Interpretation of Aeromagnetic Data over the Southern Joseph Bonaparte Gulf in the Context of Petroleum Prospectivity

By

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SUMMARY

A large portion of the southern Joseph Bonaparte Gulf area, north western Australia, was originally underlain by extensive contiguous Proterozoic sills and volcanics. This igneous sheet is a magnetic marker horizon which allows magnetic data to be used for structural mapping in the area.

Basin extension during the Palaeozoic fractured this horizontal basic magnetic sheet. Evidence of this fracture pattern and the extensions are obvious in images of the present day magnetic field over the basin. A series of transfer fault accommodation zones trending at 35 degrees and an associated series of perpendicular normal faults have been mapped. Onshore geology, gravity and seismic data support the transfer fault model which can be used to explain features of the depositional history of the area..

A significant underexplored graben, which formed as a result of the extension process, has been mapped on the western basin margin adjacent to the Proterozoic Kimberley Basin. A series of tilted fault blocks have been mapped within and adjacent to this graben which is assessed as being prospective for hydrocarbons.

In addition to outlining the main structural units of the area, the aeromagnetic data has detected anomalies due to intrasedimentary faults. Unfortunately the delineation of such subtle features is confused by the magnetic responses of an extensive channel system that apparently developed on or near the present day sea floor during recent times. The correlation of seismic and aeromagnetic data is the optimal approach to map such features.

KEYWORDS: Joseph Bonaparte Gulf, Bonaparte Basin, aeromagnetic, gravity, seismic, extension, transfer fault, accommodation zones, depocentres, mapping, petroleum prospectivity.

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Figure 15 Computer modelling results. The locations of the profiles are shown on Figure 17. The section at the bottom has been digitised from seismic lines TP5. The gravity, magnetic and seismic data are all indicating a series of half-graben structures adjacent to the coastline. The apparent discrepancy between the magnetics and the seismic data at the western end of the profile appears to be due to seismic side swipe from a structure adjacent to the profile

Figure 16 Plot of depth determinations calculated using the Euler automatic depth determination routine. The routine in this example was set to determine to identify and calculate the depths to the edges of horizontal plate-like magnetic bodies.

Figure 17 Locations of seismic lines referred to in this report.

Figure 18 Interpretation summary.

1. INTRODUCTION

The Joseph Bonaparte Gulf area of northwestern Australia (Figure 1) contains a significant sedimentary assemblage which, despite significant gas discoveries and various oil shows and one oil flow, has received significantly less attention from explorers than may be warranted. Gunn and Ly (1989), in describing the petroleum prospectivity of the area, have noted that, while all the components necessary for the formation and entrapment of both oil and gas are present, the successful discovery of economic accumulations has been frustrated by various factors including a steep northwards regional dip which has resulted in many of the structural closures in the area being at uneconomic depths and/or having degraded reservoir characteristics due to diagenetic modifications associated with depth of burial. This report presents an interpretation of aeromagnetic data collected by the Australian Geological Survey Organisation during 1994 over the southern Joseph Bonaparte Gulf. The interpretation develops a coherent model for the structural development of the area, and identifies an underexplored, highly structured section of the area where all the ingredients for hydrocarbon entrapment are likely and where structural closures and possible reservoir depths may be relatively shallow. The location of the aeromagnetic survey is shown in Figure 1.

It is important to note that since the publication of Gunn and Ly's paper, the Barnett 2 well, drilled in 1989, virtually in the centre of the area of the aeromagnetic survey, flowed 921 BOPD from an interval between 1491 and 1506 m KB as well as recovering oil from a deeper interval between 2393 and 2421 m KB. This discovery, the first recorded oil flow in the basin, confirms the oil potential of the area.

2. GEOLOGICAL SETTING

The geology of the Joseph Bonaparte Gulf area have been described by Lee and Gunn (1988) and Mory (1991). A stratigraphic column is shown in Figure 2. Apart from limited outcrop information on the flanks of the Gulf, current geological concepts of the area are almost entirely based on drill and seismic reflection data collected during petroleum exploration programs.

A sedimentary assemblage, variously known as the Bonaparte or Petrel Sub-Basin, underlies the Joseph Bonaparte Gulf area (Figure 1). In its present form, this basin, which will be referred to as the Bonaparte Basin in this paper, contains two distinct sedimentary megasequences. The lower sequence, which has been identified as the remnants of a failed rift system, comprises thick accumulations of highly structured and faulted Late Devonian to Early Carboniferous sediments effectively confined between two major conjugate fault systems (Figure 1). The upper sequence which drapes the rift and onlaps flanking shelves of Proterozoic basement, consists of thick, basically unfaulted Late Carboniferous to Quaternary sediments (Lee and Gunn, 1988). No igneous rocks have been recorded in the Devonian and younger sediments in the study area.

Basement to the sedimentary sequences consists of the Proterozoic rocks mapped on the Medusa Banks (BMR, 1971) and Port Keats (BMR, 1971) 1 : 250 000 Map Sheets which cover the onshore areas west and east of the gulf respectively. The Proterozoic comprises sandstones, siltstones, shales and carbonates with an igneous component that includes basalts, dolerites and gabbros. As is explained below, these Proterozoic basic rocks provide a significant magnetic marker whose effects dominate the magnetic field of the study area.

Geological mapping of onshore areas to the south of the study area (BMR, 1968) has revealed Cambrian rocks overlying the Proterozoic. These include the widespread Antrim Plateau Volcanics which have aeromagnetic responses (Gunn, 1975).

The Joseph Bonaparte Gulf area of northwestern Australia (Figure 1) has been recognised by various workers (e.g. Gunn, 1988; O'Brien *et al.*, 1993) as having originally evolved as a Devonian-Carboniferous rift that ceased spreading before complete crustal separation was attained. In its present form it contains pre-rift, syn-rift and post-rift sediments from the Devonian-Carboniferous rifting episode which are overlain by Permo-Triassic and Jurassic-Cretaceous sediments associated with younger rifting episodes along the present day western margins of the Australian continent. Both Gunn (1988) and O'Brien *et al.* (1993) have recognised that the degree of extension in the Devonian-Carboniferous rift system increased towards the northwest and proposed a series of transfer faults to accommodate this differential extension. Transfer faults are a type of strike slip fault first proposed by Gibbs (1987) to accommodate the extensional processes in the North Sea rift systems. The present study, which presents an evaluation of recently acquired high sensitivity aeromagnetic data over the southern Joseph Bonaparte Gulf, is fortunate in that an extensive magnetic marker unit existed in the area prior to the Devonian Carboniferous extension. The fracturing and movements of this magnetic marker have produced a magnetic pattern which allows recognition of the transfer faults. This paper describes the mapping of these transfer faults and how they can be related to the evolution of the basin and its present day prospectivity. The findings of this study complement an earlier application of aeromagnetics to the mappings of transfer faults in sedimentary basins (Gunn *et al.*, 1995).

3. AEROMAGNETIC SURVEY

The aeromagnetic survey data presented herein was flown between July and September 1994 by the Australian Geological Survey Organisation (AGSO). The aeromagnetic data were acquired along east west flightlines spaced 500 metres apart. Tielines were flown in the north south direction with a spacing of 5 kilometres. The survey altitude was 100 metres above the sea and the land. The data were recorded with a 0.01 nanotesla resolution at a sample interval of 7 metres. Navigation using GPS provided spatial positioning to within 10 metres. The images presented in this paper are based on the original line data interpolated to a 110 metre grid. The total survey comprised 67569 line kilometres. The area of the survey coverage is shown in Figure 1.

Prior to 1994 the only aeromagnetic coverage of the Joseph Bonaparte Gulf was a survey flown by Compagnie Generale de Geophysique (1966) with a square grid of flight bands each consisting of four lines 3.2 kilometres apart. Although the spacing of these bands resulted in gaps approximately 40 kilometres square, this survey was successful in mapping the general form of the basin. It did not, however, have the resolution to map fault systems.

4. BASIC DATA PROCESSING

The basic processing of the aeromagnetic dataset consisted of removal of the effects of diurnal magnetic variations and the regional effects of the Earth's magnetic field followed by levelling of the data. After levelling of the data, a 110 metre grid of the total magnetic intensity was produced using the AGSO minimum curvature routine (Briggs, 1974) which is incorporated in the AGSO in-house INTREPID system for processing aeromagnetic data. This grid was used to produce a 1: 250 000 scale contour map of the total magnetic intensity (Figure 3) and 1: 250 000 scale gradient enhanced greyscale (Figure 4) and colour (Figure 5) images of the data. The images were produced using the ER Mapper imaging system and colour hard copy output was produced on a Novajet colour plotter. These products served for quality control and a starting point for the interpretation of the data.

5. DATA ENHANCEMENT

In order to facilitate the interpretation of the magnetic image data various processing routines were applied to the gridded data using the INTREPID software and subsequently imaged with ER Mapper.

The inclination of the earth's magnetic field in the study area is 44 degrees. This means that magnetic anomalies in the area caused by induction in the earth's field have an extreme asymmetry, to the extent that magnetic highs are significantly offset from positions vertically above their sources. Such anomalies are extremely difficult to interpret. As the majority of magnetic anomalies are in fact caused by induction in the Earth's field, this effect needs to be addressed in any magnetic interpretation of the study area. To this end, a "reduction to the pole" process has was applied to eliminate the effects of the inclination of the Earth's magnetic field by relocating anomalies to positions directly above their sources. The results of this process can be seen in Figures 6, 7 and 8, which are contours and greyscale and colour images of the field reduced to the pole.

The verity of the reduced to the pole results depend on the assumption that anomalies in the area being transformed are due to magnetic induction and not to remanent (permanent) magnetisations of the rocks causing the anomalies. This latter possibility sometimes occurs and when it does its existence sometimes manifests itself as a smeared "comet tail" during reduction to the pole processes. (Macleod *et al.*, 1994). The fact that no such comet tails are evident in the transformed data set of Figure 3 supports the assumption that the magnetisation in the area is predominantly induced.

A second, more quantitative validation of the reduction to the pole process as applied in the study area was provided by the production of an analytic signal image (Figure 9), in which the highs in the analytic signal image correlated closely in position with highs in the reduced to the pole image. This implies that the reduction to the pole process is correct because, as is explained by Roest *et al.* (1992) and Shuang Qin (1994), the analytic signal function, computed from combinations of the derivatives of the magnetic fields without any assumptions of directions of magnetisation, gives anomaly peaks directly over sources of magnetic anomalies.

Further confirmations of the success of the reduction to the pole process is provided by Bouguer gravity data, which, when superimposed on the reduced to the pole data (Figure 8), shows a close correspondence between gravity and magnetic highs and lows and by seismic data which in several instances verifies the positions of structures indicated by the reduced to the pole data (see Figures 13 and 14).

Because of the significant difference between the original magnetic intensity as recorded and the reduction to the pole image and the key role of the reduced to the pole image in the interpretation process, this confidence in the validity of the transformation process is extremely important.

The line contour map of the reduced to the pole data was extremely useful for the determination of precise anomaly amplitudes and for evaluation of the contour gradients necessary to determine the positions of body edges and depths. The grey scale image of the reduced to the pole data illuminated from the east was useful for studying the structure in the shallow onshore area's, but did not greatly assist in the interpretation of the offshore areas, as the broader anomalies were difficult to see without colour.

The total magnetic intensity maps and images show dense concentrations of high frequency anomalies over a large portion of the offshore area. These are not due to oceanic swell noise, such as has been encountered in other offshore magnetic surveys (see for example Gunn *et al.*(1995)). Our confidence in this assertion is based on the general absence of oceanic swell in the sheltered Joseph Bonaparte Gulf, the absence of the periodicity in the response that is typical of oceanic swell noise, and the fact that a convincing geological explanation, as described below, was ultimately found for these features.

Various data processing techniques were applied to enhance the high frequency anomalies which, in the offshore areas, are largely obscured by steep magnetic gradients of the broad intense anomalies due to deeper sources. A primary objective of this high frequency enhancement process was to delineate faults within the sedimentary section. Initially, the classical approach of applying a vertical gradient (first vertical derivative) filter to the data was attempted (Figure 10). While this highpass operator had the desired effect of suppressing the effects of the broader regional anomalies it enhanced the high frequency content of the data to the extent that the resultant image of the offshore area has a spotty semi-random character. Several approaches of smoothing the data including applications of high cut and upward continuation filters before the calculation of the vertical gradient filter were tried in attempts to improve the results. None were entirely successful because the vertical gradient operator appeared to over enhance the high frequencies while the smoothing processes removed information. The best display of the high frequency anomalies was obtained with a bandpass filter which removed all anomaly wavelengths except those between 20 kilometres and 500 metres. The result, shown in a grey scale gradient enhanced form in Figure 11 indicates that the high frequency anomalies actually map extensive, overlapping, drainage systems emanating from river systems at the head of the Joseph Bonaparte Gulf. It appears that these channel systems occur on or close to the sea floor which is only approximately 20 metres below sea surface in the area. The magnetic responses of the channels are interpreted as due to detrital magnetic material deposited in the channels.

After this clarification of the nature of the bulk of the high frequency magnetic responses several processing and imaging routines were applied with the objective of enhancing structural detail within the sedimentary section. Various sun angle illuminations were applied to the smoothed vertical gradient images in an attempt to delineate linear features distinct from the meanders commonly associated with the channel systems. An automatic gain control routine was also applied to a vertical gradient image from which all wavelengths less than 1 kilometre had been removed. Automatic gain control routines (Rajagopalan, 1987) output responses of similar amplitudes for all anomalies regardless of the original amplitudes of the anomalies and the resultant images are extremely useful for structural mapping. These approaches produced various apparent lineaments but it must be admitted many of these could well be the result of random alignments and artefacts of the imaging process. Given that intrasedimentary features have typically weak responses, the cover of the magnetic channel system and the fact that few faults in the offshore Bonaparte Basin occur close to the surface (see Figure 4 of Gunn (1988)) imaging of intrasedimentary faults in the Bonaparte Basin is difficult. Despite the above problems, the various images, when considered in association with other data sets such as seismic profiles, do appear to be mapping such faults. These mappings are discussed in the section on Interpretation.

The detailed structure of the deeper magnetic structures in the offshore areas is shown in image of the vertical gradient of the total magnetic intensity reduced to the pole from which the all wavelengths less than 3 kilometresm have been removed by high cut filtering (Figures 12 and 13). The high cut filter of the processing to produce this image has been successful in removing most of the high frequency anomalies due to the sea floor channels which obscure the detail of the deeper features while the vertical gradient operation, which is a type of high pass operation has enhanced the resolution of the anomalies due to the deeper magnetic sources. The vertical gradient process has been particularly successful in reducing the effects of the anomalies due to neighbouring magnetic sources coalescing and thereby obscuring the details of the individual features.

All of the above products were examined to produce the composite interpretation map of Figure 18.

6. QUANTITATIVE INTERPRETATION

Quantitative interpretation of magnetic features (i.e. determinations of their depths and geometries) was based on two methods:

- the Encom Technology Modelvision software package, which has the ability to directly access random profiles and grids of magnetic data from ER Mapper images was used for detailed modelling of profiles and grids of data over specific magnetic features. Results of using this package are illustrated in Figures 14 and 15.

- the Euler automatic depth determination routine (Reid *et al.*, 1990) which has been incorporated into INTREPID was applied to the entire grid of data to give a first order estimate of magnetic source depths and boundaries. Figure 16 shows the results where the routine was set to determine to identify and calculate the depths to the edges of horizontal plate-like magnetic bodies. This model was chosen to give the depths of a deep sub-horizontal basic sheet thought to occur at the base of the Bonaparte Basin sedimentary sequence, the evidence for which is presented below.

7. INTERPRETATION OF THE AEROMAGNETIC DATA

The most striking feature of the image of the total magnetic intensity reduced to the pole (Figure 8) is the broad semi-contiguous magnetic high located in the centre of the study area. This high is interpreted to arise from a sub-horizontal sheet of Proterozoic basic igneous material which originally occurred as an extensive lava flow or sill. The Proterozoic lavaflow/sill appears to have originally extended from the extreme western onshore limits of the study area to the eastern limits of the study area in the vicinity of the Moyle 1 well. The intense, high frequency anomalies in the onshore areas appear to map areas where this lavaflow/sill occurs at relatively shallow depths, whereas the areas of broader, low frequency highs in the centre of the study area have been interpreted as being areas where the lavaflow/sill has been downfaulted and now occurs beneath several kilometres of Bonaparte Basin sediments. No anomalies attributable to the Cambrian Antrim Plateau Volcanics are evident in the data. Either the Antrim Volcanics do not exist in the area or their effects are masked by the Proterozoic igneous units.

Good control exists for this interpretation. Outcrops of Proterozoic quartz dolerite Carson Volcanics on the Medusa Banks 1 : 250 000 geological map correlate with magnetic highs. The Berkley 1 well, which was drilled on a magnetic high, is reported as bottoming in an igneous intrusion between 815 and 873 metres. The Cambridge 1 well, also drilled on a magnetic high, penetrated "Precambrian" quartz dolerite between 2213 metres and T.D. at 2228 metres. The Moyle 1 well drilled on an onshore magnetic high in the extreme east of the study area intersected Precambrian gabbro at 535 metres. Given the common imprecision in reporting basement igneous rocks in older petroleum wells, such as the four quoted above, it is probable that all these wells sampled portions of the same igneous sheet.

The present geometry of the Proterozoic igneous sheet appears to be the result of crustal scale fracturing associated with rifting in the area. This is most convincingly demonstrated in the west of the area, where a large rectangular portion of the igneous sheet, centred on Cambridge 1, appears to have ruptured along a northwest trending fault coincident with what is now the present day coastline and to have moved northeastward over a distance of approximately 25 kilometres.

The existence of transfer faults to accommodate this extension is provided by major linear features evident in the magnetic data.

At the northwestern end of the rectangular block of the igneous sheet two prominent northeast trending lineaments which separate magnetic sources of obvious different character and depths appear to define transform faults. These narrow linear features are magnetic lows. The magnetic low effect could be due to weathering along the fault planes with resultant oxidation of magnetic minerals adjacent to the fault to non-magnetic material. Another possibility is that the magnetic lows are due to the emplacement of reversely magnetised dykes along the faults. This latter possibility is discounted by the fact that fault planes have been mapped where these features continue into the onshore regions and no record has been made of dyke emplacement. These faults in the northeastern corner of the study area have been geologically mapped (they are shown on the Medusa Banks 1: 250 000 Sheet (BMR, 1971)) and are evident in Landsat imagery (see for example Figure 18 of Gunn (1989)). Magnetic and gravity gradients indicate a significant, sudden increase to the depth of magnetic basement on the southeastern offshore portions of these faults. Seismic line MM80 - 19B which perpendicularly traverses these faults (see Figure 17), confirms the existence of the faults and indicates an apparent increase in the depth to basement to the southeast.

The presence of a transfer fault on the southeastern side of the igneous block, southeast of Cambridge 1 and Leseur 1, is suggested by the straight alignment of the southeastern edge of the block and an apparent second block further to the southeast.

The magnetic high along the coastline southwest of the Cambridge 1 magnetic block is interpreted to be due to an edge effect of faulting of the Proterozoic sheet. It is possible to almost exactly recreate a continuous magnetic sheet by moving the magnetic block containing Cambridge 1 back against the magnetic high along the coastline. This reassembly is assumed to be the geometry of the sheet in this area prior to extension.

Such a model implies that a trough would have been created between the coastline and the Cambridge 1 block. The existence of such a trough is supported by:

(i) Magnetic modelling, as illustrated in Figures 14 and 15, which supports the existence of a magnetic sheet which has been fractured and extended to produce a half graben between Cambridge 1 and the coast.

(ii) Euler depth determinations which indicate that Cambridge 1 is on a shallow basement ridge seaward of a deep trough. The shallow basement intersection in Cambridge 1 supports these determinations.

(iii) The Bouguer gravity field, which as shown in Figure 3, suggests that Cambridge 1 is separated from the coastal area by a low density sediment trough.

(iv) Seismic data, an examples of which is shown in Figures 14 and 15, show the presence of extensional structures between the Cambridge 1 high and the coast. Seismic lines MM80-21, MM80-36 and MM81-39 whose locations are shown in Figure 17 further confirm these structures. These seismic lines show sedimentary sequences more suggestive of the Palaeozoic rift sequences than faulted Proterozoic. (The authors have noted what appears to be a four-way dip closure in the interpreted

Paleozoic sequence at the intersection of lines MM81- 39 and MM8 1-42.) The existence of a Palaeozoic section is further supported by the fact that stacking velocity determinations across shallow Proterozoic in the vicinity of the Berkley 1 well are significantly higher than the stacking velocities in the trough

It is interesting to note that, while the Bonaparte Basin portion of the1 : 2 500 000 scale regional tectonic map of the North West Shelf of Australia compiled by Stagg (1993) shows a structural configuration consistent with the above interpretation, most depictions of the regional geology of the area have assumed shallow Proterozoic basement between Cambridge 1 and the coast. This impression that the area has no prospectivity probably explains why, apart from two regional AGSO seismic lines no seismic has been shot in the area since the early 1980s.

For the purposes of this paper, the high underlying Cambridge 1 and the landward trough are referred to respectively as the Cambridge High and the Cambridge Trough.

A possible geometry for the magnetic sheet underlying the Cambridge High is presented in the interpretation synthesis of Figure 18. This sheet is interpreted to consist of several faulted slices. The existence of compartments within the block is supported by the magnetic and gravity data presented in Figures 14 and 15 as well as by the various seismic lines in the area. The interpreted fragmented into tilted blocks is especially supported by the vertical gradient image of Figure 13. This image, the computer modelling results and composite seismic sections of Figures 14 and 15, the Euler depth estimates of Figure 16 and the gravity data all indicate significant differences between the northwestern and southeastern ends of the Cambridge High and the Cambridge Trough. The combination of these features has been interpreted to indicate that a minor transfer fault zone has accommodated differential movement between the ends of these features and that the result of this differential movement has been the creation of a series of half graben structures at the northwest in contrast to what is basically a single half graben structure and associated ridge in the southeast. Depth estimates indicate a significant increase in depth between the features at the northwestern end of the Cambridge High and those at its southeastern end.

Fault traces interpreted from the syn-rift section using seismic data show that, even though the magnetic sheet causing the anomalies may be deeply buried, its morphology can be related to faulting and depositional patterns in the overlying units. Seismic data at the eastern end of the Cambridge High, in the Vicinity of the Matilda 1 well indicate a significant thickening of the sedimentary section across the transfer fault that has been interpreted in this area (see for example Figure 9 of Durrant *et al.* (1990)). This thickening can be interpreted to be a reflection of the existence of the transfer fault and the termination of the Cambridge High.

Figure 18 shows an interpreted distribution for the basal magnetic sheet and transfer faults which explain its geometry in the eastern half of the study area. Control for this interpretation is more equivocal than that in the area of the Cambridge Horst because a marked increase in sediment thickness across the transfer fault at the southeastern end of the Cambridge Horst obscures supporting detail. The interpretation has however produced a transfer fault movement model which allows the basal magnetic sheet to be reassembled into a simple continuous body that would once have extended right across the study area.

In contrast to the western margin of the offshore Bonaparte Basin which appears to be controlled by normal faults associated with extension in the direction of the transfer faults, the eastern basin margin is basically a single linear north striking fault separating shallow basement from a very thick sedimentary sequence which occur to the west of the fault.. This fault, whose existence has been previously deduced from drilling, is shown as the Moyle River Fault on the Port Keats 1: 250 000 Geological Map Sheet (BMR 1971). The Euler depth determinations of Figure 15 clearly show the increase in depth to the magnetic markers across this fault.

While the aeromagnetic data appears to have been extremely successful in mapping major structural units, the data were less applicable to mapping intrasedimentary detail. This can be largely ascribed to the widespread responses of seafloor channel systems containing magnetic material. These responses largely obscure magnetic responses to intrasedimentary faults and in many situations it is difficult to distinguish fortuitous alignments of channel related features from fault related features. While several linear features have been identified and shown on the interpretation map of Figure 18 as possible intrasedimentary faults, it must be concluded that the anomalies due to the intrasedimentary faults cannot be mapped with any confidence in the offshore Bonaparte Gulf area using aeromagnetic data without supporting information such as that provided by seismic sections.

Several linear northwesterly trending features near the coast south west of Cambridge 1 are in fact due to sand bars on the sea floor.

The utility of the high frequency responses may however not be completely negative. For example the north trending channel system passing 15 kilometres to the west of Cambridge 1 commences at the mouth of the Ord River which is the drainage catchment for any material eroded from the diamondiferous Argyle lamproite pipe.

7. CONCLUDING REMARKS

The transfer fault direction identified in this study is parallel to a major Proterozoic wrench complex, called the Halls Creek - Fitzmaurice Mobile Zone, which passes to the south of the Bonaparte Basin (Figure 1). Many other faults with identical directions can be recognised in the published geological maps of the areas flanking the Basin. The geological map of the southern Bonaparte Basin (BMR, 1968) provides several clear examples of such faults plus indications of perpendicular faults paralleling the normal fault system identified in the offshore area. We conclude that the initial extension in the southern Bonaparte Basin was along a series of transfer faults inheriting their direction from movements associated with the Halls Creek Fitzmaurice - Mobile Zone. These findings are a variation of an idea first suggested by Warris (1973) that the initial rifting in the Bonaparte Gulf was associated with right lateral movement along the Halls Creek Mobile zone.

The tectonic/structural model devoloped in this paper has direct implications for petroleum exploration with the most obvious result being the delineation of the Cambridge High and the Cambridge Trough. These areas, which are shown in most publications pertaining to the area, as shallow Proterozoic basement, are revealed to contain narrow highly structured troughs which may well contain significant thicknesses of untested Palaeozoic rift sediments. The sediments in the Cambridge Trough, by virtue of occurring near the basin margin, may have not been as deeply buried as the sediments in the centre of the basin which have been drilled with discouraging results in terms of reservoir prospectivity. In addition, as these troughs occur close to the basin margin they may contain coarser clastic material and hence superior reservoir rocks to what has been drilled further out in the basin. If the source rocks known to produce oil elsewhere in the basin occur in these troughs then they must be regarded as highly prospective. The restricted depositional environment of Cambridge Trough may have favoured the development and preservation of high quality source rocks.

As well as the specific identification of these prospective areas' the interpretation has mapped major structural features and depocentres in the basin. This information can be integrated with proprietary seismic and drilling data to obtain better ideas about the likely distribution of depositional facies, maturation of source rocks and migration pathways.

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FIGURES

Where appropriate, 1 : 250 000 scale versions have been produced for the following figures and these larger scale versions are available from AGSO for detailed analysis.

Figure 1

Locality map. The Bonaparte Gulf lies between the Fitzroy Trough and the Money Shoals Graben. All these features have been interpreted as contemporaneous rifts.

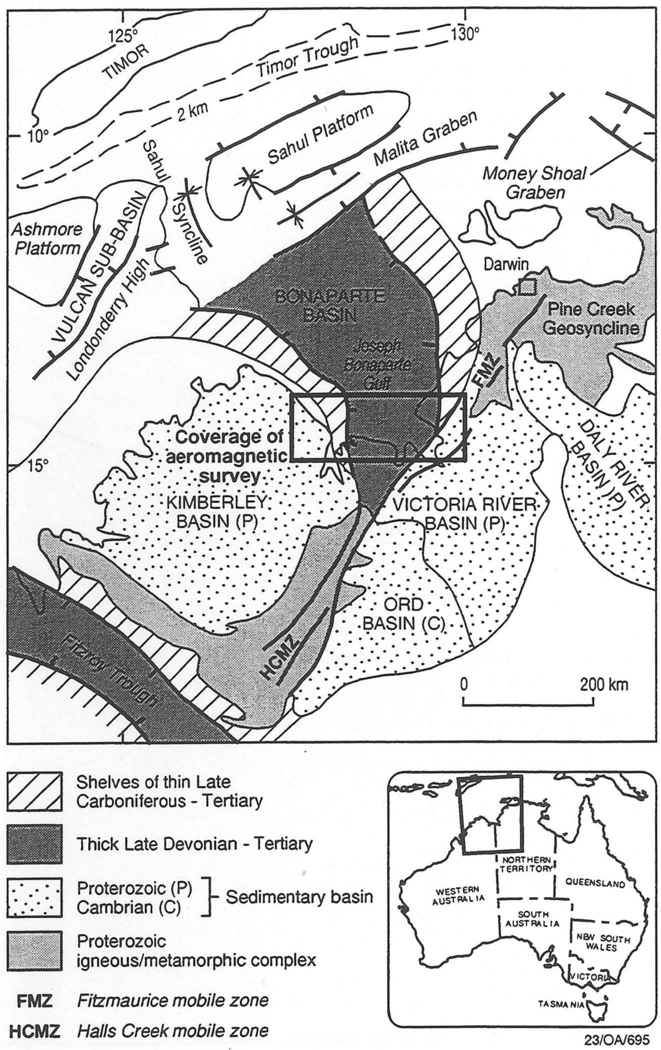
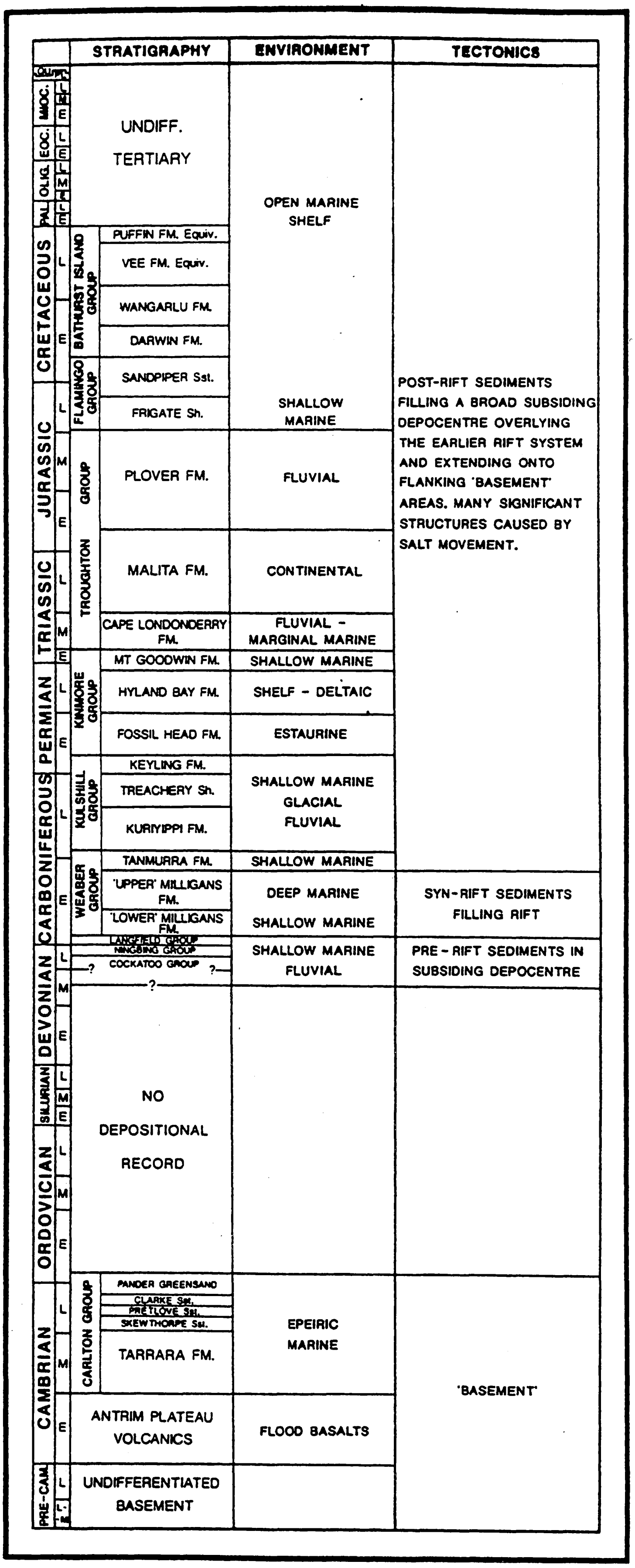

125°
130°
10°
15°
TIMOR
Timor Trough
2 km
Sahul Platform
Malita Graben
Sahul Syncline
Money Shoal Graben
Ashmore Platform
VULCAN SUB-BASIN
Londonderry High
Darwin
Pine Creek Geosyncline
BONAPARTE BASIN
Joseph Bonaparte Gulf
FMZ
Coverage of aeromagnetic survey
KIMBERLEY BASIN (P)
VICTORIA RIVER BASIN (P)
DALY RIVER BASIN (P)
ORD BASIN (C)
HCMZ
Fitzroy Trough
0
200 km
Shelves of thin Late Carboniferous - Tertiary
Thick Late Devonian - Tertiary
Proterozoic (P)
Cambrian (C)
Sedimentary basin
Proterozoic igneous/metamorphic complex
FMZ Fitzmaurice mobile zone
HCMZ Halls Creek mobile zone
NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TASMANIA
23/OA/695

Figure 2

Stratigraphic column (after Gunn (1988)).

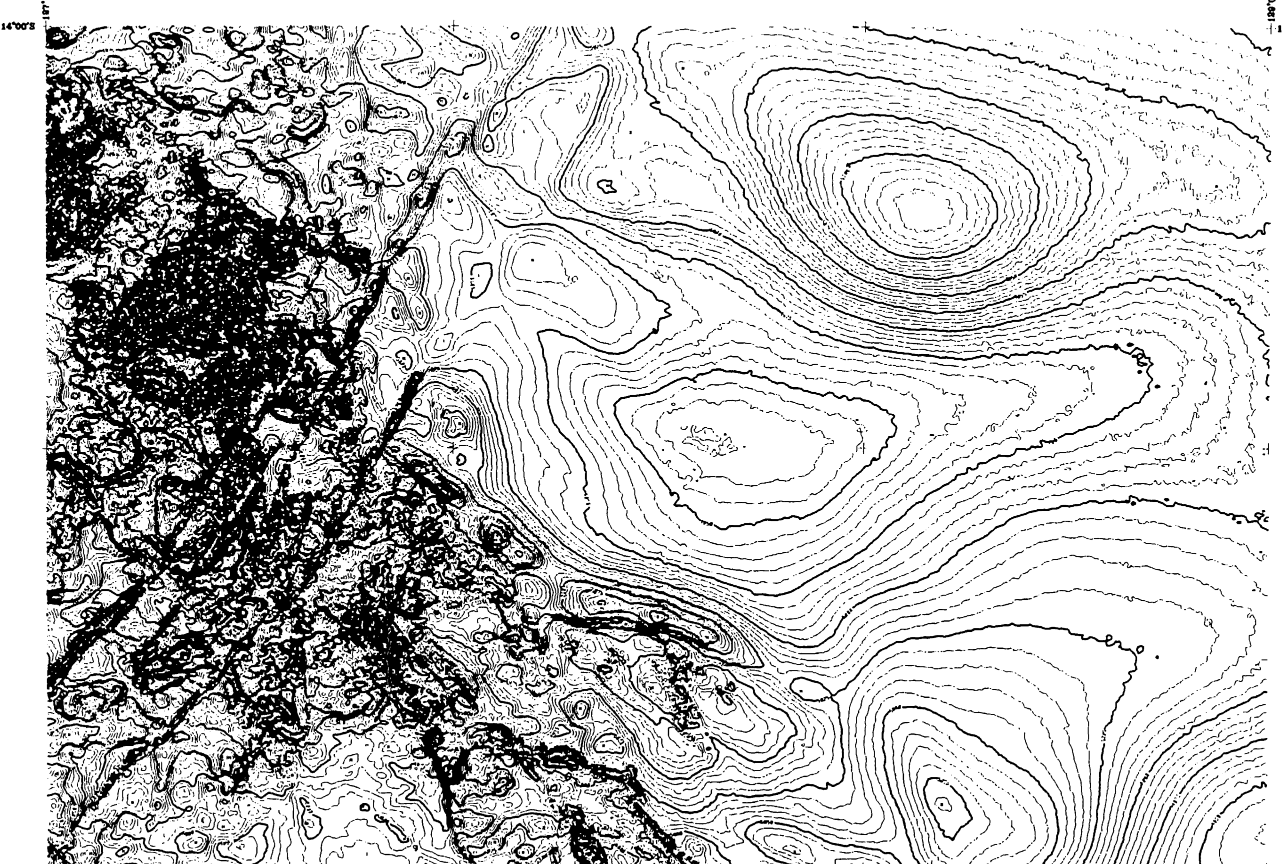


STRATIGRAPHY
ENVIRONMENT
TECTONICS
QUAT.
MIOC.
EOC.
OLIG.
PAL.
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRE-CAM.
UNDIFF. TERTIARY
OPEN MARINE SHELF
PUFFIN FM. Equiv.
VEE FM. Equiv.
WANGARLU FM.
DARWIN FM.
BATHURST ISLAND GROUP
FLAMINGO GROUP
SANDPIPER Sst.
FRIGATE Sh.
SHALLOW MARINE
POST-RIFT SEDIMENTS FILLING A BROAD SUBSIDING DEPOCENTRE OVERLYING THE EARLIER RIFT SYSTEM AND EXTENDING ONTO FLANKING 'BASEMENT' AREAS. MANY SIGNIFICANT STRUCTURES CAUSED BY SALT MOVEMENT.
TROUGHTON GROUP
PLOVER FM.
FLUVIAL
MALITA FM.
CONTINENTAL
CAPE LONDONDERRY FM.
FLUVIAL - MARGINAL MARINE
MT GOODWIN FM.
SHALLOW MARINE
KINMORE GROUP
HYLAND BAY FM.
SHELF - DELTAIC
FOSSIL HEAD FM.
ESTAURINE
KULSHILL GROUP
KEYLING FM.
TREACHERY Sh.
KURIYIPPI FM.
SHALLOW MARINE
GLACIAL
FLUVIAL
WEABER GROUP
TANMURRA FM.
SHALLOW MARINE
'UPPER' MILLIGANS FM.
DEEP MARINE
'LOWER' MILLIGANS FM.
SHALLOW MARINE
SYN-RIFT SEDIMENTS FILLING RIFT
LANGFIELD GROUP
NINGBING GROUP
COCKATOO GROUP
SHALLOW MARINE
FLUVIAL
PRE-RIFT SEDIMENTS IN SUBSIDING DEPOCENTRE
NO DEPOSITIONAL RECORD
CARLTON GROUP
PANDER GREENSAND
CLARKE Sst.
PRETLOVE Sst.
SKEWTHORPE Sst.
TARRARA FM.
EPEIRIC MARINE
'BASEMENT'
ANTRIM PLATEAU VOLCANICS
FLOOD BASALTS
UNDIFFERENTIATED BASEMENT

Figure 3

Total magnetic intensity contours.

14°00'S



15°00'S

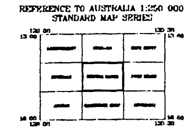
DATA ACQUISITION

DATA PROCESSING AND PRESENTATION

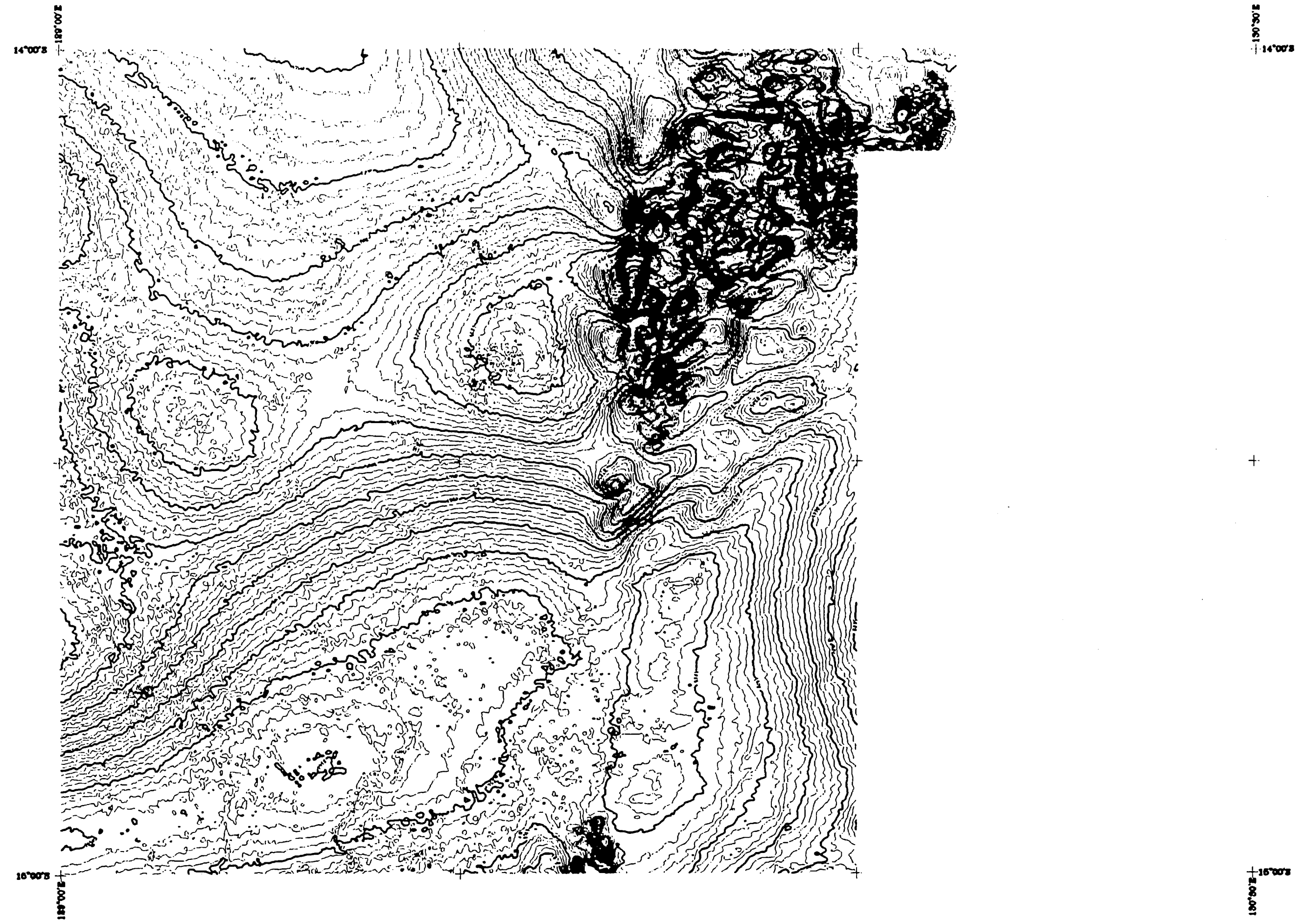
MEDUSA BANKS

TOTAL MAGNETIC INTENSITY CONTOURS

REFERENCE TO AUSTRALIA 1:250 000
STANDARD MAP SERIES



PRELIMINARY EDITION 20/11/94
MEDUSA BANKS , WA 22-1/D52-10/1



PORT KEATS

TOTAL MAGNETIC INTENSITY CONTOURS

DATA ACQUISITION

DATA PROCESSING AND PRESENTATION

scale 1:250 000

kilometres 5 0 5 10 15 20 25 kilometres

REFERENCE TO AUSTRALIA 1:250 000
STANDARD MAP SERIES

PRELIMINARY EDITION 20/11/94

PORT KEATS , NT

Figure 4

Grey scale image of total magnetic intensity illuminated from the north east.

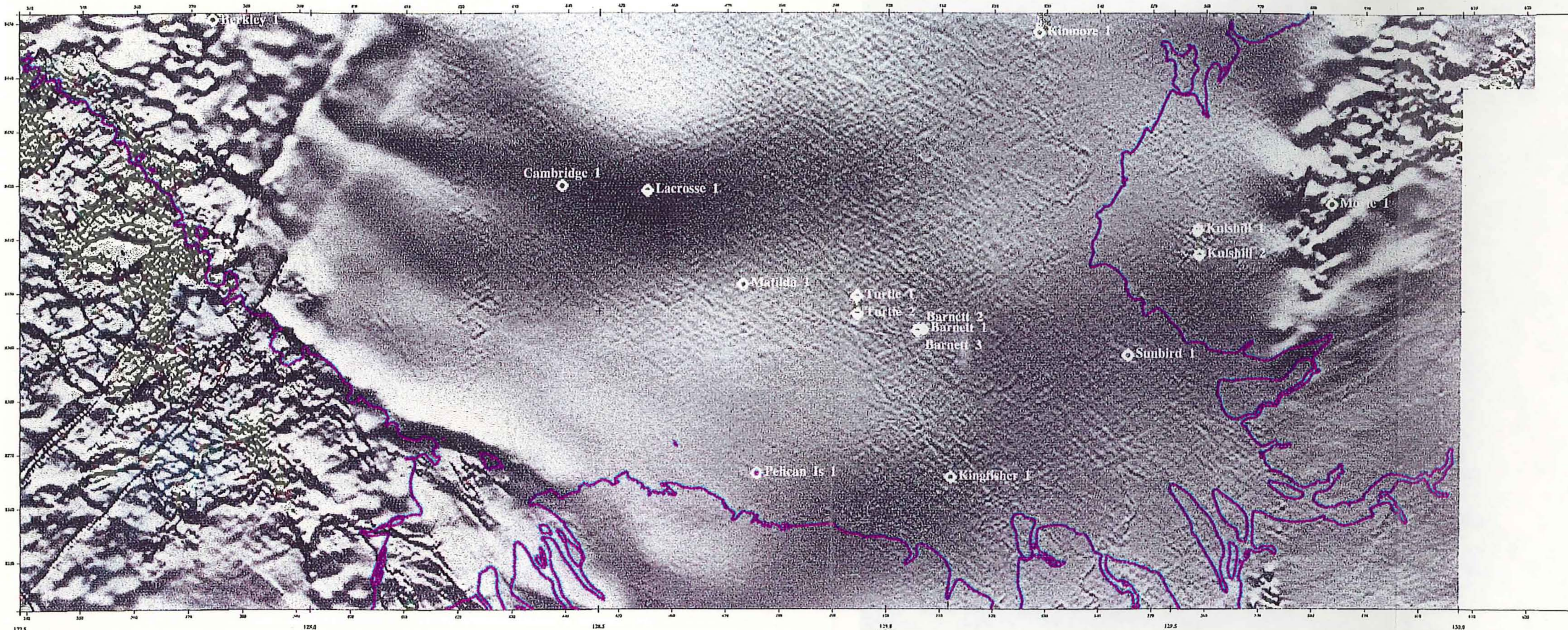
R9504003

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF

WESTERN AUSTRALIA / NORTHERN TERRITORY

TOTAL MAGNETIC INTENSITY
WITH NORTHERLY ILLUMINATION



AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

TOTAL MAGNETIC INTENSITY
WITH NORTHERLY ILLUMINATION

SCALE 1:250 000

Kilometres

MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11

AGSO 22-1/SPECIAL/17

Figure 5

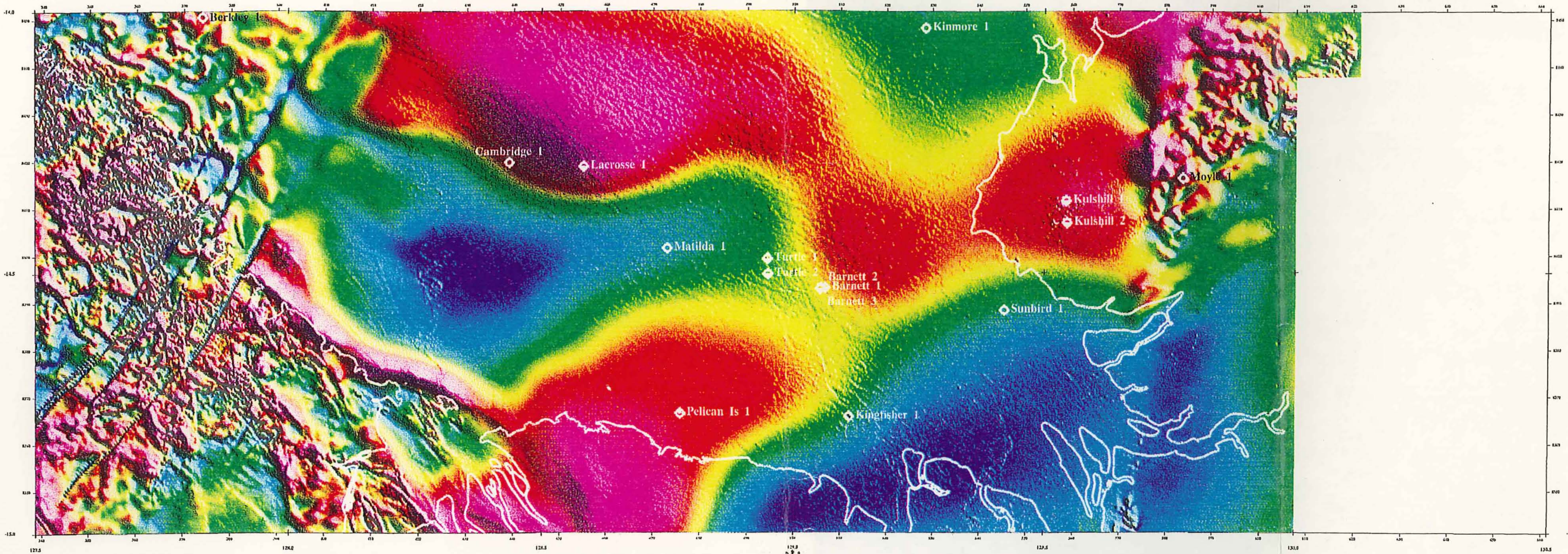
Colour image of total magnetic intensity illuminated from the north east.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF

WESTERN AUSTRALIA / NORTHERN TERRITORY

TOTAL MAGNETIC INTENSITY
WITH NORTH EASTERLY ILLUMINATION



AGSO

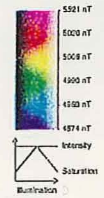
GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

TOTAL MAGNETIC INTENSITY
WITH NORTH-EASTERLY ILLUMINATION

SCALE 1:250 000

Kilometres



MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

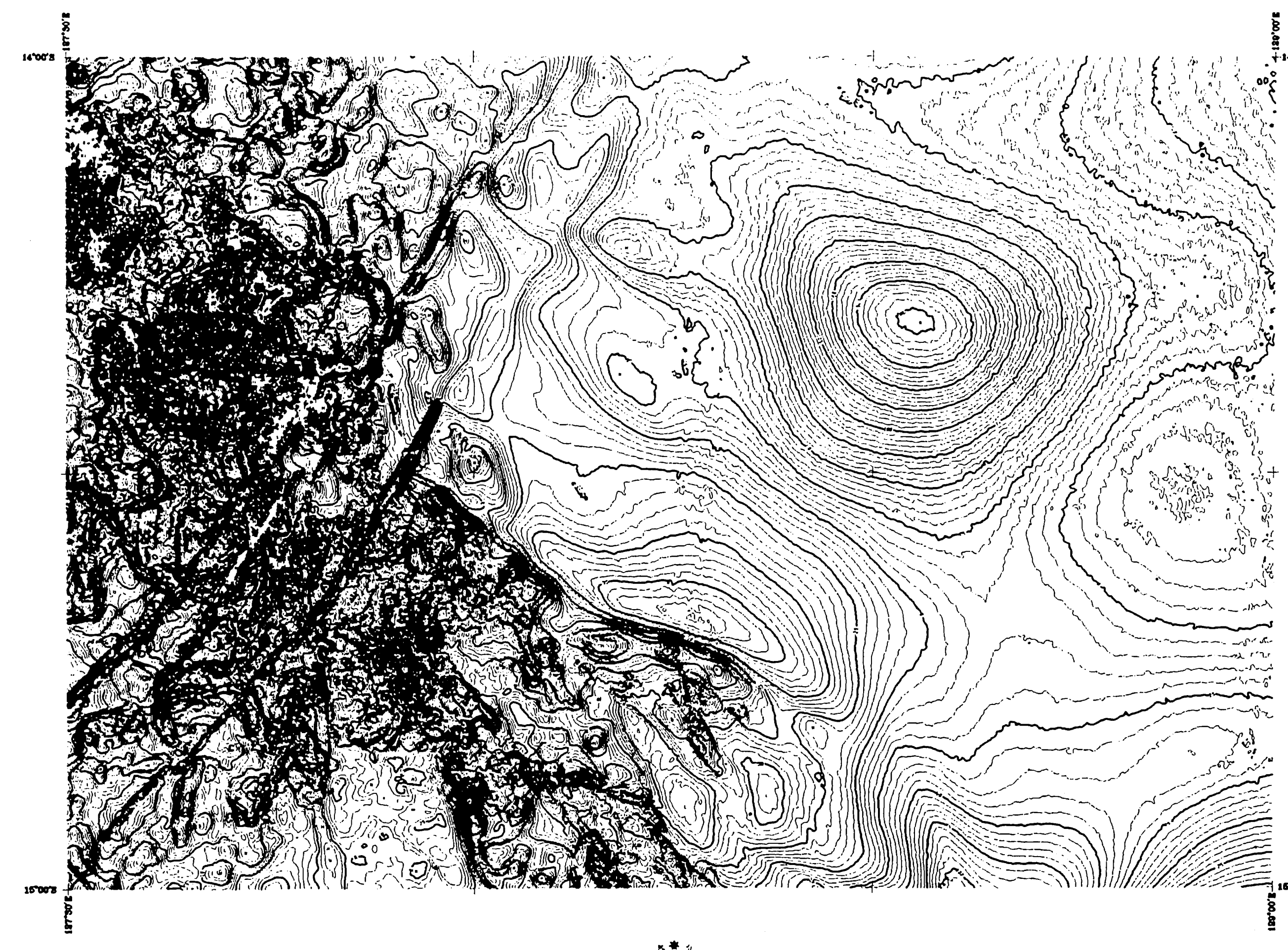
SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11
FIRST EDITION

AGSO 22-1/SPECIAL/16

Figure 6

Contours of total magnetic intensity reduced to the pole.



MEDUSA BANKS

CONTOURS OF REDUCED TO THE POLE
TOTAL MAGNETIC INTENSITY

DATA ACQUISITION

DATA PROCESSING AND PRESENTATION

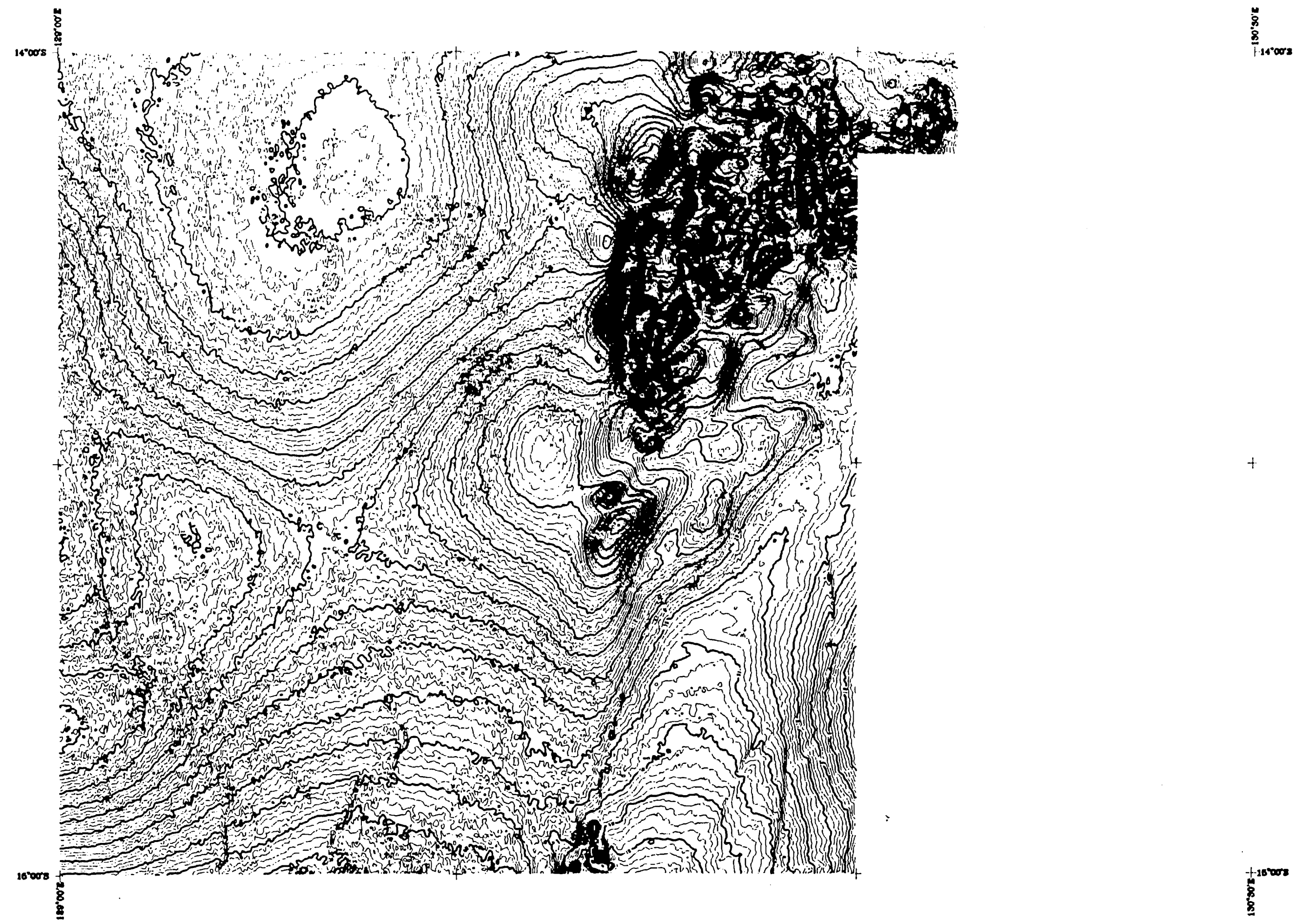
scale 1:250 000

Kilometres 5 0 5 10 15 20 25 Kilometres

REFERENCE TO AUSTRALIA 1:250 000
STANDARD MAP SERIES

PRELIMINARY EDITION 20/2/95

MEDUSA BANKS , WA SD-1/D52-10/SPECIAL



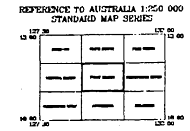
PORT KEATS

CONTOURS OF REDUCED TO THE POLE
TOTAL MAGNETIC INTENSITY

DATA ACQUISITION

DATA PROCESSING AND PRESENTATION

REFERENCE TO AUSTRALIA 1:250 000
STANDARD MAP SERIES



PRELIMINARY EDITION 20/2/94

PORT KEATS , NT 22-1/DGS-11/SPECIAL

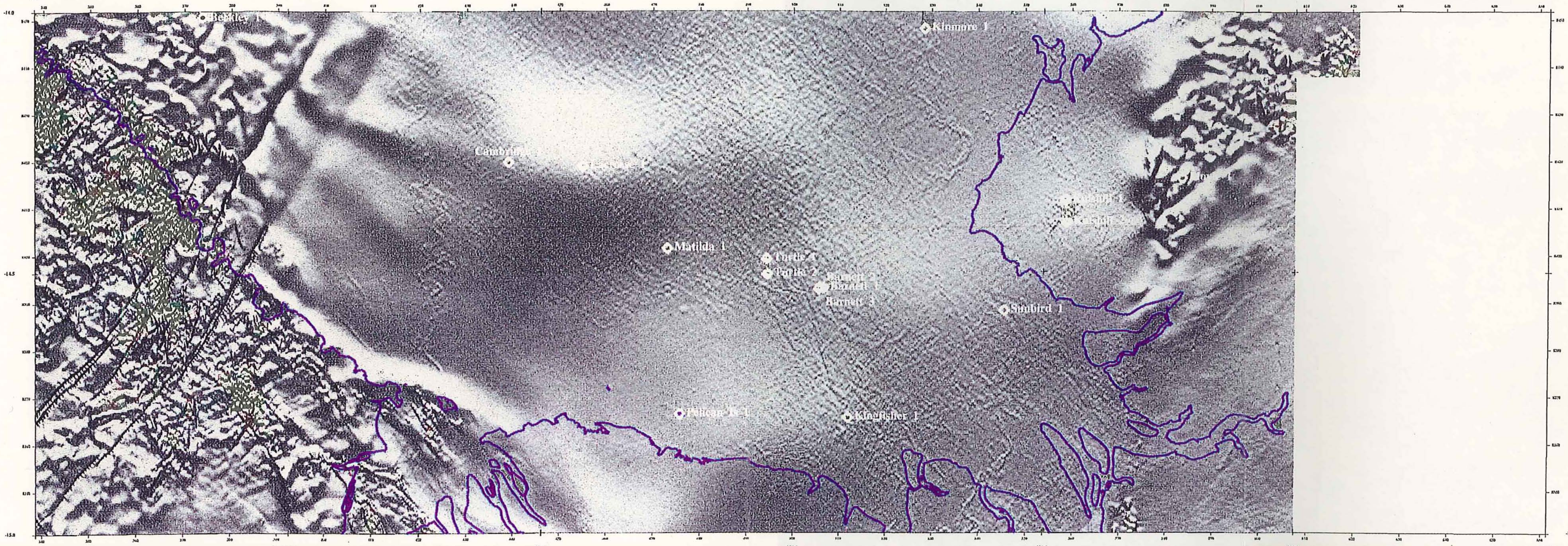
Figure 7

Grey scale image of total magnetic intensity reduced to the pole illuminated from the north east.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

TOTAL MAGNETIC INTENSITY (RTP)
WITH NORTHERLY ILLUMINATION



AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

TOTAL MAGNETIC INTENSITY (RTP)
WITH NORTHERLY ILLUMINATION

Kilometres

MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11

AGSO 22-1/SPECIAL/25

Figure 8

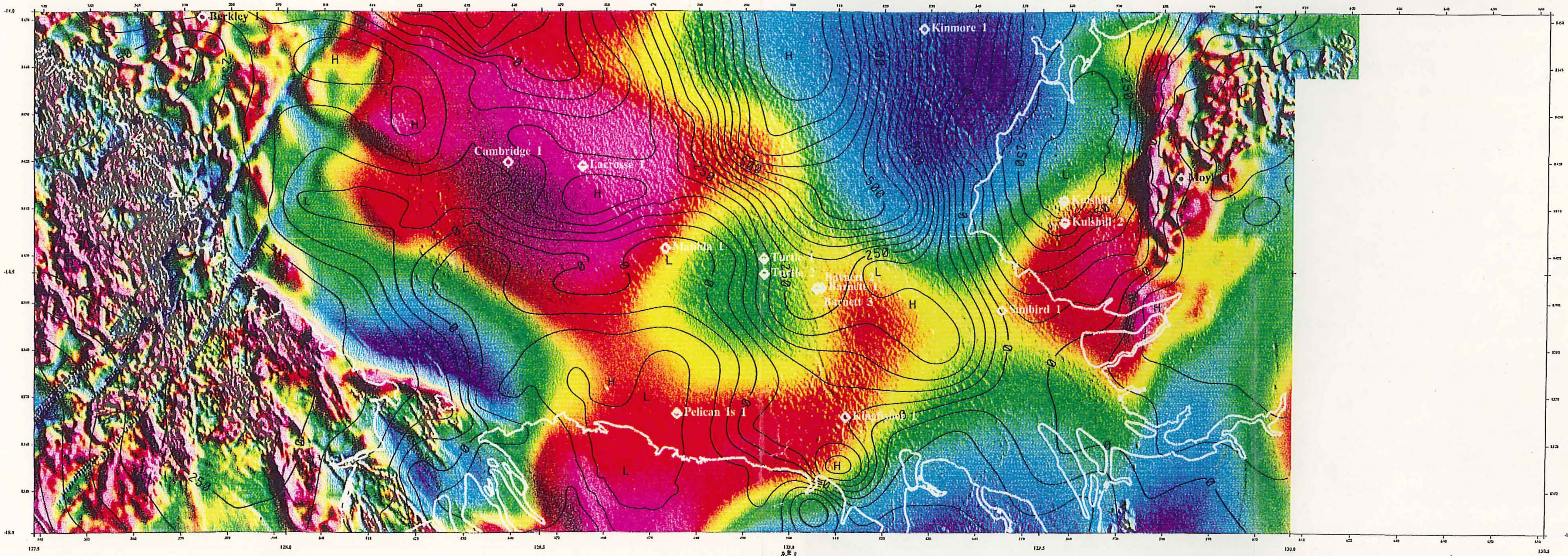
Colour image of total magnetic intensity reduced to the pole illuminated from the north east with superimposed Bouguer gravity contours. Note the marked difference with Figure 5 and the generally excellent correspondence between the magnetic and gravity features.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF

WESTERN AUSTRALIA / NORTHERN TERRITORY

TOTAL MAGNETIC INTENSITY (RTP) WITH NORTH-EASTERLY ILLUMINATION AND BOUGUER GRAVITY CONTOURS



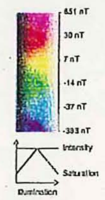
AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

TOTAL MAGNETIC INTENSITY (RTP) WITH NORTH-EASTERLY ILLUMINATION AND BOUGUER GRAVITY CONTOURS

Kilometres



MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

[illegible]	[illegible]	CAPE SCOTT	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
ASHTON	CAMBRIDGE GULF	AUVERGNE	DELAMERE

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11

AGSO 22-1/SPECIAL/21

Figure 9

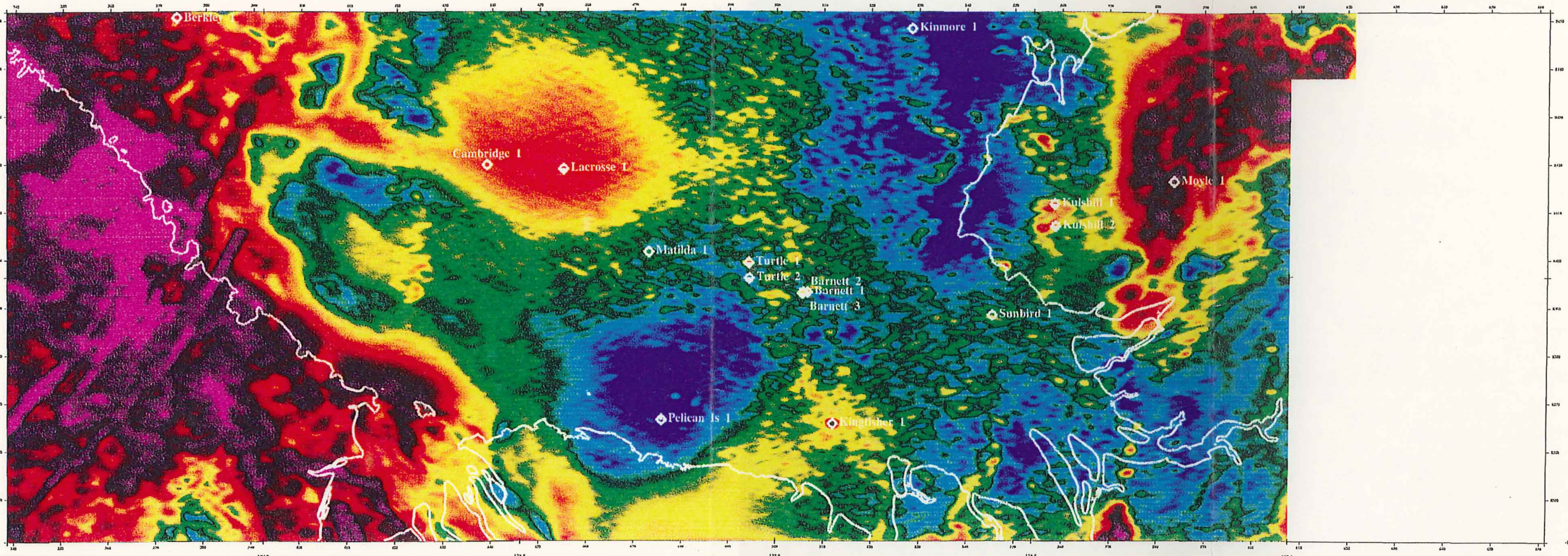
Analytic signal of total magnetic intensity.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF

WESTERN AUSTRALIA / NORTHERN TERRITORY

ANALYTIC SIGNAL
LOW PASS FILTERED (TWO KILOMETRE CUT OFF WAVELENGTH)



AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

ANALYTIC SIGNAL

LOW PASS FILTERED
TWO KILOMETRE CUT-OFF WAVELENGTH

SCALE 1:250 000

Kilometres

MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11

AGSO 22-1/SPECIAL/27

Figure 10

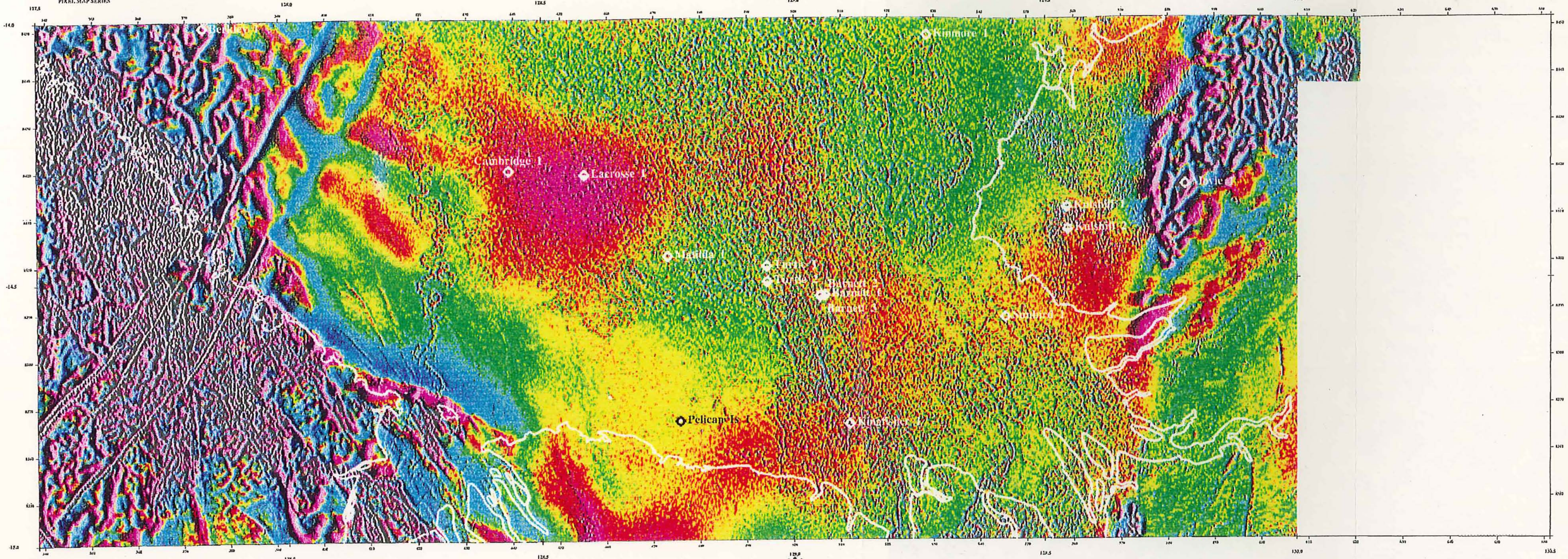
Colour image of the vertical gradient of the total magnetic intensity reduced to the pole illuminated from the north east.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF

WESTERN AUSTRALIA / NORTHERN TERRITORY

FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY (RTP)
WITH EASTERLY ILLUMINATION



AGSO

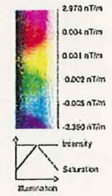
GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY (RTP) WITH EASTERLY ILLUMINATION

SCALE 1:250 000

Kilometres



MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

LONDON-DERRY	[illegible]	CAPE SCOTT	[illegible] CREEK
[illegible]	[illegible] BANKS	PORT KEATS	[illegible] RIVER
ASHTON	CAMBRIDGE GULF	AUVERGNE	DELAMERE

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11
FIRST EDITION 1995

AGSO 22-1/SPECIAL/26

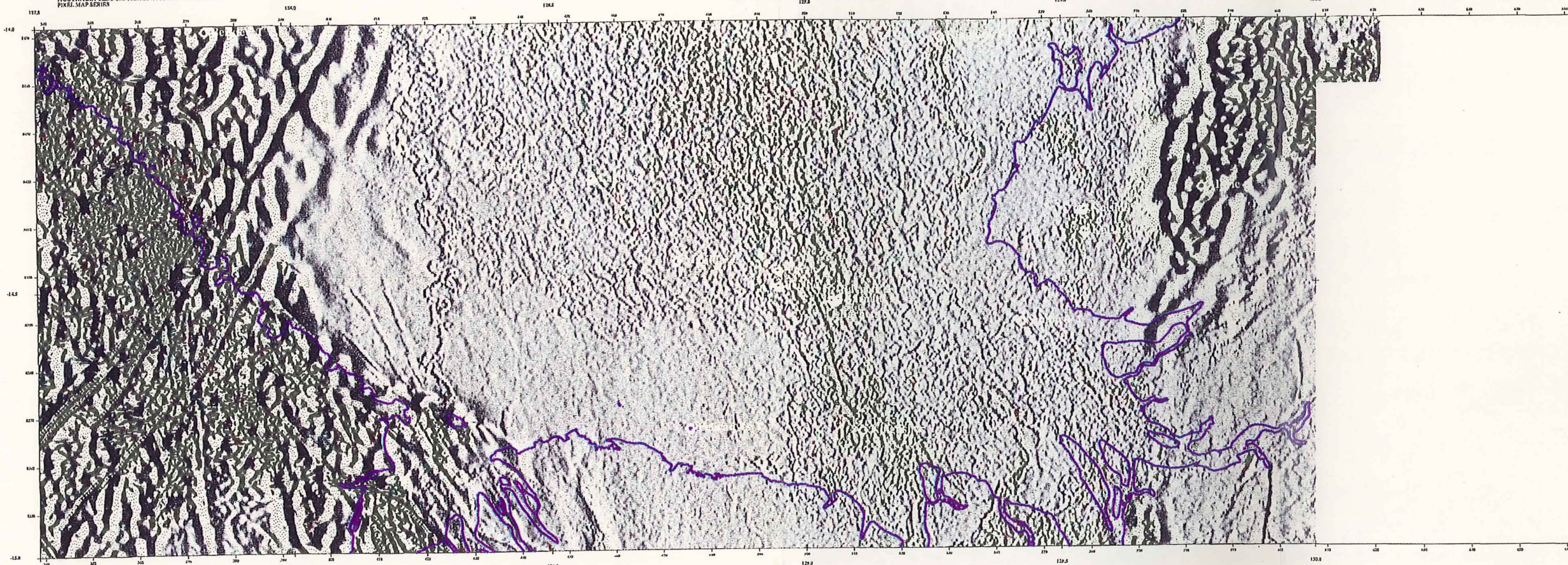
Figure 11

Gradient enhanced greyscale image of the aeromagnetic data with all wavelengths between 20 km and 500 m removed. The high frequency patterns in the offshore area are interpreted to be due to magnetic minerals deposited in shallow channel systems.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

TOTAL MAGNETIC INTENSITY (RTP)
WITH BAND PASS FILTERING (20 km - 500 m) AND EASTERLY ILLUMINATION



AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

TOTAL MAGNETIC INTENSITY (RTP)
BAND PASS FILTERED (20 km - 500 m)
WITH EASTERLY ILLUMINATION

SCALE 1:250 000

Kilometres

0 5 10 15 20 25

MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

[illegible]	[illegible]	CAPE SCOTT	[illegible] CREEK
DRYSDALE	[illegible]	[illegible]	[illegible]
ASHTON	CAMBRIDGE GULF	AUVERGNE	DELAMERE

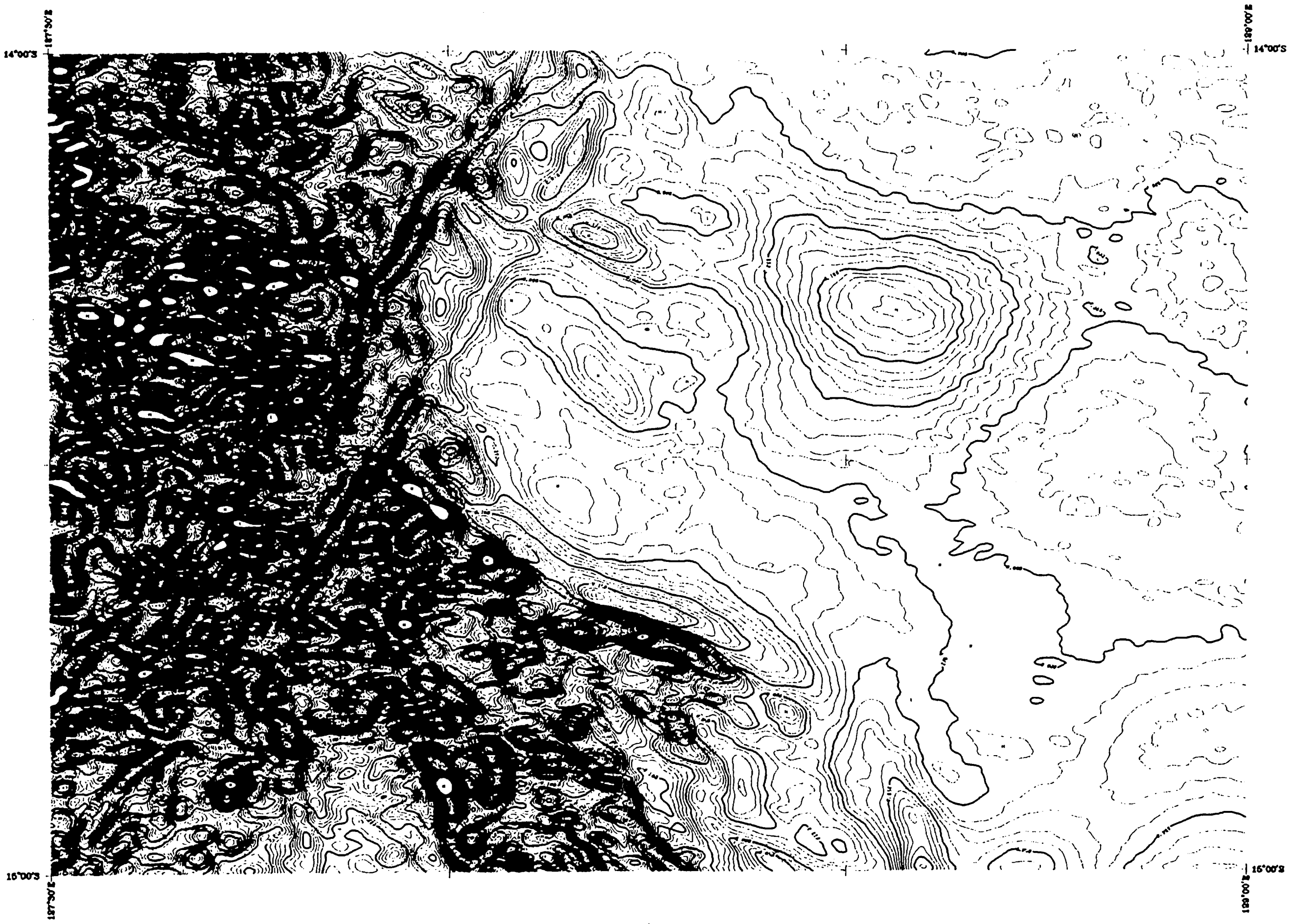
SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11

AGSO 22-1/SPECIAL/24

Figure 12

Contours of the vertical gradient of the total magnetic intensity from which all wavelengths less than 3 km have been removed by bandpass filtering.



DATA ACQUISITION

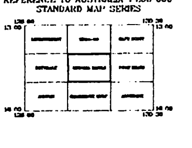
DATA PROCESSING AND PRESENTATION

MEDUSA BANKS

CONTOURS OF LOW PASS FILTERED FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY REDUCED TO THE POLE

scale 1:250 000

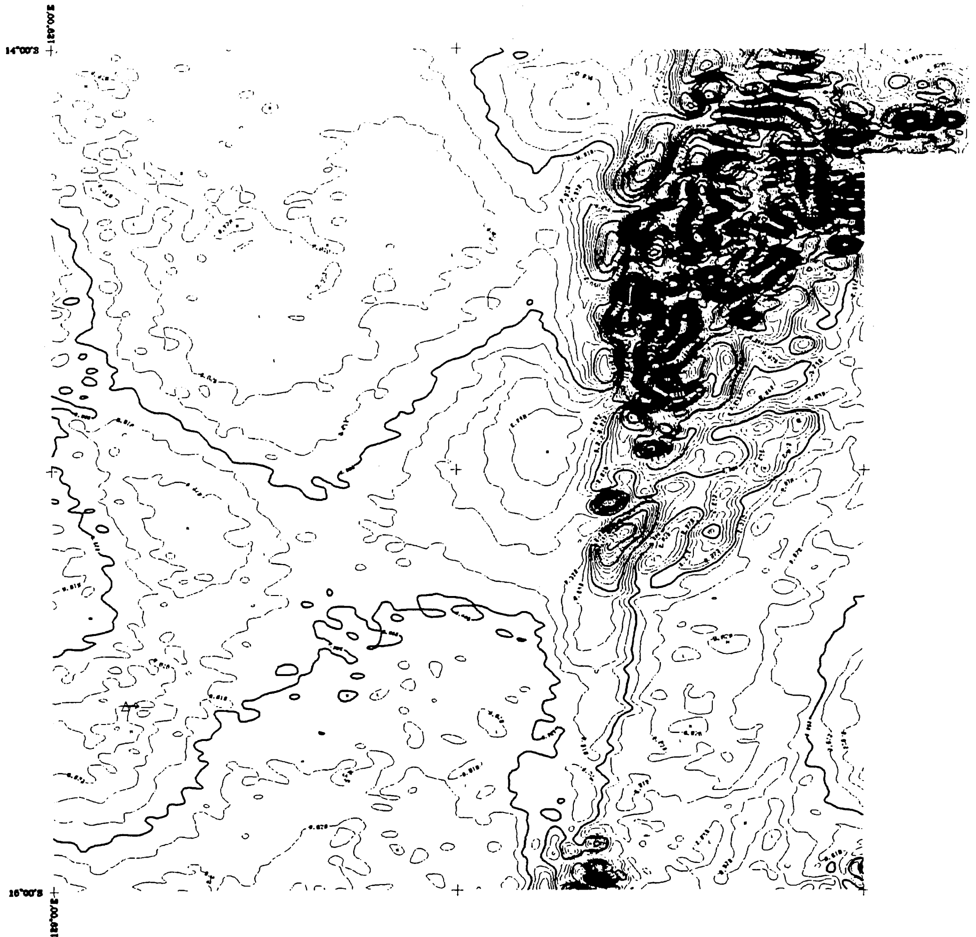
REFERENCE TO AUSTRALIA 1:250 000 STANDARD MAP SERIES



AGSO

PRELIMINARY EDITION 20/2/95

MEDUSA BANKS , WA 22-1/D52-10/SPECIAL



DATA ACQUISITION

Operator .... AGSO

DATA PROCESSING AND PRESENTATION

PORT KEATS

CONTOURS OF LOW PASS FILTERED FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY REDUCED TO THE POLE

scale 1:250 000

REFERENCE TO AUSTRALIA 1:250 000 STANDARD MAP SERIES

AGSO

PRELIMINARY EDITION 20/2/94

PORT KEATS , NT 22-1/D52-11/SPECIAL

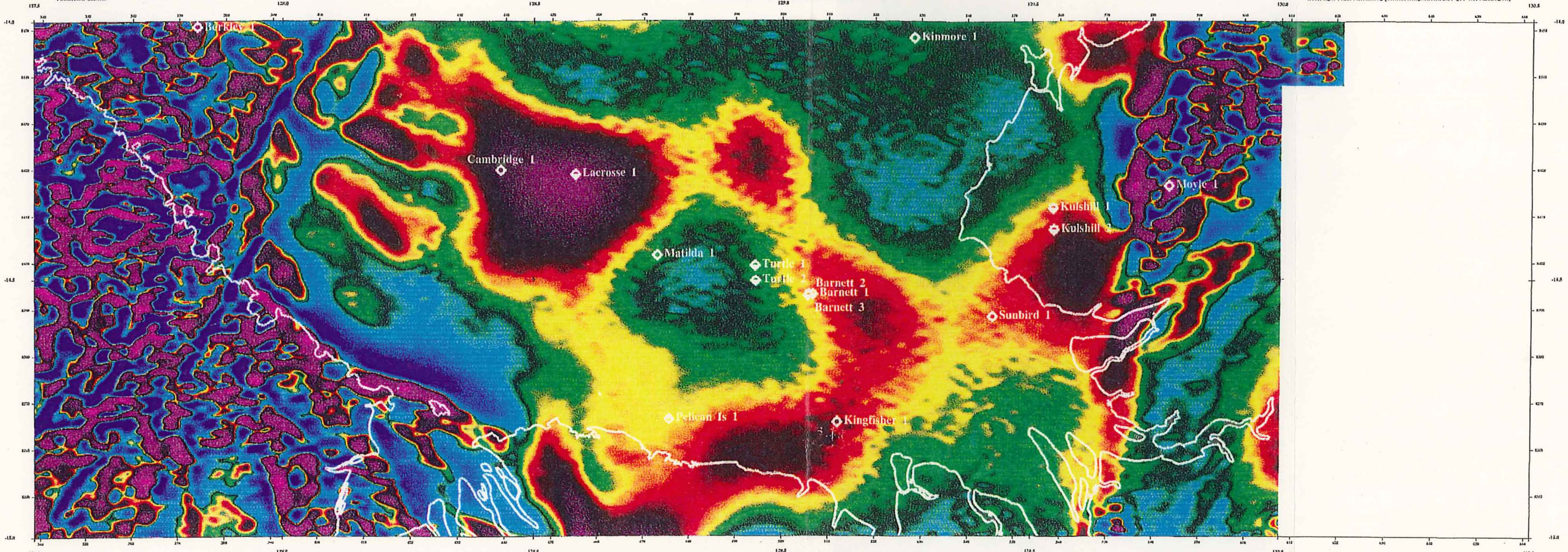
Figure 13

Colour image of the vertical gradient of the total magnetic intensity from which all wavelengths less than 3 km have been removed by bandpass filtering.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY (RTP)
WITH LOW PASS FILTERING (THREE KILOMETRE CUT OFF WAVELENGTH)



AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

FIRST VERTICAL DERIVATIVE OF
TOTAL MAGNETIC INTENSITY (RTP) - LOW PASS FILTERED
THREE KILOMETRE CUT-OFF WAVELENGTH

SCALE 1:250 000

Kilometres

MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11
FIRST EDITION 1993

AGSO 22-1/SPECIAL/28

Figure 14

Computer modelling results. The locations of the profiles are shown on Figure 17. The section at the bottom has been digitised from seismic lines MM80-31, MM80-42, PI-5 and AGSO line 100. The gravity, magnetic and seismic data are all indicating a localised deep sediment trough adjacent to the coastline.

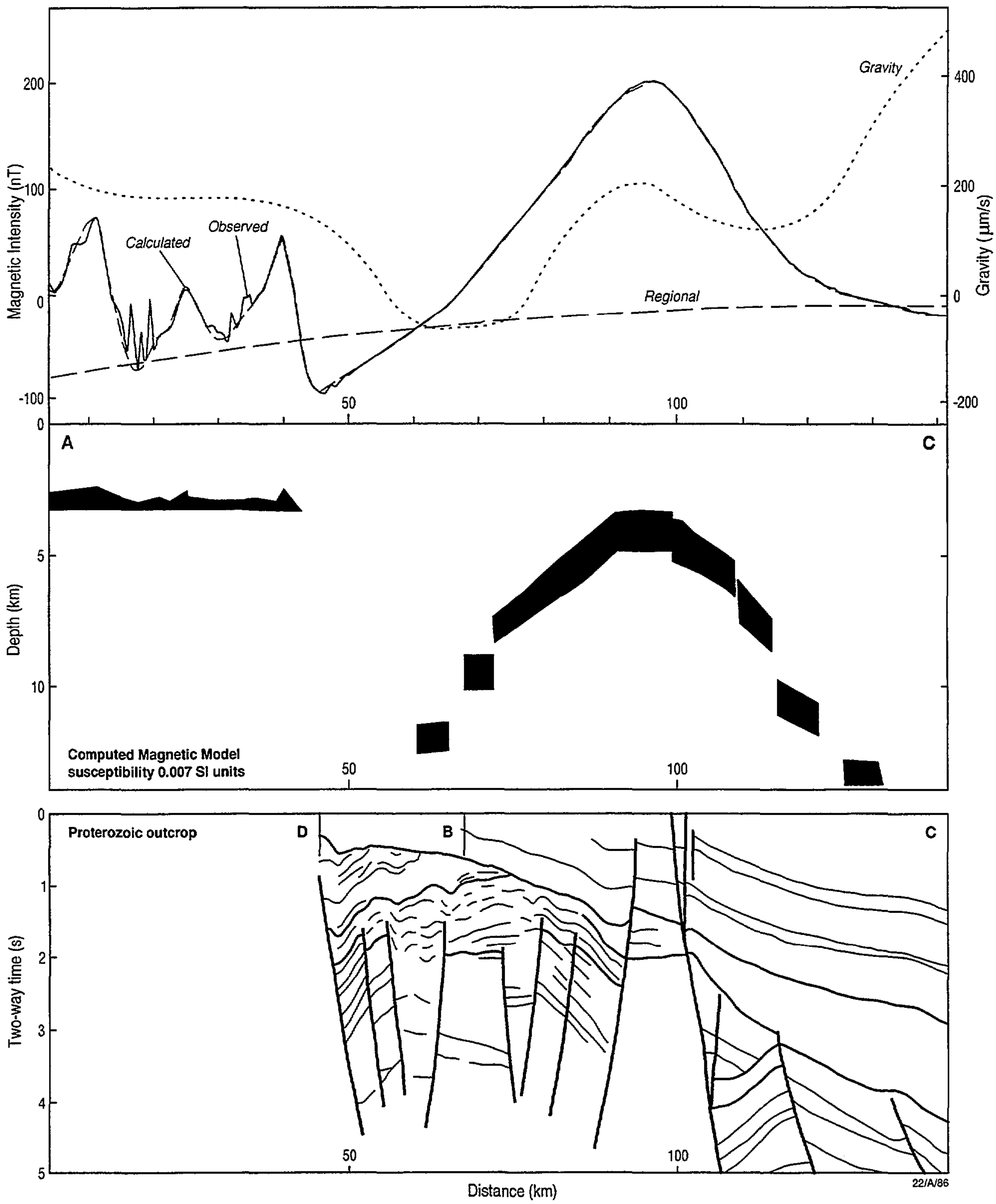
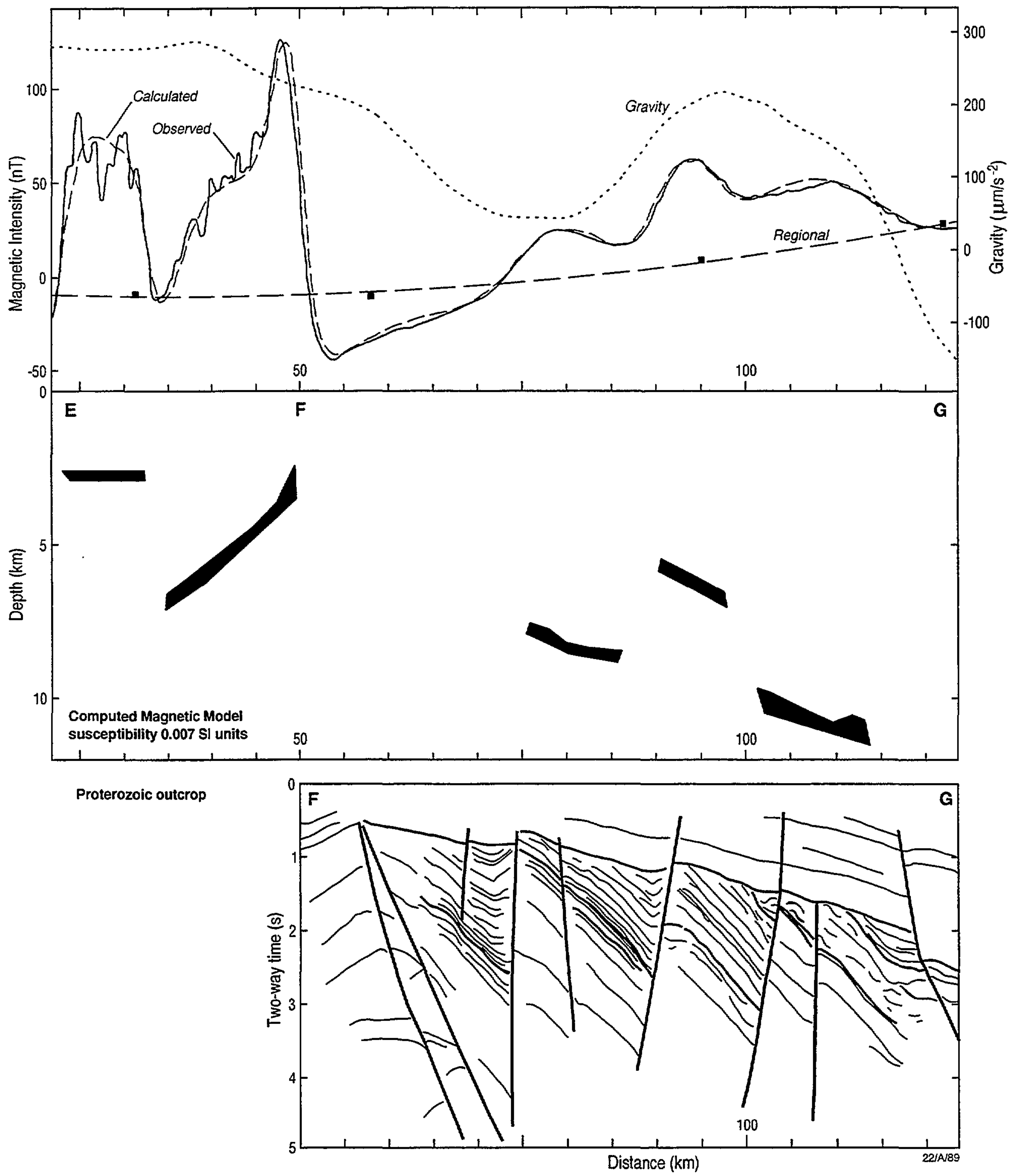

Magnetic Intensity (nT)
Gravity (µm/s)
Gravity
Calculated
Observed
Regional
200
100
0
-100
400
200
0
-200
50
100
A
C
Depth (km)
5
10
Computed Magnetic Model
susceptibility 0.007 SI units
Two-way time (s)
Proterozoic outcrop
D
B
C
0
1
2
3
4
5
Distance (km)
22/A/86

Figure 15

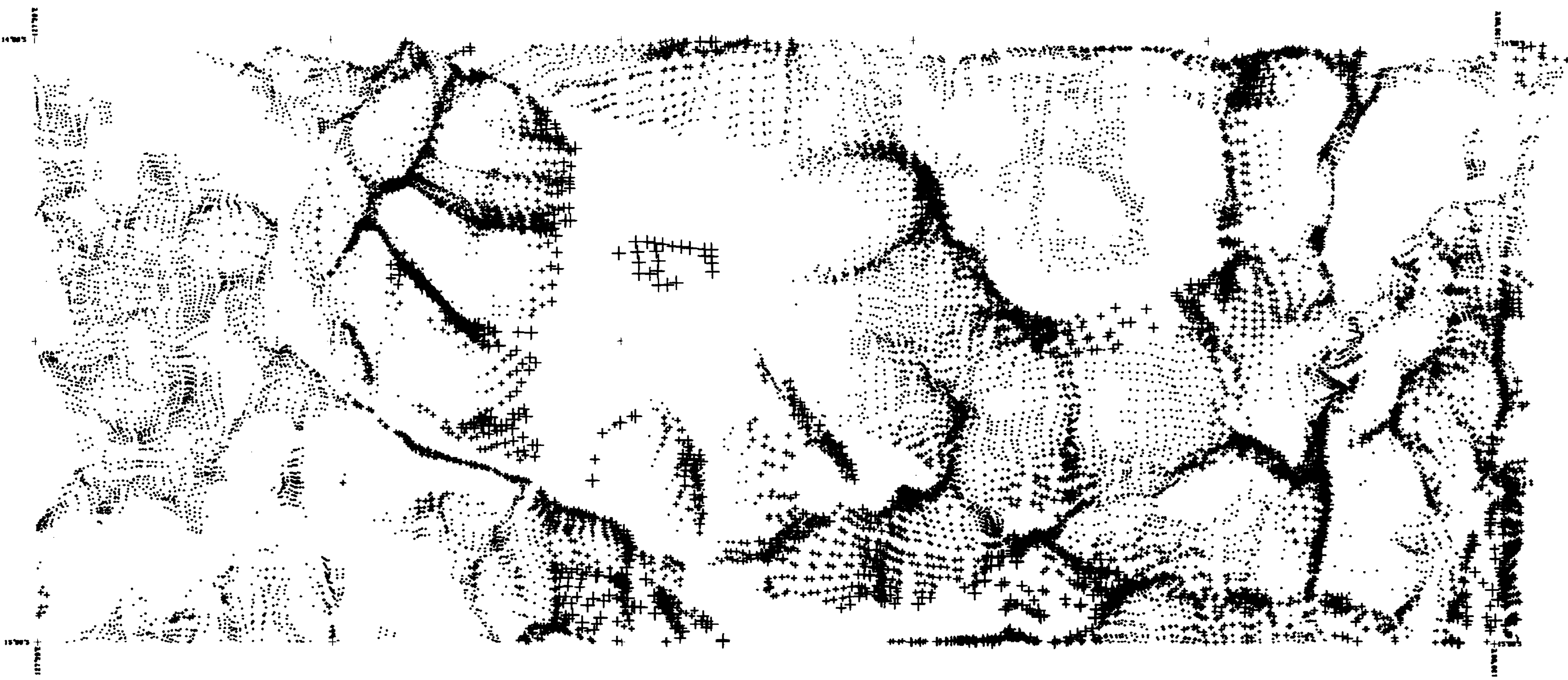
Computer modelling results. The locations of the profiles are shown on Figure 17. The section at the bottom has been digitised from seismic lines TP5. The gravity, magnetic and seismic data are all indicating a series of half graben structures adjacent to the coastline. The apparent discrepancy between the magnetics and the seismic data at the western end of the profile appears to be due to seismic side swipe from a structure adjacent to the profile



Calculated
Observed
Gravity
Regional
Magnetic Intensity (nT)
Gravity (μm/s-2)
100
50
0
-50
300
200
100
0
-100
50
100
E
F
G
Depth (km)
5
10
Computed Magnetic Model
susceptibility 0.007 SI units
Proterozoic outcrop
F
G
Two-way time (s)
0
1
2
3
4
5
100
Distance (km)
22/A/89

Figure 16

Plot of depth determinations calculated using the Euler automatic depth determination routine. The routine in this example was set to determine to identify and calculate the depths to the edges of horizontal plate-like magnetic bodies.



SOUTHERN JOSEPH BONAPARTE GULF

EULER DEPTH ESTIMATES

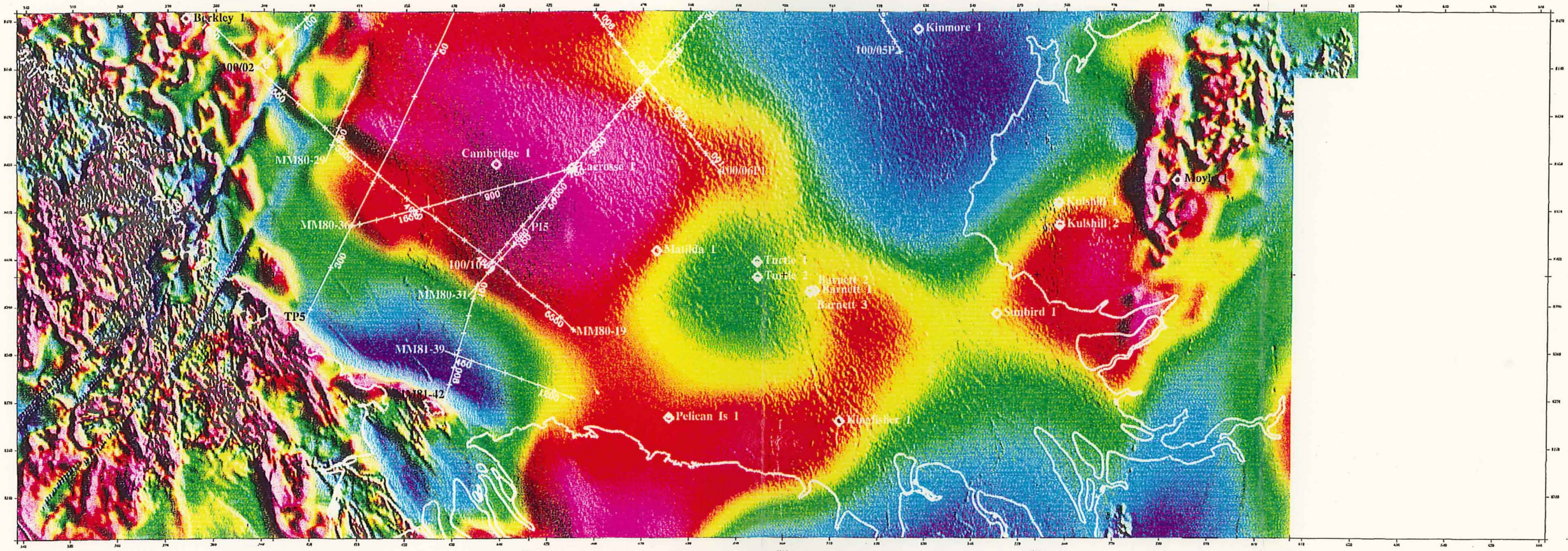
Figure 17

Locations of seismic lines referred to in this report.

AUSTRALIA 1:250 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

TOTAL MAGNETIC INTENSITY (RTP) WITH NORTH-EASTERLY ILLUMINATION AND SELECTED SEISMIC LINES



Data Specifications

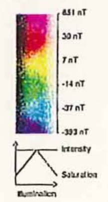
AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

TOTAL MAGNETIC INTENSITY (RTP) WITH NORTH-EASTERLY ILLUMINATION AND SELECTED SEISMIC LINES

SCALE 1:250 000

Kilometres



MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

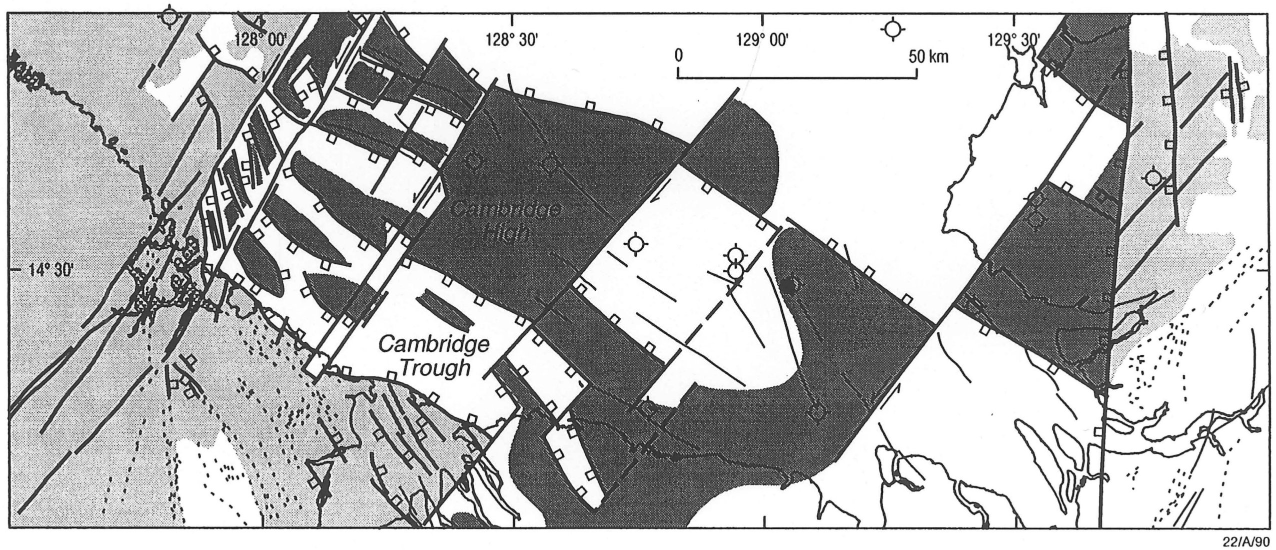
SOUTHERN JOSEPH BONAPARTE GULF
WESTERN AUSTRALIA / NORTHERN TERRITORY

SD52-10 / SD52-11
FIRST EDITION 1995

AGSO 22-1/SPECIAL/21

Figure 18

Interpretation summary



Shallow magnetic basement containing Proterozoic basic igneous sills/volcanics

Interpreted position of deep Proterozoic basic igneous sills/volcanics

Quartz basalt outcrop

Normal fault

Transfer fault

Possible intra-sedimentary fault

Faults interpreted from magnetic data

Mapped onshore fault