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THE STRUCTURE AND EVOLUTION OF THE BASS AND DURROON BASINS AS DELINIATED BY AEROMAGNETIC DATA

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A contribution to the National Geoscience Mapping Accord

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THE STRUCTURE AND EVOLUTION OF THE BASS AND DURROON BASINS AS DELINEATED BY AEROMAGNETIC DATA

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Abstract

The Bass Basin, is a failed Mesozoic rift, located offshore between Tasmania and Victoria, formed as a results of crustal extension associated with the separation of the Australian and Antarctic continents. Integrations of the first available complete aeromagnetic coverage of the area, newly available gravity data (computed from satellite measurements), and existing seismic, drill hole and outcrop geology mapping, indicate that northeastward-southwestward extension ruptured and separated fragments of the upper crust to create a depocentre up to 60 kilometres wide. Fracturing along pre-existing basement lithologic contacts and structures allowed transfer fault-type movements which accommodated this extension. Three main compartments developed in the basin, each of which underwent different degrees of extension. These compartments overlie accumulations of dense, magnetic, mafic material, evident on 14 second seismic reflection data, which were apparently produced by a mantle decompression process associated with crustal thinning. The largest of these mafic bodies displays the characteristics of a preserved, embryonic oceanic spreading centre.

The Durroon Basin, located immediately to the east of the Bass Basin, was initiated by the same crustal extensional forces as created the Bass Basin. The manifestations of the extension in the Durroon Basin area are a diffuse series of upper crustal half grabens.

INTRODUCTION

The Bass Basin is an elliptical northwest-southeast trending Mesozoic-Cainozoic intracratonic failed rift basin located between Tasmania and Victoria (Figure 1). The Durroon Basin is a related feature that occurs immediately to the east of the Bass Basin. The origins of these basins have been related to tension associated with the separation of the Australian and Antarctic continents (see Etheridge et al., 1987). This paper presents an interpretation of the area in which these basins occur which integrates aeromagnetic, gravity, seismic and drilling data. Our work adds new detail to the mechanisms of the basins' formation and defines the structuring and igneous activity associated with their development.

A review of literature associated with the geology of the area has been given by Morrison and Davidson (1989). A stratigraphic column has been published by Williamson et al. (1985) who give the most complete published overview of the area. Seismic sections, (e.g. figure 3 of Williamson et al., 1985), indicate what appears to be a classic section for a failed rift as per models reviewed by Gunn (1988), with the Early

Cretaceous Otway Group appearing to correspond to a pre-rift stage, the Late Cretaceous to Middle Eocene Eastern View Coal Measures corresponding to syn-rift rift fill and the remaining Late Eocene to Pliocene section corresponding to a post rift sag phase. Williamson et al. present depth structure maps of the boundaries between these stages which are marked by unconformities.

While general agreement exists on the main stratigraphic units and the broad geometry of the basin, a significant range of tectonic and structural models have been invoked to explain the basin's development. The three main variants of these models are rotation, involving right lateral displacement (Davidson, 1980; Carey, 1986), extension, accommodated by northeasterly trending transfer faults (Etheridge et al., 1984, 1985 and 1987) and a strike-slip transtensional system accommodated by an extensive mid-crustal detachment (Willcox et al., 1992). The study presented in this paper, while supporting aspects of the Etheridge et al. and Willcox et al. models, introduces several new ideas. We refine the geometry and controls of the extension and detail magma chambers generated at the top of the lower crust under areas of the basin that have undergone maximum extension and subsidence. The study has also defined intrusives related to these magma chambers.

DATA AVAILABLE FOR ANALYSIS

The data available for analysis consisted of:

Aeromagnetic Data

The main basis of this study was the first-ever compilation of aeromagnetic data providing a complete coverage between Tasmania and Victoria over the area encompassing the Bass Basin. This data set was produced by merging the grid of the recently published Aeromagnetic Map of Tasmania (Mackey et al., 1995), which incorporates data acquired during 1994 by the Australian Geological Survey Organisation (AGSO) over the southern portion of the Bass Basin along north-south flightlines, 130 metres above sea level and spaced at 800 metres, and a grid of magnetic values based on data from the Bass Strait and Encounter Bay Aeromagnetic Survey (Haematite Explorations Proprietary Limited, 1965), which covers the area between the northern limits of the data incorporated into the Aeromagnetic Map of Tasmania and the Victorian coastline.

The data used to produce the Aeromagnetic Map of Tasmania are available as a 200 metre grid and the AGSO data over the southern Bass Basin are also available as 1:250000 scale contour maps and images of total magnetic intensity and computed vertical gradient. The Bass Strait and Encounter Bay Survey, was flown in 1961 in the Bass Basin area along northeasterly lines 600 metres (2000 feet) above sea level. The flightlines were mainly flown as swathes with groups of four lines at 3.2 kilometre spacings, other groups of four lines were flown at 6.4 kilometre spacings and other groups of four lines were flown at 9.4 kilometre spacings and still wider line spacings were flown in some areas. The original results of this survey were presented as total magnetic intensity contours. The original analogue records of this survey have been digitised and the results have been levelled and interpolated to a 1000 metre grid for the Geological Survey of Victoria (GSV) by Geoterrex Ltd. in a project jointly funded by the GSV, AGSO, the Tasmanian Division of Mines of the Department of State Development and Resources and the Department of Mines and Energy South Australia (Geoterrex, 1993).

For the purposes of this study, data from the grids of the Aeromagnetic Map of Tasmania and the Bass Strait and Encounter Bay Survey were displayed as adjacent separate data sets. Both grids were resampled to 100 metre pixels for display purposes. No attempt was made to "stitch" the grids mathematically because, with the marked differences in data quality, flying heights and navigation precision, such a process would degrade the accuracy of both data-sets in the area of the join. Image displays showing both data-sets abutting (see for example Figures 3 and 4) nevertheless show good continuity of magnetic features considering the differences in flying height and line spacing between the surveys. The junction between the grids is evident but not markedly obvious. This is most likely due to the fact that most of the magnetic sources are relatively deep and their definition is not affected markedly by the differences in the altitude of the data collection and line spacings. These composite images proved satisfactory for a detailed analysis of the aeromagnetic data across the entire Bass Strait area, although in certain cases it was necessary to check the flightline positions and original contours of the Bass Straight and Encounter Bay Survey results to verify some of the anomaly outlines resulting from the gridding of these data. Several examples of aliasing were identified by these checks.

The main bases for the interpretation of the magnetic data were comtal colour palette images of the total magnetic intensity reduced to the pole (Figure 3) and of the computed vertical gradient of the total magnetic image reduced to the pole (Figure 4). The reduction to the pole process removes apparent anomaly asymmetries due to the inclination of the Earth's magnetic field which, in the vicinity of Bass Strait, is 70 degrees upwards. The vertical gradient transformation, which in effect is a high pass filtering operation, enhances shallow features relative to deep features and improves resolution of structural detail. Both the reduction to the pole and the vertical gradient transformation were performed using the INTREPID processing system. The comtal colour palette has been found from experience to give a good representation of anomaly amplitudes. No sun angle-type enhancements have been applied to the images of Figures 2 and 3. Sun angle enhancements produce obscuring shadows in assemblages of broad intense anomalies such as comprise these images. The interpretation of these data was best achieved using non illuminated data. Illuminated images were produced and studied, however they are not reproduced in this paper. Contour map representations of the total magnetic intensity and the vertical gradient were also used. These provided detail on true anomaly amplitudes and contour gradients not easily attainable from the images.

Gravity Data

Figure 4 shows an image of the gravity data used for the interpretation. This image is based on a grid obtained by merging a 1.5 kilometre grid of offshore data (obtained from the Geosat and ERS-1 satellite results made available by Sandwell and Smith (1996)) and onshore gravity results (obtained from the Australian National Gravity

Database maintained by AGSO). Additional offshore gravity data measured by shipborne gravimeters exists in the area but the coverage of these data is sparse and of variable accuracy. The shipborne gravity results have not been integrated into this interpretation.

Seismic Data

The Bass and Durroon Basins has been the focus of extensive petroleum exploration and a comprehensive grid of industry seismic reflection data is available in the area. In addition, AGSO has shot several regional seismic lines in the area (Williamson et al., 1985: Willcox et al., 1992). This study has relied primarily on published mapping incorporating industry data by Williamson et al. (1985) for the generalised structure of the sedimentary units. Where appropriate, AGSO regional seismic lines, which in several cases were recorded to 14 seconds and which image the basement to the sedimentary section, were integrated into the study.

Well Data

The distribution of wells drilled for petroleum exploration is illustrated on Figure 3. Data from these wells were used for calibrations of depths to basement and for identifications of igneous units in the sedimentary section.

INTERPRETATION

Interpretation Methodology

The interpretation process involved the assemblage of all relevant data sets as overlays in an ArcInfo Geographic Information System (GIS) and the subsequent tracing of body outlines and structures directly on to a workstation screen using various combinations of GIS overlays as a basis for tracing body outlines and structure as an additional overlay on the workstation screen. The overlays entered into the GIS included images of the total magnetic intensity and vertical gradient, images of the gravity field, well locations, known onshore geology, seismic line locations and digitised versions of published data such as the seismic horizon maps of Williamson et al (1985), the structural interpretation of Etheridge et al. (1984) and the occurrences of intrasedimentary igneous rocks mapped by Smit (1988).

The southeastern corner of the Bass Basin, which is covered by the 800 metre line spacing data of the 1994 AGSO survey, has been the subject of specialised processing in order to enhance intrasedimentary detail. This involved the application of a high-pass filter to remove all anomaly wavelengths greater than 10 kilometres and a low-pass filter to remove "noise" with wavelengths less than 160 metres. Figure 5 shows the results of this processing. The results clearly show the terminations of the basement rocks and several narrow, linear features that traverse the area of thickest sediments. These latter features are thought to arise from faults in the sedimentary section which contain small amounts of magnetic minerals. This is the only portion of the study area where the data density warrants such processing.

Interpretation Synthesis

Figure 6 summarises the results of the interpretation. The details of the features illustrated and the justifications for the interpretations are given below.

Bass Basin

The main depocentre of the Bass Basin, as defined by mapping published by Williamson et al. (1985), appears to overlie an area where the pre-existing Proterozoic basement has been fractured and dislocated by northeastward-southwestward tensional forces to such an extent that the conjugate portions of basement on the northern and southern margins of the basin are now separated by as much as 60 kilometres. This fracture and extension is thought to have occurred along a large fault in the brittle upper crust which soled out into a regional, sub-horizontal detachment plane at a depth of approximately 15 kilometres.

This model is consistent with features inferred by Collins et. al. (1992) and Willcox et al, (1992), from regional deep seismic reflection and refraction data, as explaining the geometry and origin of the Gippsland Basin 150 kilometres to the northeast of the Bass Basin. The Gippsland Basin is generally regarded as having been initiated contemporaneously with the Bass Basin as a result of the same extensional event (the separation of the Australian and Antarctic continents (Etheridge et al., 1987)). Willcox et al, (1992), have recognised a continuation of the detachment plane, apparently at, or near, the junction between upper brittle crust and ductile lower crust, from the Gippsland Basin area to the Bass Basin area. The result of the fracturing and pull apart of the upper crust in the Bass Basin area appears to have been the creation of a depression with a generalised rectangular plan, up to 60 kilometres wide, that provided the topographic low which received the sediments of the Bass Basin.

The bases for interpreting the fracturing and pulling apart of the upper crust in the Bass Basin area are the abrupt terminations of the magnetic basement units on the northern and southern sides of the basin, jigsaw-type matches between what appear to be fragments of corresponding magnetic units on the northern and southern borders of the interpreted zone of rupturing and the complete absence of any indication in the magnetic data of any continuation of these magnetic basement units at depth across the floor of the basin. Deep penetrating seismic data, particularly AGSO Line 90/27, supports the idea of rupturing of the upper crust in that a detachment plane appears to exist and no evidence for downfaulted basement appears below the main sediment depocentre (see Figure 7).

The fracturing of the upper crust, including the basement to the sediments, as defined by terminations of magnetic basement units, appears to have occurred in directions broadly orthogonal to the northeastern-southwestern extension direction. The actual separation of the basement fragments varies along the axis of the basin. The magnetic anomaly pattern in the basement and magnetic lineations arising from sources in the sediment section (see Figure 5) suggest that differential extension between the different compartments is accommodated by movements, that are of the transfer fault-type proposed by Etheridge et al. (1985) to explain the origin and character of the Bass Basin.

Three main compartments to the extension are recognised on the basis of interpreted matches between what appear to be fragments of originally continuous magnetic bodies on opposite margins of the basin. These exhibit a progressively greater degree of extension towards the southeast. The existence of compartments is supported by three clearly defined areas of differing thickness in the isopach map of the post Eastern View Coal Measures (sag phase) sediments published by Williamson et al. (1985) and which is superimposed on Figure 3. These differences in isopachs suggest areas with different subsidence histories. The compartments are indicated as A, B and C on Figure 6. Compartment C appears to contain sub-compartments bound by transfer-type faults on which less lateral movement has occurred than the major transfer zones bounding the main compartments.

The primary controls of the "transfer fault" locations and directions appear to be basement lithologic contacts and/or faults. These features, which predated the development of the Bass Basin, formed zones of weakness along which transfer faults developed during the extensional development of the basin. The relatively abrupt southeastern limit to the basin corresponds to an offshore extension of the Arthur Lineament (Turner, 1989) which is a linear zone of Proterozoic high grade metamorphic rocks that causes a distinct intense linear magnetic anomaly. The relatively abrupt northwestern margin to the basin corresponds to the contact between a highly magnetic basement unit, identified on the basis of field mapping on King Island as due to Proterozoic basaltic volcanics by M. Roach of the University of Tasmania (personal communication, 1995) and a wide, less magnetic unit to the east. The boundary between compartment A and compartment B is another junction between magnetic and non-magnetic basement units. The control on the transfer zone between compartments B and C appears to have been a north-striking strongly magnetic unit, which, based on correlations with outcrops of Cambrian "greenstones" at Waratah Bay in Victoria, appears likely to be due to a zone of ultramafic rocks.

The specialised processing and imaging presented in Figure 5 shows a series of cross-basinal lineations that appear to be closely, but not exactly, associated with the interpreted transfer type zones accommodating the widening of the basin. These appear to be expressions of transfer type movements within the sediment section. The intrasedimentary faults defined by the cross basin lineations appear to correspond to faults or groups of faults developed in the syn-rift sediments in response to basement movements but having no direct physical linkage with the basement fractures. It should be noted that the area containing the intrasedimentary transfer-type faults overlies an area where the upper crust has been pulled apart and where none of the original Precambrian basement is left at depth.

The location of the Bass Basin appears to have been controlled by a zone of ultramafic rocks. A southward continuation of the anomalies associated with outcrops of ultramafics at Waratah Bay has been interpreted as indicating that a semi-continuous zone of ultramafic rocks occurs along the northern margin of the Bass Basin. A reconstruction of the basement units to their estimated locations prior to the extension of the upper crust which created the Bass Basin indicates a likely original connection between the offshore extension of a linear zone of ultramafics outcropping at Beaconsfield in Tasmania. Interpretations by Gunn et al. (1997) have identified southeastern extensions of the Beaconsfield ultramafics associated with intense magnetic anomalies similar to those occurring over the ultramafics interpreted beneath Bass Strait. The Beaconsfield ultramafic zone appears to define the junction between known Proterozoic rocks to the west and known Palaeozoic rocks to the east and, as such, could be evidence of a major crustal suture. The ultramafics beneath Bass Strait could mark the continuation of this suture. Such a suture, which could be a zone of weakness susceptible to rupture during extension, may be the reason why the Bass Basin is located where it is.

Major positive magnetic and gravity anomalies correspond to the areas within compartments B and C where the upper crust is interpreted as being absent due to the pull-apart process on the mid-crustal detachment plane. Modelling and interpretations of 14 second seismic records indicate that these anomalies arise from major magma chambers at depths of approximately 15 kilometres (see Figures 7 and 8). The magma is thought to have resulted from mantle and/or lower crustal decompression (c/f. processes described by White, 1992). A relatively minor axial anomaly in compartment A may be due to an intrusion related to the beginnings of a similar magma generation process.

The deep igneous body beneath compartment C has a geometry that indicates its emplacement may have been controlled by extensions on the transfer zones and that the intrusive body has grown as extension progressed. The justifications for this comment are the blocky rectangular shape of the intrusion and the fact that the variations in the width of the intrusion appear to be bound by transfer faults (see Figure 6).

Vertical gradient enhancements (Figure 9) and detailed magnetic modelling (Figure 3) indicate that isolated intrusive-like culminations exist on the upper surface of the igneous mass underlying compartment C which tend to have a symmetry relative to the long axis of the Bass Basin and the intrusive mass. We suggest that this symmetry results from the splitting of the igneous intrusion due to the extension in the area. Such a process is consistent with a model for the development of rift systems and continental margins presented by Gunn (1988). According to our interpretation, the features beneath compartment C may be the remnants of the first stages of an oceanic spreading centre whose development failed because of cessation of crustal extension in the Bass Basin area. A solitary exception to this symmetry is an intrusive body that, according to the modelling shown in Figure 8, penetrated much closer to the surface than any of the other culminations. This intrusive body appears to have influenced structuring associated with the Pelican gas accumulation.

Durroon Basin

The earliest development of the Durroon Basin to the east of the Bass Basin (Baillie and Pickering, 1991) appears to have been related to the same extensional forces as the Bass Basin although, with a less dramatic result. The extension in the Durroon Basin resulted in the mid-Cretaceous development of a series of northwest-southeast-trending half grabens containing Otway Group sediments. Extensive mafic vulcanism accompanied this structuring. These volcanics, which have magnetic responses, are generally confined to the half grabens and, as a result, the magnetic data maps the traces of the half grabens and offsets in these structures. Modelling, such as the example shown in Figure 10, illustrates the correspondence between the distribution of volcanic rocks in the grabens, as interpreted from magnetic anomalies, and the geometry of the grabens. Interpretations of the vertical gradient enhancements of these data indicate an extensive series of grabens, with axes having a general northwesterly-southeasterly direction. These grabens appear to have been offset by a series of minor transfer-type zones trending northeast-southwest. These trend directions accord with the primary structural directions interpreted in the Bass Basin.

If the Bass and Gippsland Basins were formed by the same mid-crustal detachment, the existence of minor crustal extension in the Durroon Basin area could be explained by greater extension occurring further north in the Gippsland Basin area and thereby balancing the significant extension occurring in the Bass Basin and Gippsland Basin areas.

IMPLICATIONS OF THE INTERPRETATION

The interpretation described above has several important implications for the geology of the Bass Strait region and for the studies of extensional basins elsewhere. These are:

(i) The uninterrupted continuity of the intense magnetic anomaly, identified as being caused by Proterozoic volcanics from northwestern Tasmania to virtually the Victorian coastline appears to preclude any significant transcurrent faulting through Bass Strait such as has been proposed by various workers such as Willcox et al. (1992).

(ii) The interpretation of the original continuity of a belt of ultramafic rocks from the Beaconsfield outcrop in northeastern Tasmania to the Cape Liptrap outcrop in Victoria appears to substantiate a direct link between Tasmanian and Victorian geology.

(iii) The interpretation supports the general idea of transfer faulting in the Bass Basin area as described by Etheridge et al. (1984, 1985 and 1987) although the faults interpreted by our study do not correspond exactly in position to the faults interpreted by Etheridge et al. This is to be expected given the sparse seismic grid and coarse presentations of magnetic data used for Etheridge et al.'s studies.

(vi) The transfer accommodation zones interpreted in our study have similar directions to those mapped by Gunn et al. (1995) using magnetic data in the Otway Basin. These mappings support the linked extensional origin of the Bass and Otway Basins as proposed by Etheridge et. al (1987) in figure 12 of their paper. We are unable to comment of the linkage of the Gippsland Basin to this system on the basis of the magnetic data as the magnetic data over the Gippsland basin are inadequate for such an analysis.

(v) The results of the Bass Basin study, particularly the development of the magma chambers causing the axial gravity and magnetic highs, complements the study of the Bonaparte Gulf area by Gunn (1988) which describes the development of similar features beneath another failed rift which underwent differential extension along its axis.

CONCLUDING REMARKS

This study of the Bass Basin area has provided considerable insights into the mechanisms of basin formation in an environment of crustal extension. The interpreted phenomena of upper crustal splitting and related intracrustal magma generation, possibly as a first stage of the formation of an oceanic spreading centre, warrant further detailed investigations. Additional 14 second reflection seismic traverses would be extremely useful for such studies as would the collection of detailed high sensitivity aeromagnetic data over the area where presently only data from the 1961 Bass Strait and Encounter Bay Survey is available.

Acknowledgment

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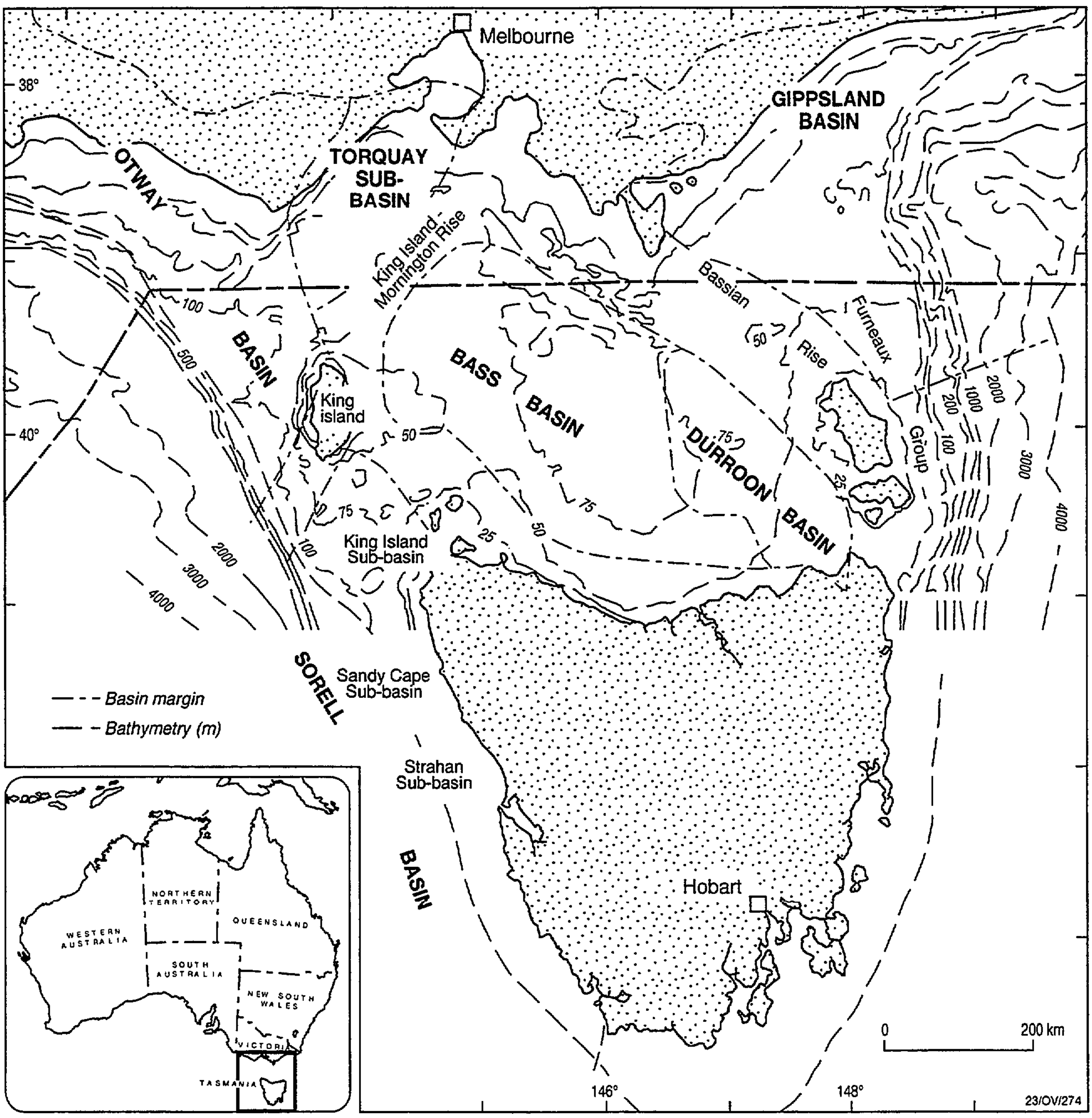
LIST OF FIGURES

FIGURE 1. Location of Bass and Durroon Basins, southeastern Australia.



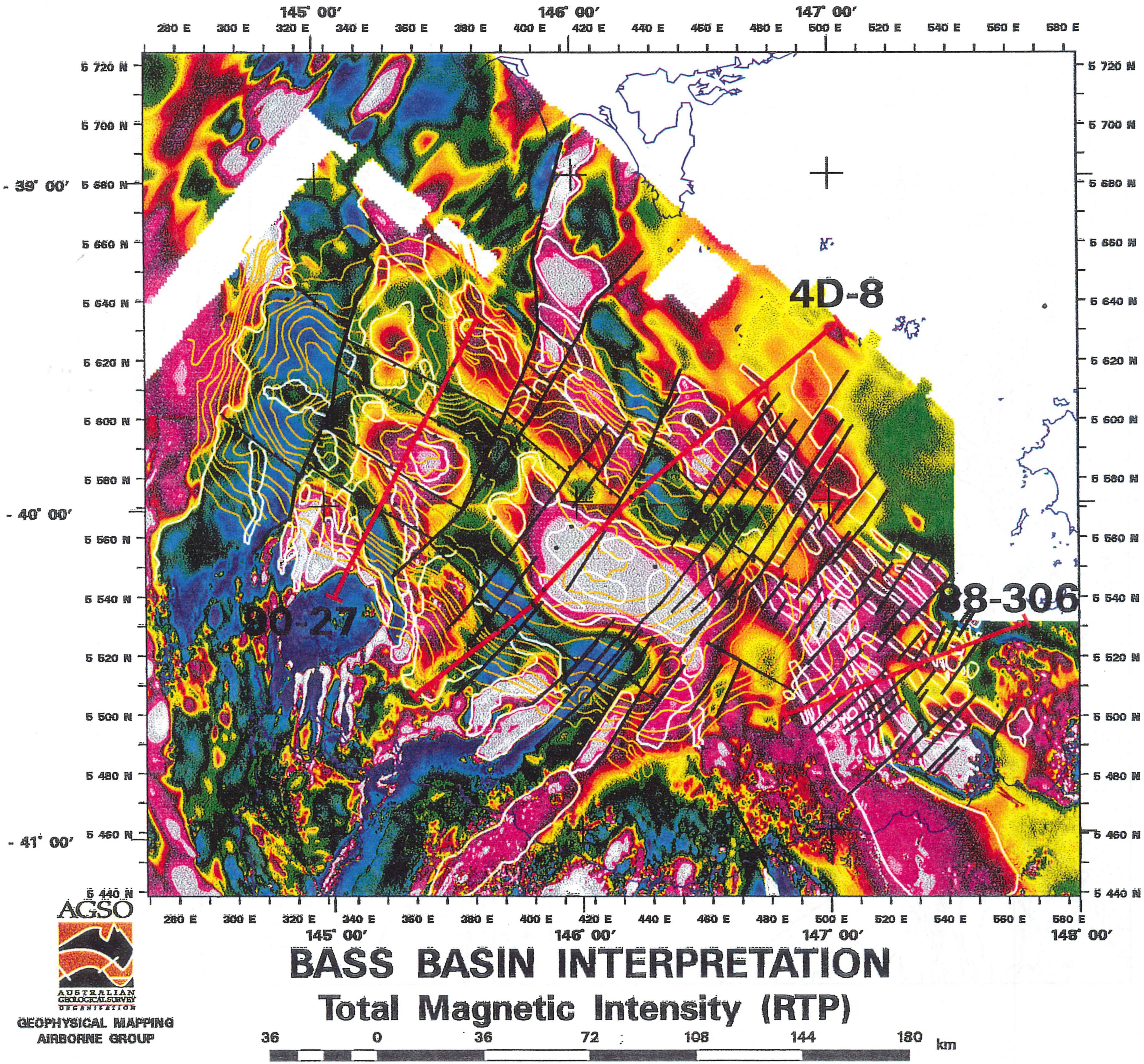


FIGURE 2. Total magnetic intensity image of the area of the Bass and Durroon Basins. The comtal colour palette has been used. Blue is low. Figure 6 provides an identification of the features that have been outlined.

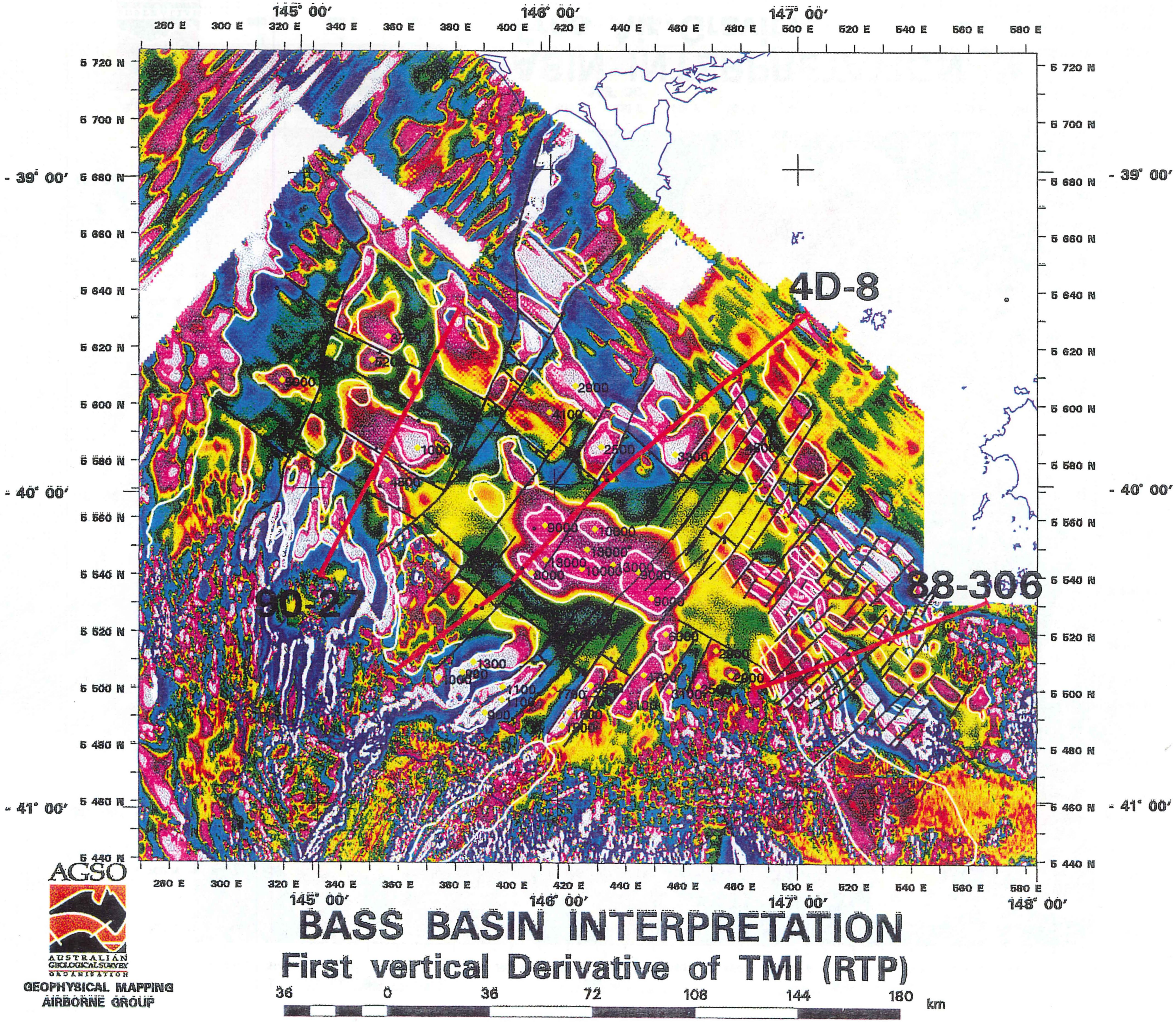


FIGURE 3. Vertical gradient image of the area of the Bass and Durroon Basins. The contal colour palette has been used. Blue is low. Figure 6 provides an identification of the features that have been outlined. Modelled depths to magnetic sources are shown as metres below sea level.

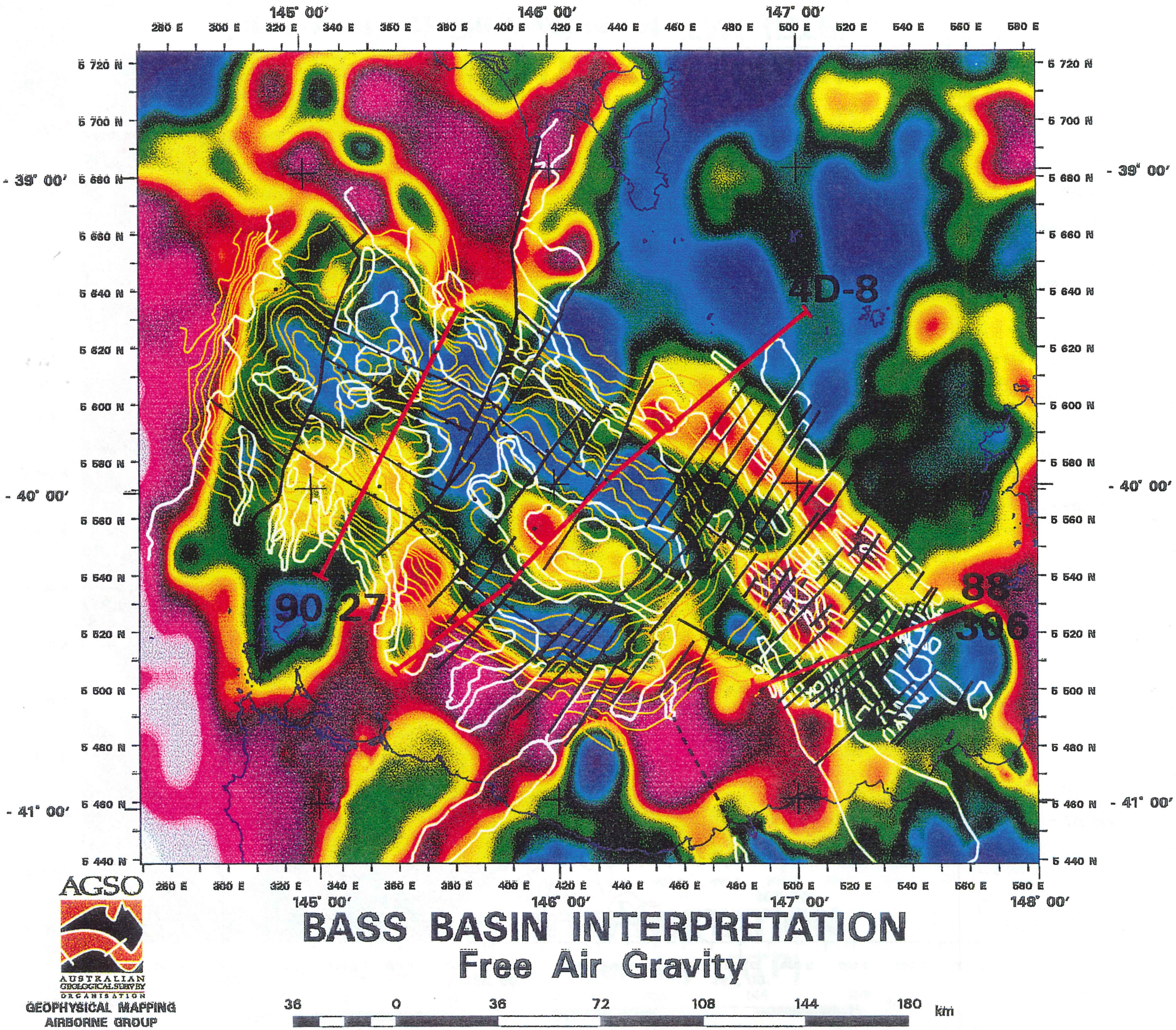


FIGURE 4. Gravity image of the area of the Bass and Durroon Basins. The comtal colour palette has been used. Blue is low. Figure 6 provides an identification of the features that have been outlined.

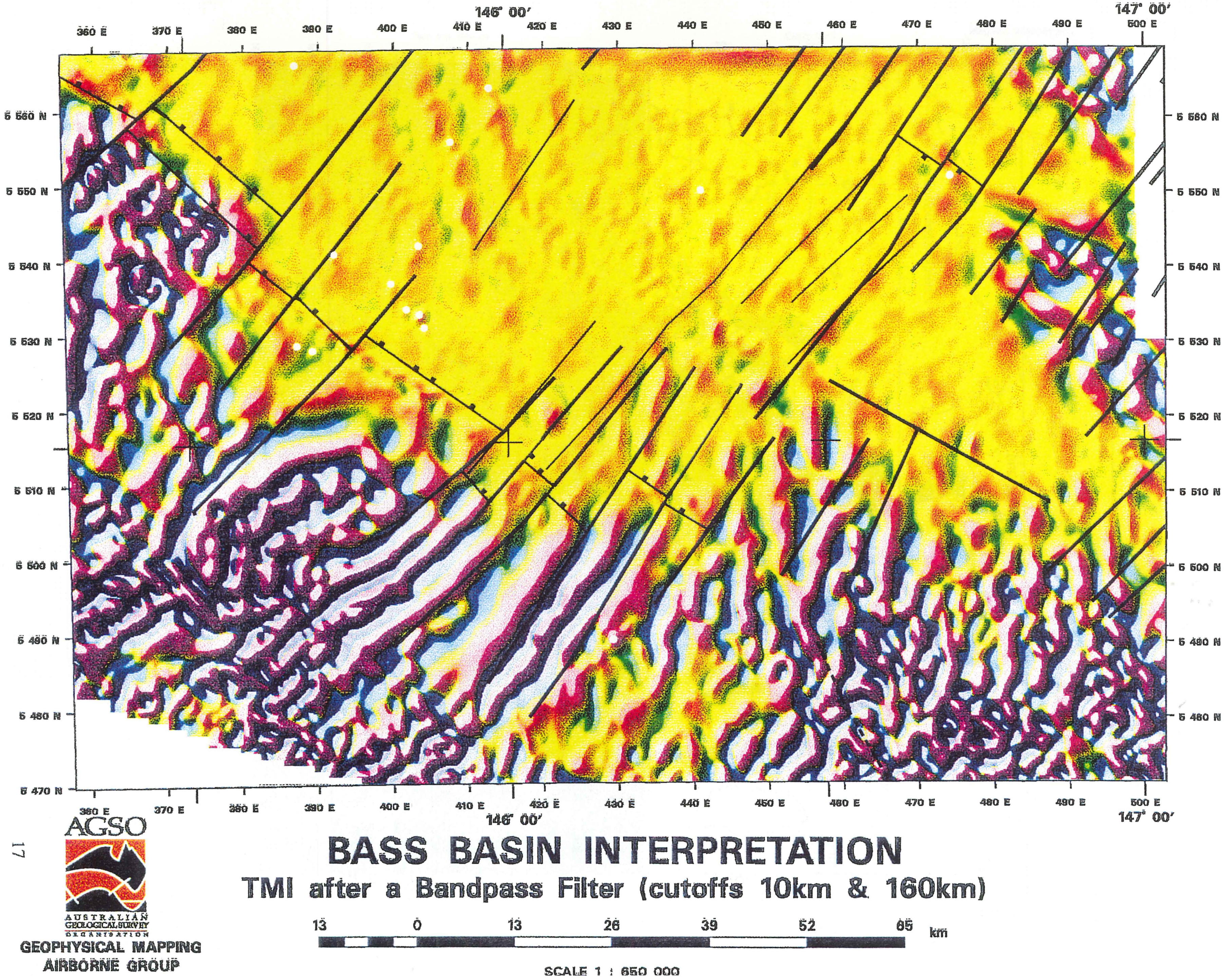


FIGURE 5. Bandpass filtering (10 km and 160 m) of total magnetic intensity data over the southeastern corner of the Bass Basin. Narrow linear features in the top half of the image are thought to be due to transform related faults in the sediment section.

FIGURE 6. Interpretation showing principal elements of the Bass and Durroon Basin area.

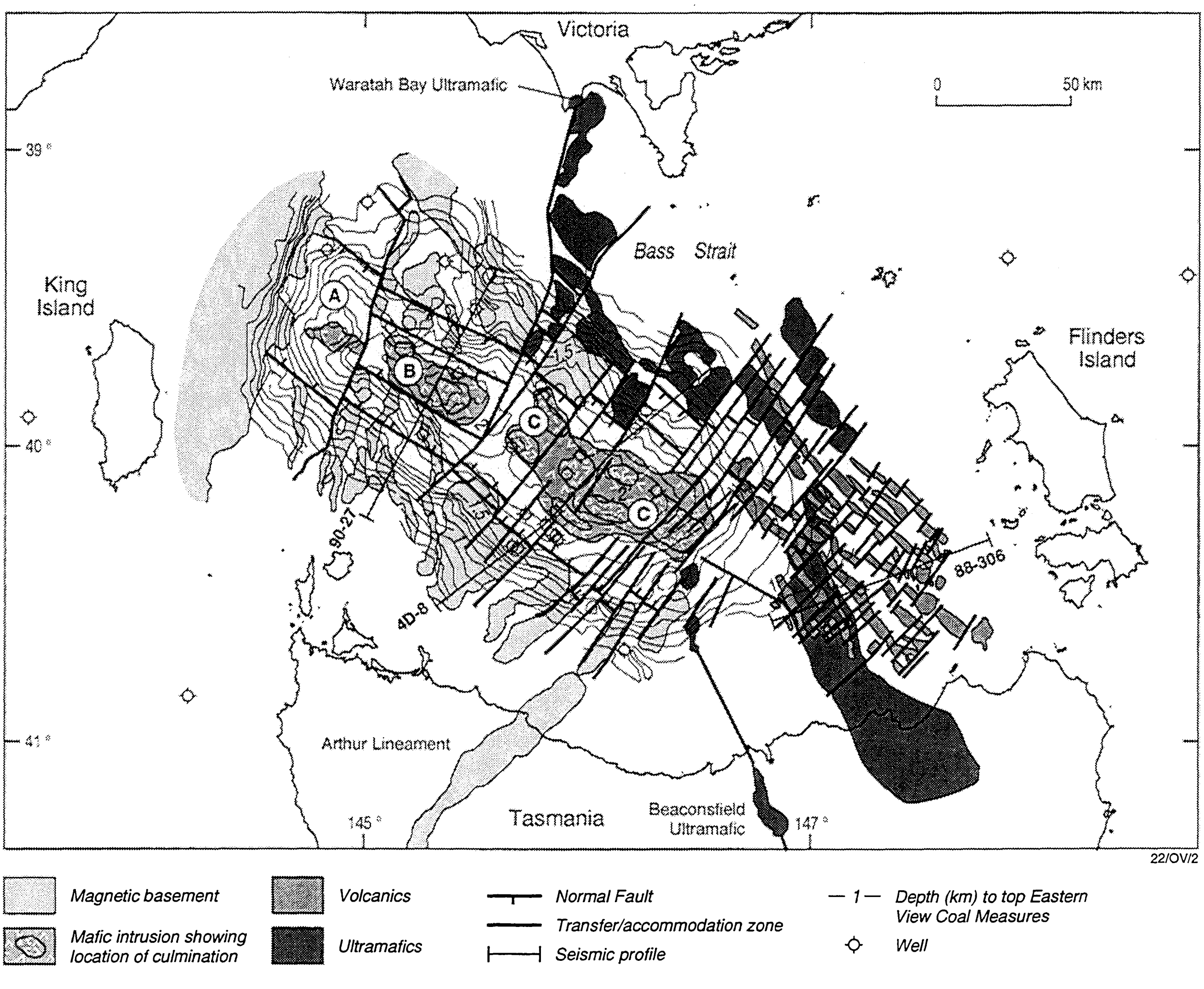


FIGURE 7. Modelling of Profile 90-27. A large domal structure evident in 14 second seismic reflection data is interpreted as a mafic body causing a magnetic and gravity high over the centre of the Bass Basin.

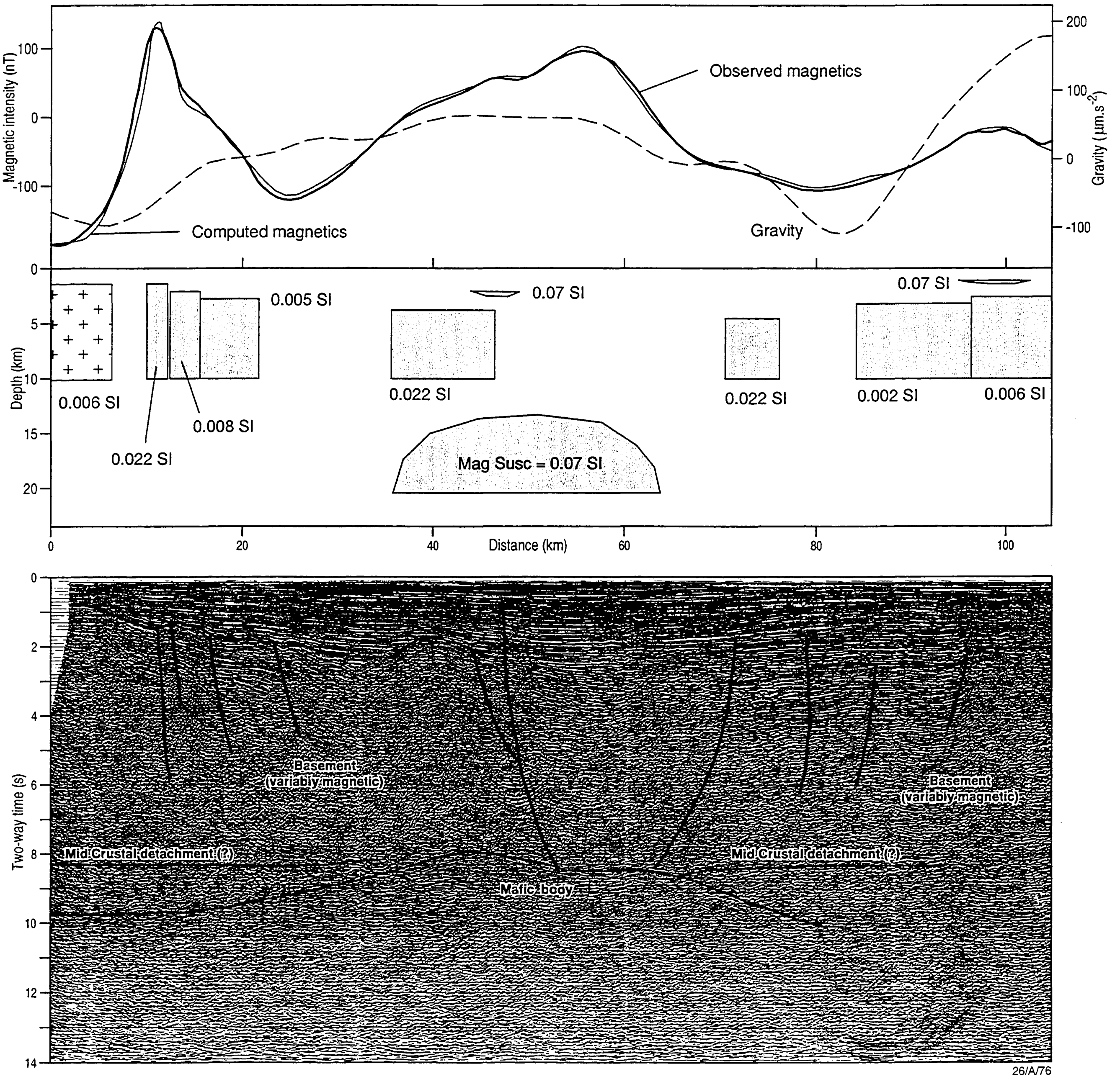


FIGURE 8. Modelling of Profile 4D-8. The magnetic and gravity high over the main depocentre of the Bass Basin is explained by a mafic body at a depth of approximately 12 km. This body is shallower and larger than the body modelled in Figure 7. The Bass Basin appears to have undergone greater extension and crustal thinning in the locality illustrated in Figure 8.

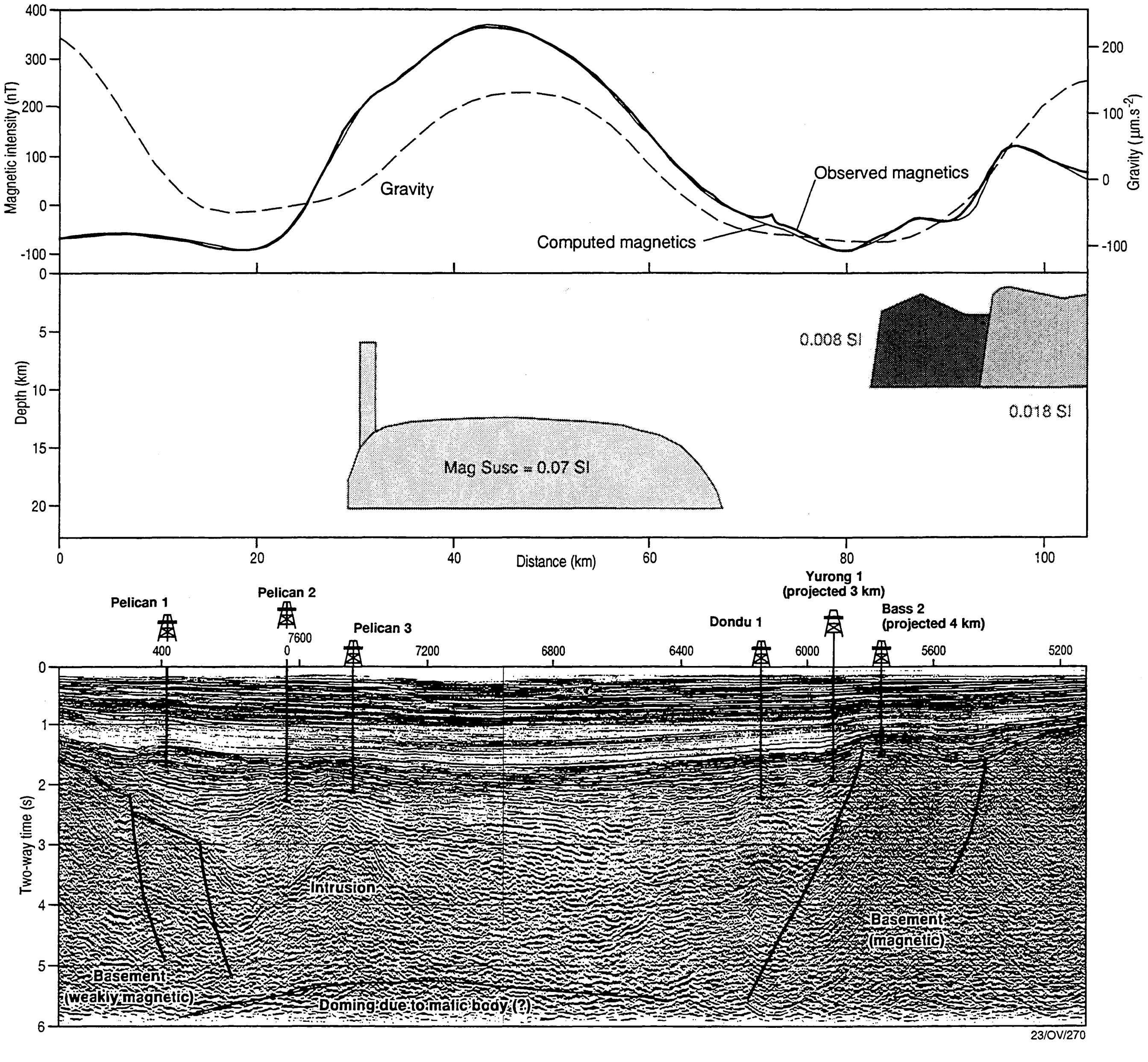


FIGURE 9. **Detailed vertical gradient contours of the magnetic field resulting from the mafic mass interpreted to occur below Compartment C. A primitive symmetry can be noted and it is proposed that the mafic body is a remnant of an embryonic oceanic spreading centre.**

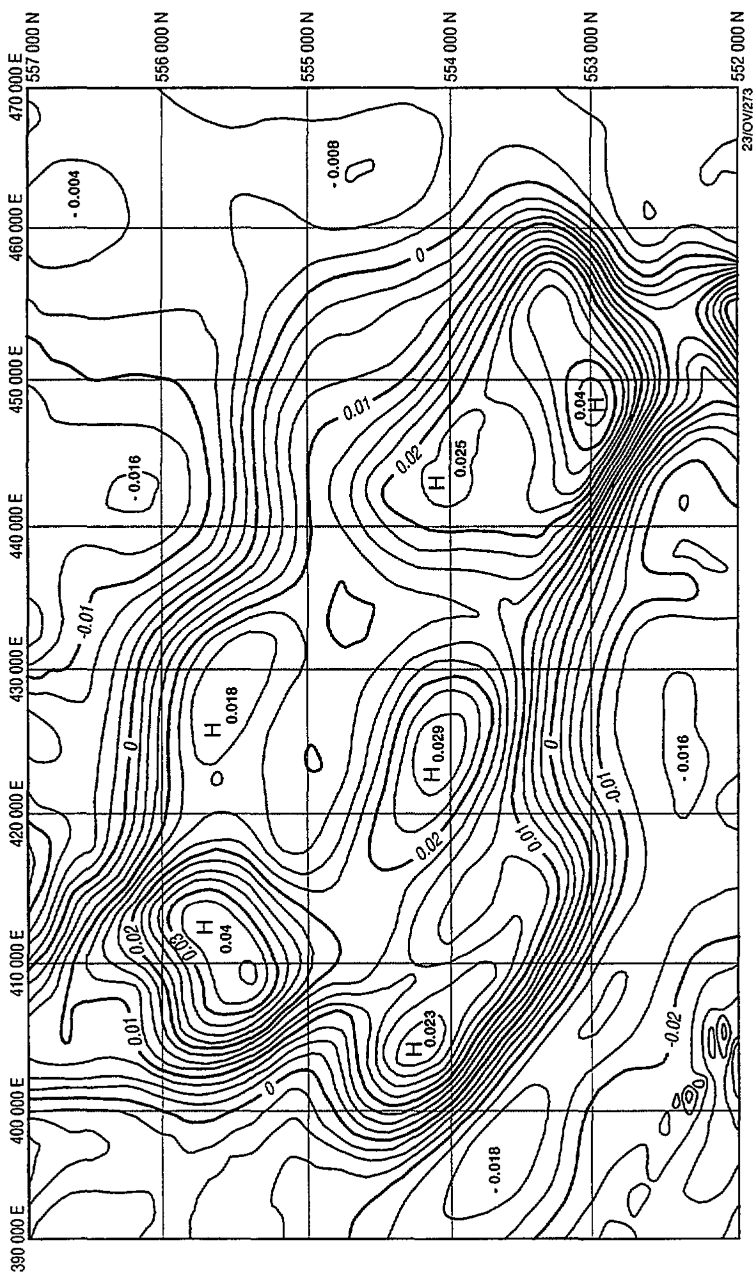


FIGURE 10. Modelling of Profile 88-306. The results illustrate how magnetic volcanic flows confined in half graben structures, located in the Durroon Basin, produce characteristic magnetic anomalies which can be used to define the distribution of the half grabens.