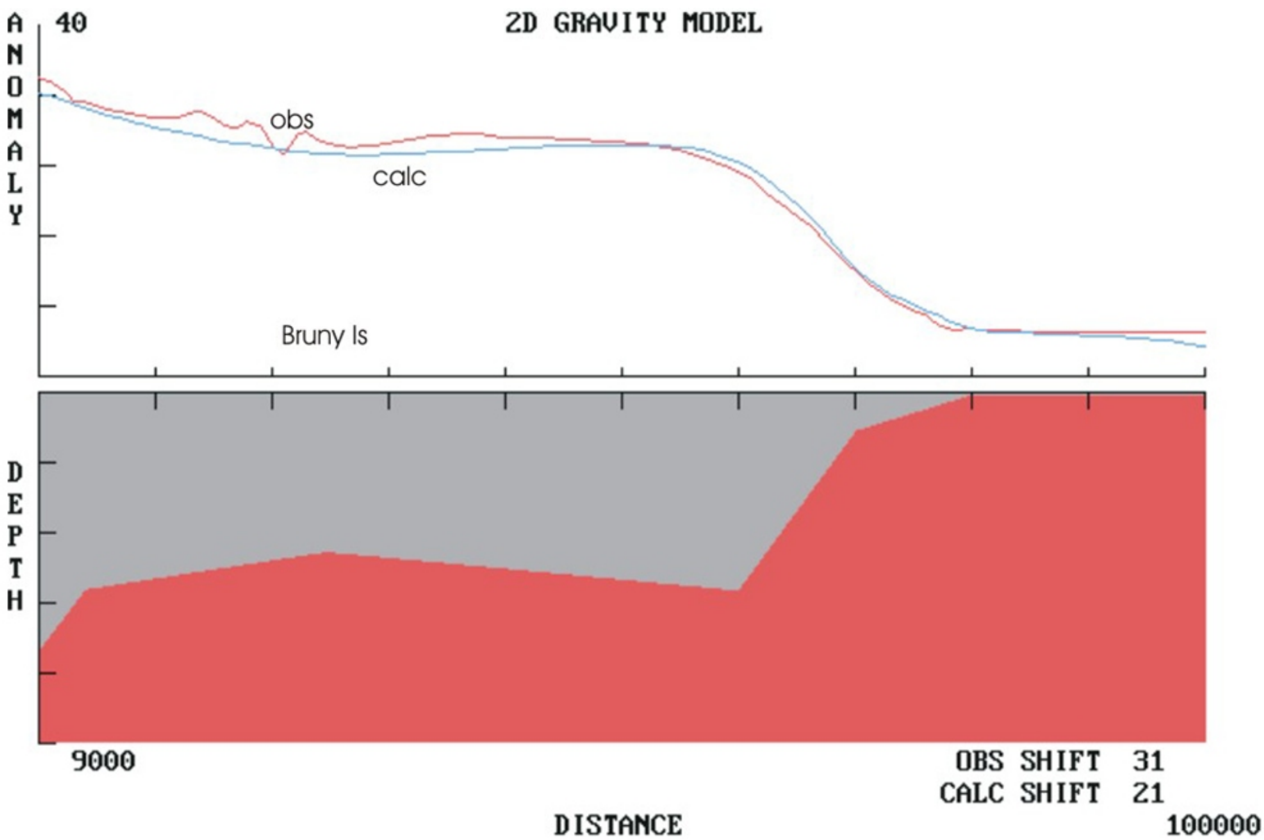


Figure 28

Line 5 200 000 mN (500 000–600 000 mE).

CONCLUSIONS

A preliminary interpretation of the form of east Tasmanian granitoids has been offered based on current gravity and magnetic (where available) data sets and use of the most recent gravity regional-residual separation (Leaman, 2009). The interpretation has been termed preliminary as it is based on simple modelling of the data and this has yet to be integrated into a refined whole for eastern Tasmania.

This caveat must be noted when assessing comments given here. The interpretation would also benefit from an equivalent magnetic study (to resolve and separate shallow sources as well as variations in batholith composition) but available magnetic data in much of eastern Tasmania lack the regional reliability and consistent integration of observation and compilation which would make this possible for the entire region.

This interpretation has been summarised in Figures 29 and 30 (roof of granitoids surfaces), Figure 31 (implied penetrative plutons) and Figure 32 (situation in Bass Strait). The various limitations and ambiguities noted in the preceding text should be borne in mind when applying the presentation to particular uses.

The present study is, however, most suggestive in terms of batholith distribution and character and, therefore, represents a significant change from earlier interpretations (such as Leaman *et al*., 1980; Leaman and Richardson, 1992, 2003).

There remains much scope for further analysis as noted above. There are a few, apparently new, concepts in this interpretation; most have been offered previously, but all are now presented in more detail here. In that sense, the present document offers validation.

Examples include a review of the role and extent of thrusting (see Leaman, 1992; figures 7, 8, 9 of Leaman and Webster, 2002) together with the inclusion and remobilisation of ultramafic rocks (Leaman, 1992; Leaman and Webster, 2002). The idea of widespread detachments which might have involved granitoids is also presented in the same sources.

Many previous, but more localised studies have benefited from the use of aeromagnetic data (survey extracts in Leaman, 1987, 1992; also Leaman and Webster, 2002 and Leaman, 2008). Several such older studies have included an appraisal of the Tasmania Basin cover (Permo-Triassic rocks plus Jurassic dolerite and some Tertiary deposits) but this has not been done here due to scale and data quality issues in eastern and central Tasmania. These covering materials generate much of the 'noise' noted on some profiles and can provide several milligal of gravity anomaly, or strong magnetic spikes.

This interpretation (gravity) has inferred two types of granitoid occurrence, detached or in place. In situ plutons are small, isolated and tend to be less common in eastern Tasmania/Bass Strait. They probably present the normal structural/intrusive mode in western Tasmania/King Island. The location of some intrusive, penetrative plutons is suggested in Figure 31. Many others may exist but identification of all of them has been beyond the scope of this study.

A tectonic pattern can be implied from available dating data (see fig. 33*a*, *b*)

Using the table (fig. 33*a*) and the inferences about specific granitoids derived here, it can be suggested that young plutons penetrate the detachment carrying older granitoids, with a critical age of about 350 to 360 million years.

A more refined view may be possible using more recent data (fig. 33*b*). There are some difficulties. Although many dates are provided using different methods it is unclear which set should be accepted even though relative patterns of age seem to hold (e.g. U-Pb is always older). McClenaghan (2006) has suggested that some dates have been reset. The report listing this data provides a numbered location map as well as the table reproduced here — which gives names but not the number key. The reader must take care to link locations.

Several younger dates correlate well with the older data (fig. 33*a*) and other sites may well do so, were comparisons possible. These matters should be reviewed and the respective databases amended. At this time some uncertainty persists in how these data are interpreted but the logic of penetrative plutons versus age suggests a detachment age of 360–380 million years (Middle Devonian).

The present interpretation has also led to a final important conclusion about the use of current gravity data compilations, in particular residuals derived from the current mantle model.

This residual separation generates a modest model shift from previous values (of the order of 10–15 mgal, see Appendix 2), which formerly led to neutral observed/calculated relationships in models with a depth range of nine to ten kilometres. The present models appear generally valid and consistent across continental Tasmania (all of the island west of the River Tamar and southeast of Launceston), where a shift of -10 mgal may apply. Further north, the presumptions of the model are inadequate and a +5 mgal shift applies. It is unclear which is correct, or best, but constraints upon models are affected by either mantle model design or its implication. It is also possible that problems are restricted to the field off the east coast (principally) due to insufficient data, which could account for the 15 mgal total discrepancy at the edge of the data set — where granite is exposed.

It is recommended that these matters be reviewed and the mantle model then revised (if necessary). Some revision in the Bass Strait region is inevitable as it is too simplistic given the present work.

It should be noted that the mantle models are derived from long line, whole crustal modelling of the observed Bouguer anomaly, with inclusion of both bathymetry and granitoids. There is thus scope for review of both inclusions and form.

Care has been taken not to over-interpret much of the geophysical data at this stage. For example, with the exception of known granite exposures along the east coast (from Bicheno to the Hippolyte Rocks off Tasman Peninsula), and the concealed cupola drilled immediately west of Bicheno and north of Llandaff, there is no control on the granite surface in eastern Tasmania (fig. 29).

Any more refined interpretation depends upon the constraints assumed and the nature of upper crustal contents and contrasts west of the batholith. On past experience, the batholiths en masse have a general density of 2.59–2.63 t/m^3.

It should also be commented that bulking of densities, of basement suites or batholiths, may mislead and conceal some important realities. Each batholith in the region of northeast Tasmania (Scottsdale, Blue Tier) consists of several plutons wide ranging in composition (granite, adamellite, porphyritic versions, diorite, granodiorite) and internal densities may range from 2.59 to 2.72 t/m^3. Similar variations may exist in the stacked, overthrust or detached intruded sequence depending on the proportion of silica, arenite or argillite. This means that reduced or reversed contrasts may exist with important consequences for interpretation. This is thought to be most critical in terms of the Scottsdale Batholith.

At various stages during this study, and in this review report, the structure flooring the depth-limited granitoids has been termed a detachment. There seems no other reasonable explanation or terminology given that more dense or magnetic materials can be inferred beneath it. This is a recital of a concept already evident at many other sites (e.g. Leaman *et al*., 1994) but now implied to also involve the sequence of granitoid intrusions (as in Le Clerc, 1996). This structural style may also account for the anomalous geophysical character of granitoids near Beulah in northern Tasmania (Leaman and Richardson, 1989*b*).

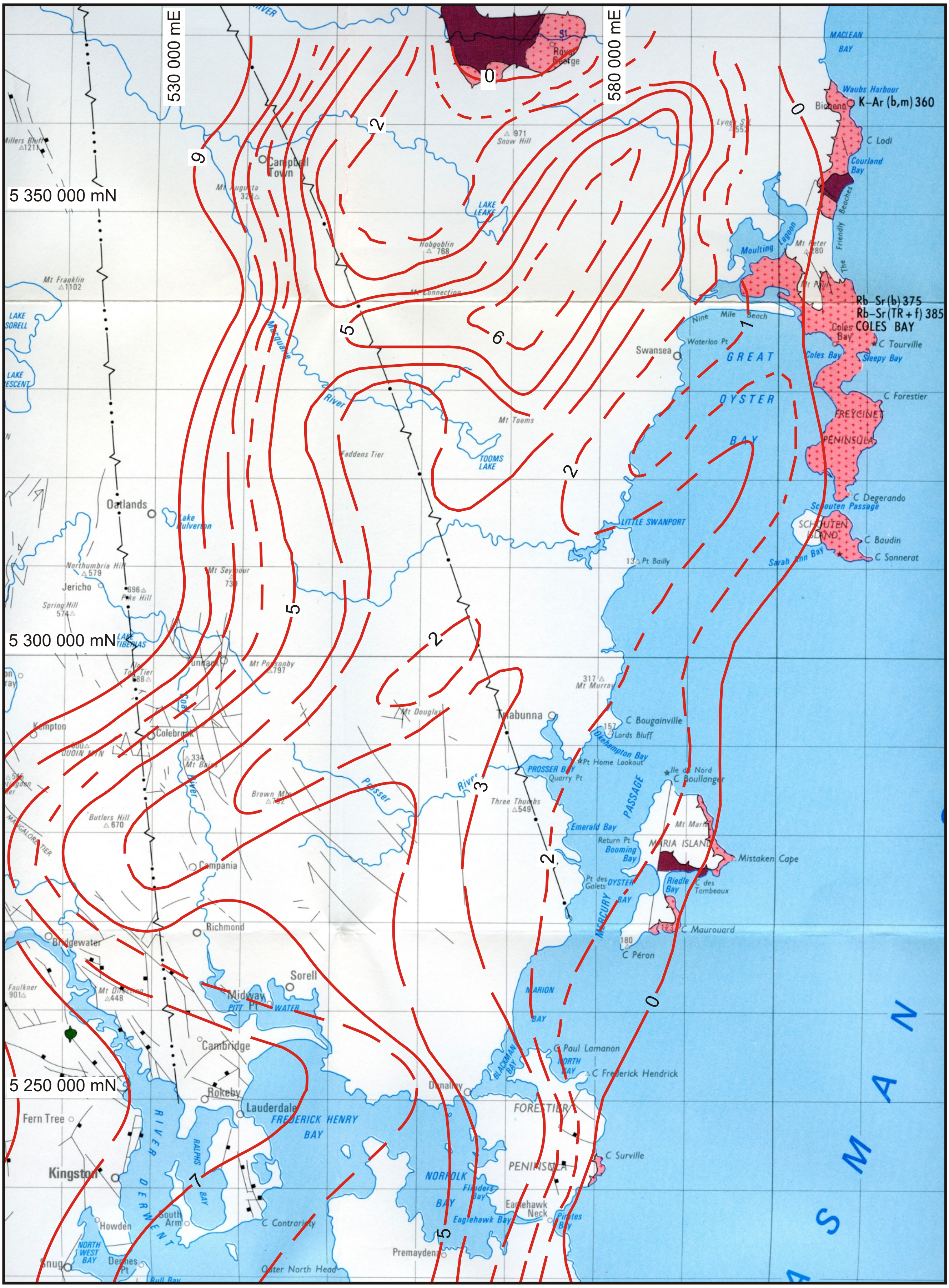


Figure 29

Interpretation of granitoid roof, eastern Tasmania. Contours in kilometres.
Note that the surface south of Royal George is generally uncontrolled except along the coast.
Base map: Structural map of Tasmania (Pre-Carboniferous) (Tasmanian Department of Mines, 1976).

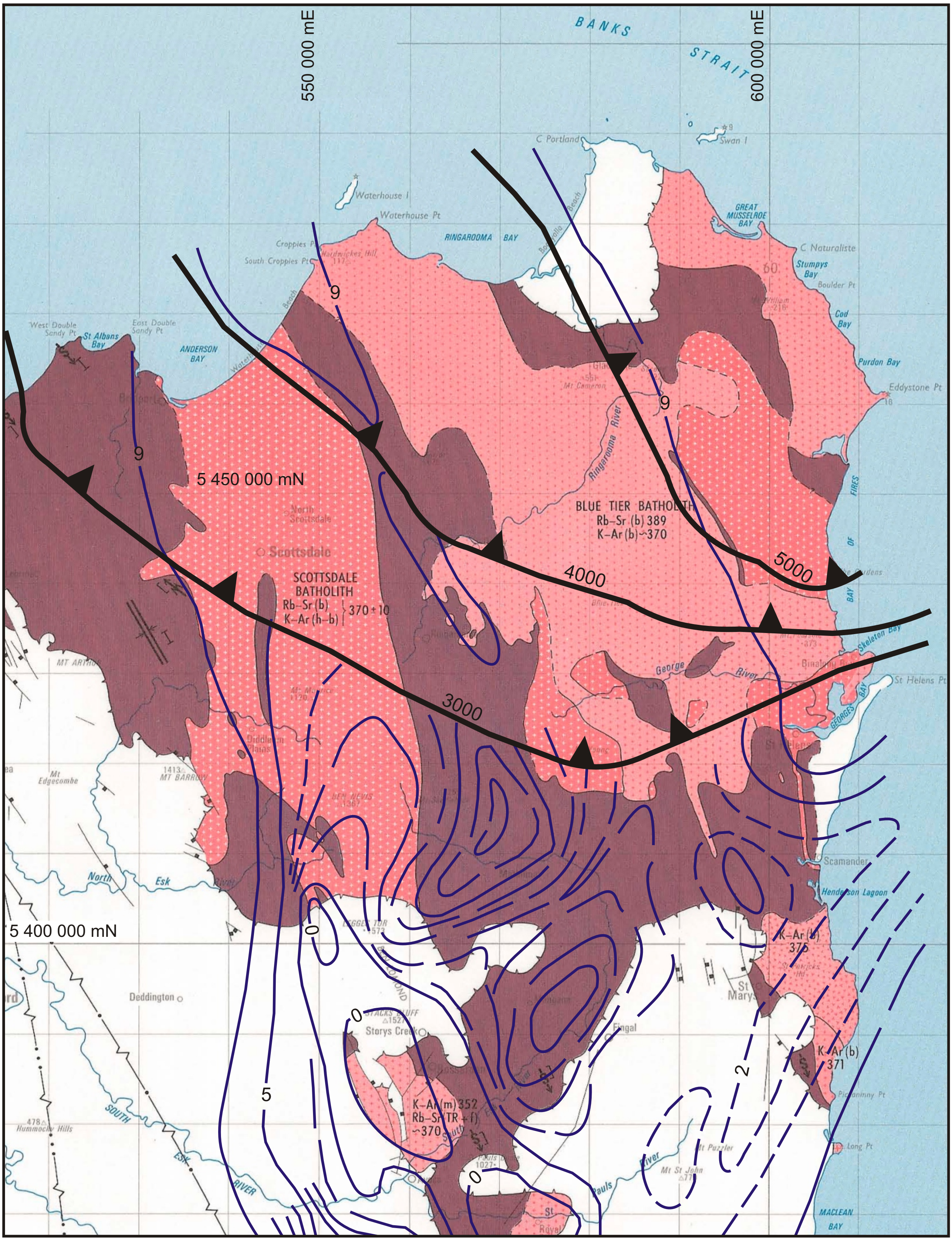


Figure 30

Interpreted depth to granitoids and regional detachment, northeast Tasmania. Contours in kilometres. Structure of granitoids ABOVE the detachment is not shown and the assessment is ambiguous north of 5 400 000 mN. Splintering of the detachment occurs but such details have not been resolved (see also Leaman and Webster, 2002; Leaman, 1992, 2008). The thrust surface indicated is the most simple single, coherent form probable. Base map: Structural map of Tasmania (Pre-Carboniferous) (Tasmanian Department of Mines, 1976).

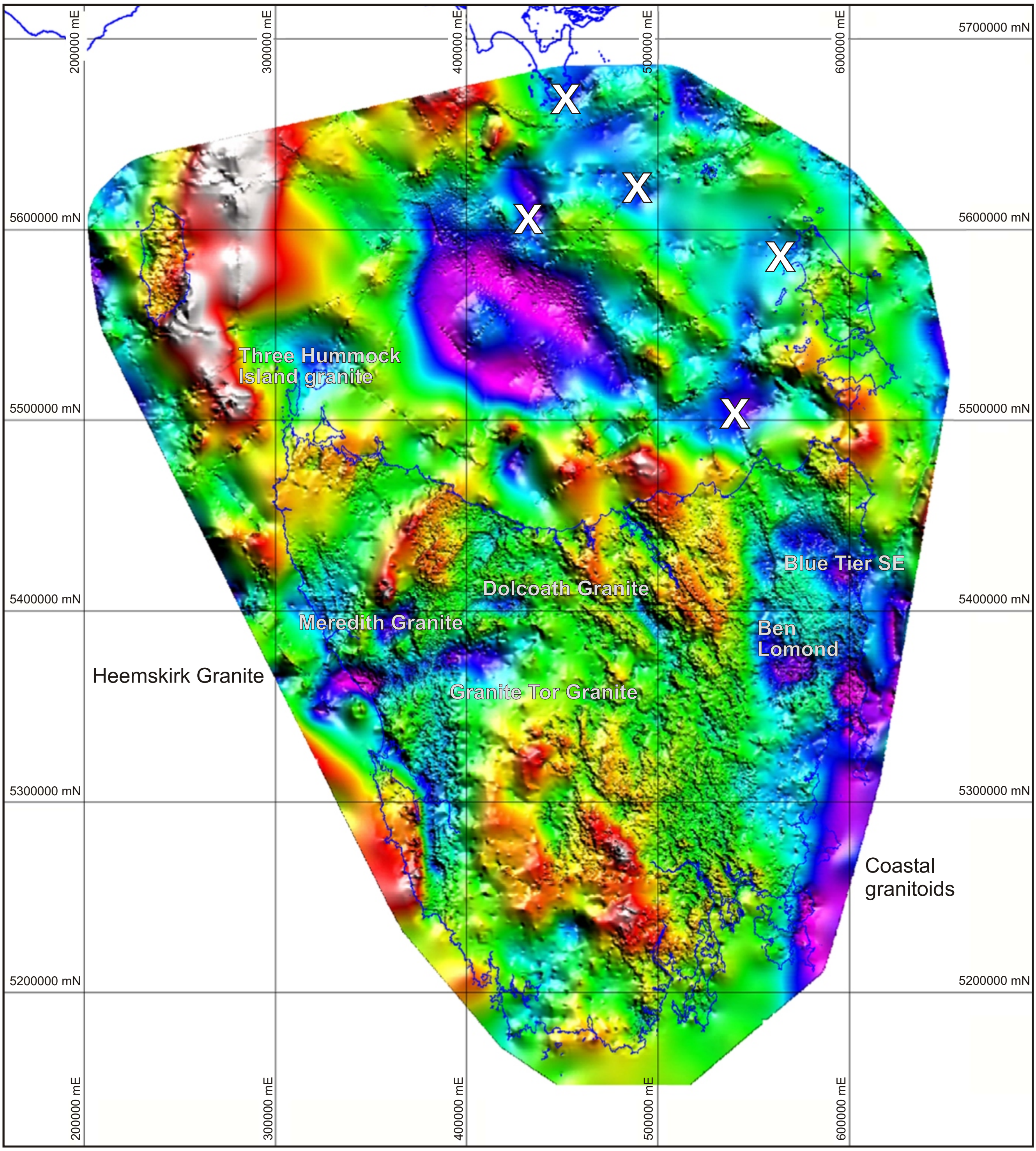


Figure 31

Location of some granitoids with a deep root. Some examples are named, others suspected to be of this type are marked "X". Review of modelling considerations as discussed in this report indicates that other intrusions of this type yield a more ambiguous signature — but one which can be resolved quantitatively. A more detailed study is required to identify these. Note that the largest plutons of this type appear to occur in eastern Tasmania and eastern Bass Strait.

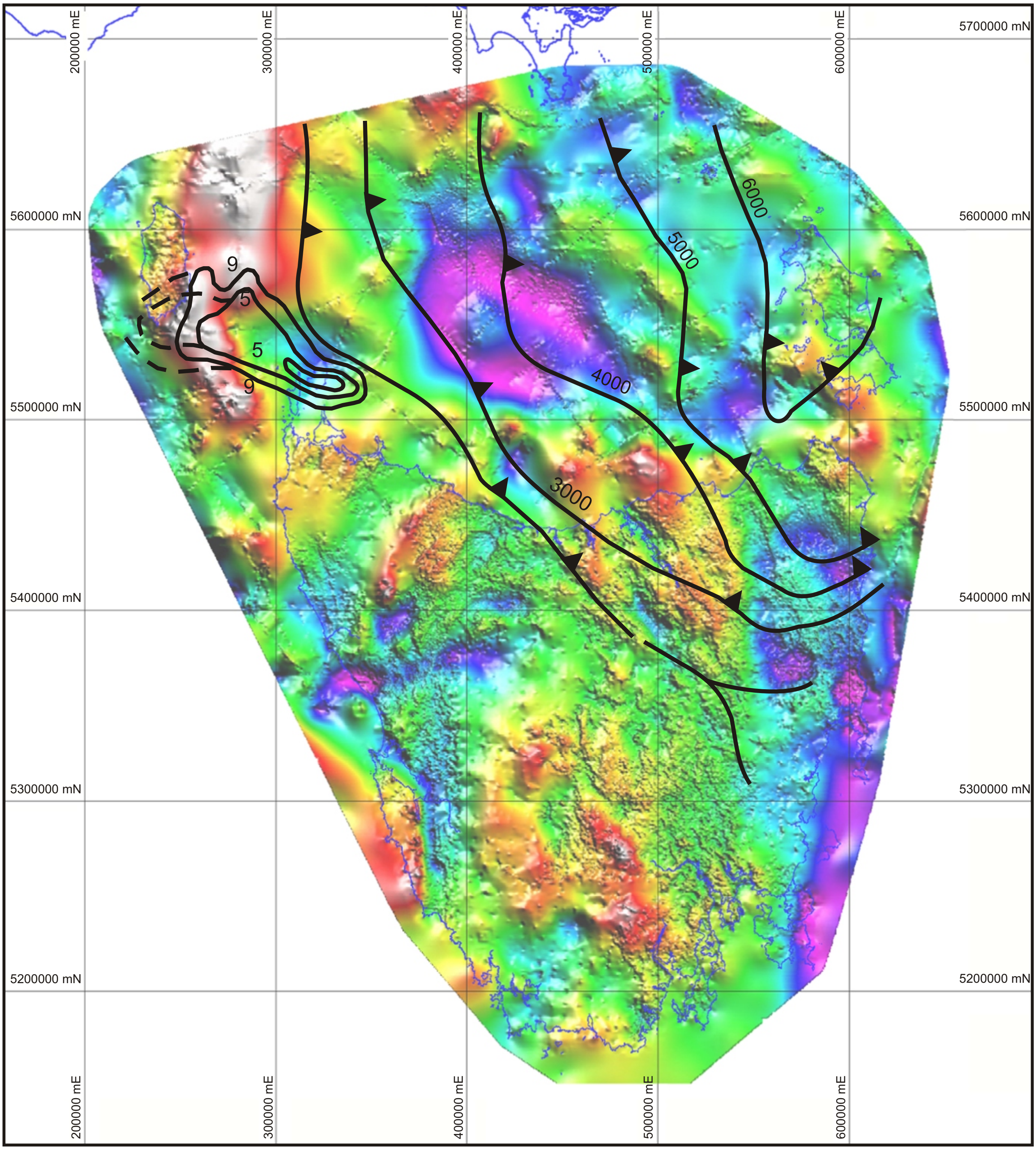


Figure 32

Interpretation of Bass Strait region; residual gravity base. Detachment contours in metres. Granite contours in kilometres. All comments apply to the granitoids as suites, regardless of composition, whether granite/adamellite/granodiorite.

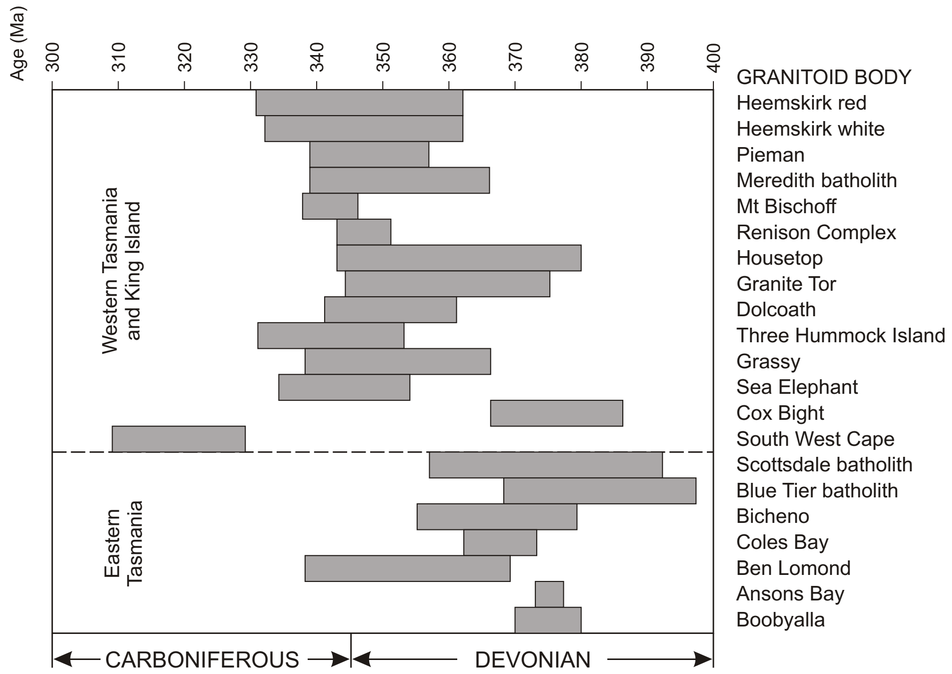


Figure 33a

Granitoid ages: 1989 summary (from Burrett and Martin, 1989)

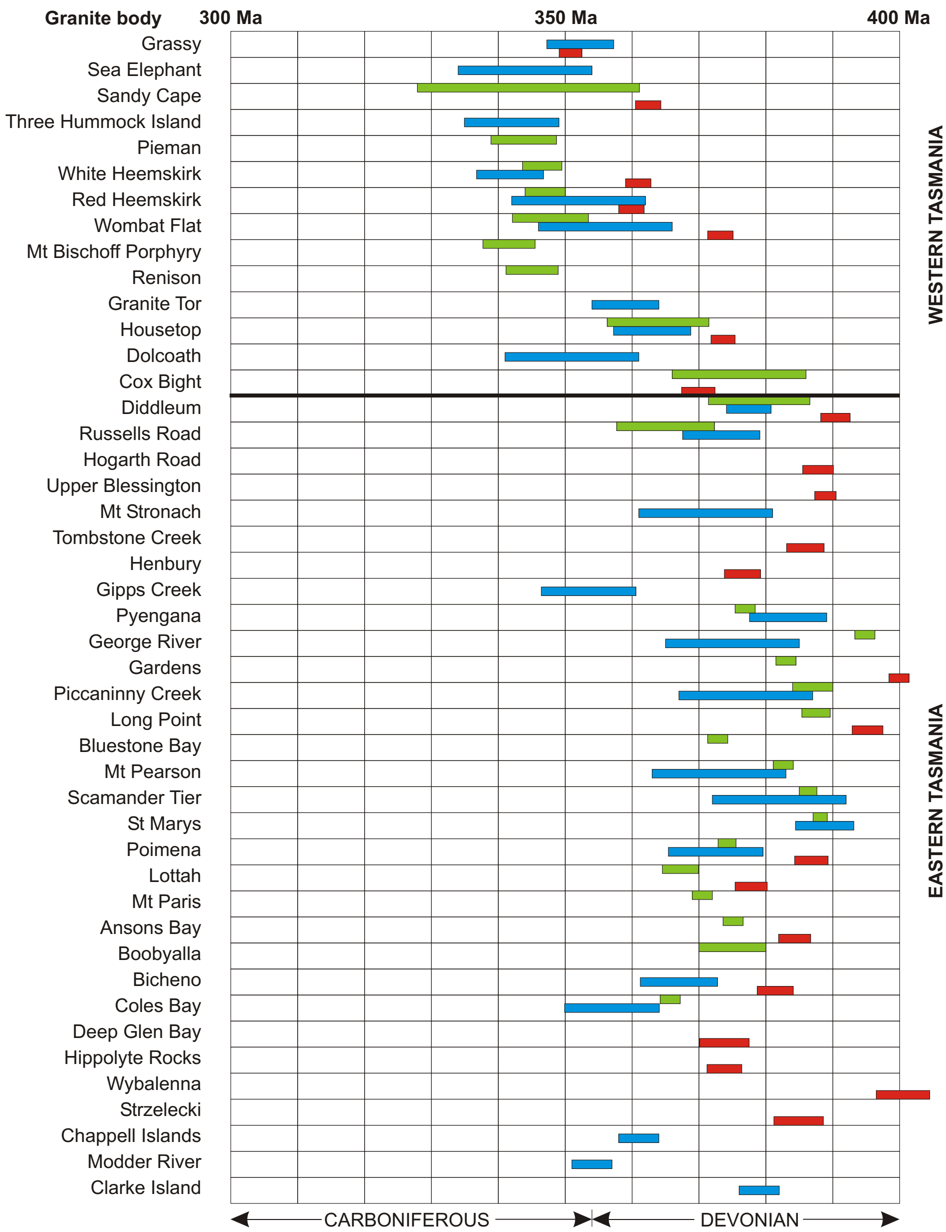


Figure 33b

Granitoid age dates: 2006 summary (95% confidence levels). From McClenaghan (2006) Green (Rb-Sr); blue (K-Ar); red (U-Pb) SHRIMP

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APPENDIX 1
Table of rock properties

Density is expressed as a contrast with background and reduction density of 2.67 t/m^3.

Age and unit	*Density g/cc, t/m³*	*Susceptibility cgs*	*Susceptibility SI*
Quaternary	-1.2	0	
Tertiary			
Sediments	-0.7	0	
Basalt	0.23	>0.001	>0.01
Jurassic dolerite	0.23	>0.004	>0.05
Triassic	-0.22	0	
Permian	-0.13	0	
Devonian			
Granite	-0.05–0.07	0	
Granodiorite	0.03	~0.0002	~0.0025
St Marys porphyrite	-0.02–0.03	0	
Siluro-Devonian			
Western Tasmania	-0.1	0	
Mathinna Supergroup	-0.07–+0.1(0.07–0.09)	0–0.0005	<0.006
Ordovician			
Gordon Group	0.07	0	
Denison Group	-0.07	0	
Cambrian			
Tyndall/Yolande groups	0.05–0.07	0.0002	0.0025
Dundas Group style	0.05–0.07	<0.0002	<0.0025
Sundry variations	var	var	
Andesites	0.1–0.15	>0.0002	>0.0025
Central volcanics	0.06–0.08	~0.0002	~0.0025
Porphyry	-0.03<0.05	<0.0002	<0.0025
Granite	-0.05/0.02	>0.0005	>0.006
Ultramafic rocks	var	>0.01	>0.12
Que style basalts	0.1–0.2	>0.0003	>0.0035
(note many Cambrian units exhibit variations in properties locally when altered)			
Precambrian/Eocambrian			
Crimson Creek Formation	>0.1	>0.001	>0.01
Success Creek Formation	>0.07		0
Lineament rocks (variants occur)	>0.1	>0.0002	>0.0025
Oonah/Burnie Formation	0.08	<0.0005	<0.006
Forth Complex	0.1	0	var
Tyennan/Badger/Rocky Cape	0	0	
Cradle Block var.	0.1	0	
Sundries/amphibolites	0.15	0.0003	0.0035
Dolomitic variations	~0.07–0.1	<0.0005	<0.006

APPENDIX 2
Reading the sections/models

This appendix should be read before reviewing any of the models presented in this report as it contains an explanation of symbols, codes and terminology as used in the text.

The following notes apply to both gravity and magnetic sections/models. A commented model presented as the geological colour code is given as Figure 34.

Each diagram is in two parts; an upper part providing details of the observed potential field and the effect calculated from the model, and a lower part showing the modelled geometry/geology.

A geological source/body/component appears in the lower portion only if it has been assigned a physical contrast relevant to that field (density — gravity; susceptibility equivalent — magnetics). No complex effects such as remanence have been included separately.

All sections look north; west to left, east to right.

The upper part of the diagrams:

This part of the diagram presents an observed data profile and a profile calculated from the geological model.

The vertical axis has five marking ticks and a value, which is the scale range. Each tick represents 1/5 of the scale in nanoTeslas (nT) or milligal (mgal).

Note that any calculation which includes both positive and negative contrasts with respect to the reference assumption (refer Appendix 1) must generate an absolute zero value somewhere. Observed data need not as it is possible for all values to be positive, all negative, or some mixture. As the software will not plot negative values everything must be retained, or made, positive. The amount which must be added to ensure that the observed profile is always positive is termed the **observed shift**. Note that a scalar shift of this type does not affect the shape of the profile, just its actual value, and there is nothing sacred or absolute about the observed values. Any zero in the calculated profile is, however, absolute in terms of the model from which it is derived. Any scalar then added to match the shifted observed profile with the calculation is termed the **calculated shift**.

These shifts have also been termed the curve-matching parameters.

For any given data set which has been observed, corrected and displayed after consistent processing there should be a constant pattern of shifts — if the model is also valid and self consistent (see also Leaman, 1994*a*). If the pattern or relationship between shifts changes across a region/interpretation then there is a problem hidden in either the data or the interpretation.

The horizontal axis of both parts carries ten tick marks and the lowest right hand corner of the diagrams carry a large number (usually 420000 or 120000). This is the length of modelled line in metres. Each tick thus represents 42 000 or 12 000 metres. If the stated origin is at 220 000 mE and the ticks are each valued at 42 000 m, then the easting of the first tick mark is 262 000 mE. All positions can be estimated in this manner.

The lower part of the diagrams:

The vertical scale carries a depth axis, with the full range stated. Each tick mark represents 1/5 of that range.

The geological units have not been labelled individually in the diagrams in order to avoid clutter and confusion, but all are colour coded (fig. 34).

The modelled and observed data may, or may not, be well matched and the fitting is adjustable. The reader may determine if or how to vary the presentation by reviewing the shifts and the data scale. If adjustment is undertaken note that it may need to be done at many profiles and that the shift *difference* (what happens to a zero in each case) should be consistent across all.

A quick inspection of presented models shows, especially in the gravity case, that this is not so. This means that further modifications of assumptions are required but, in the absence of control, this is a pointless and wasteful exercise as balancing factors dominate and ambiguity is inevitable.

About the models

Mineral Resources Tasmania (MRT) can make model files available should details of depths and locations be required. Final model files carry a descriptive header, details of line length, elevation with respect to AHD, orientation in degrees, and background magnetic field intensity, inclination, declination, and the number of geological bodies.

Each body is specified by a title, density contrast, susceptibility contrast, remanence magnitude-inclination-declination, and number of coordinate corners.

A list of X,Z coordinates then follows.

Model files supplied to MRT include a short form of the northing in the file name. The models supplied are the versions relevant to figures in this report and not necessarily final versions. Many models/variants were tested at each northing and too many files are involved for complete reproduction.

Sampling of the gravity and magnetic fields has been undertaken with intervals of 1 or 2.5 km. Consequently only large scale, or regional, features have been included and assessed in this treatment.

Comments on Figure 34

The upper part of the diagram offers only the calculated profile using typical contrasts on blocks of material six kilometres wide extending from 500 to 7000 m in depth. The zero line, which would have been the observed data profile, can be inferred from the general background values at line ends — where no geology has been included.

This zero position is 103 mgal up the vertical axis as the shift in calculated values is 103, which reflects the dominance of negative source contrasts and the negative response over Tertiary materials.

The model/profile length is 150 000 m (from origin) with a depth range of 8000 metres.

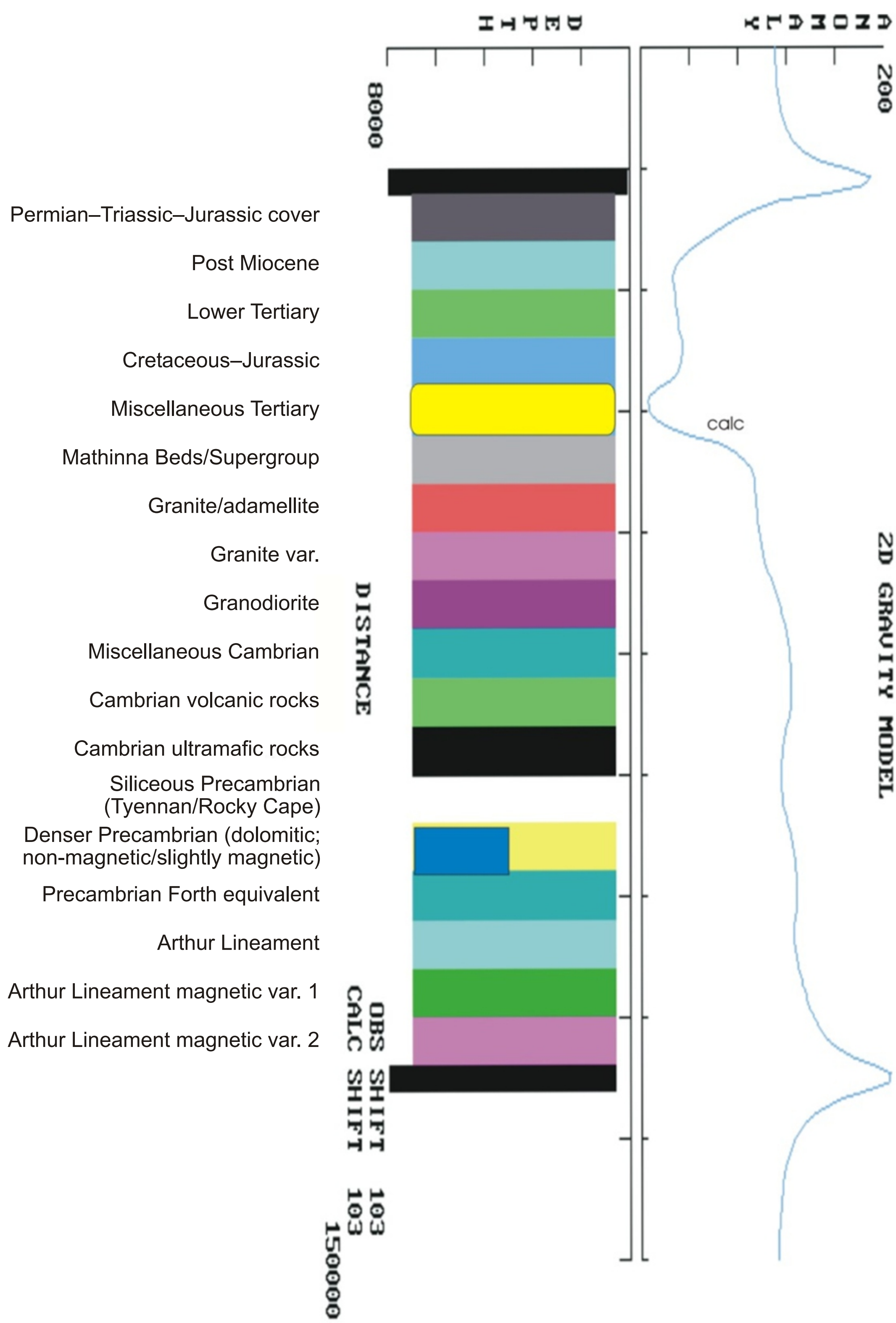

Figure 34

Model format guide and colour code/geological legend.