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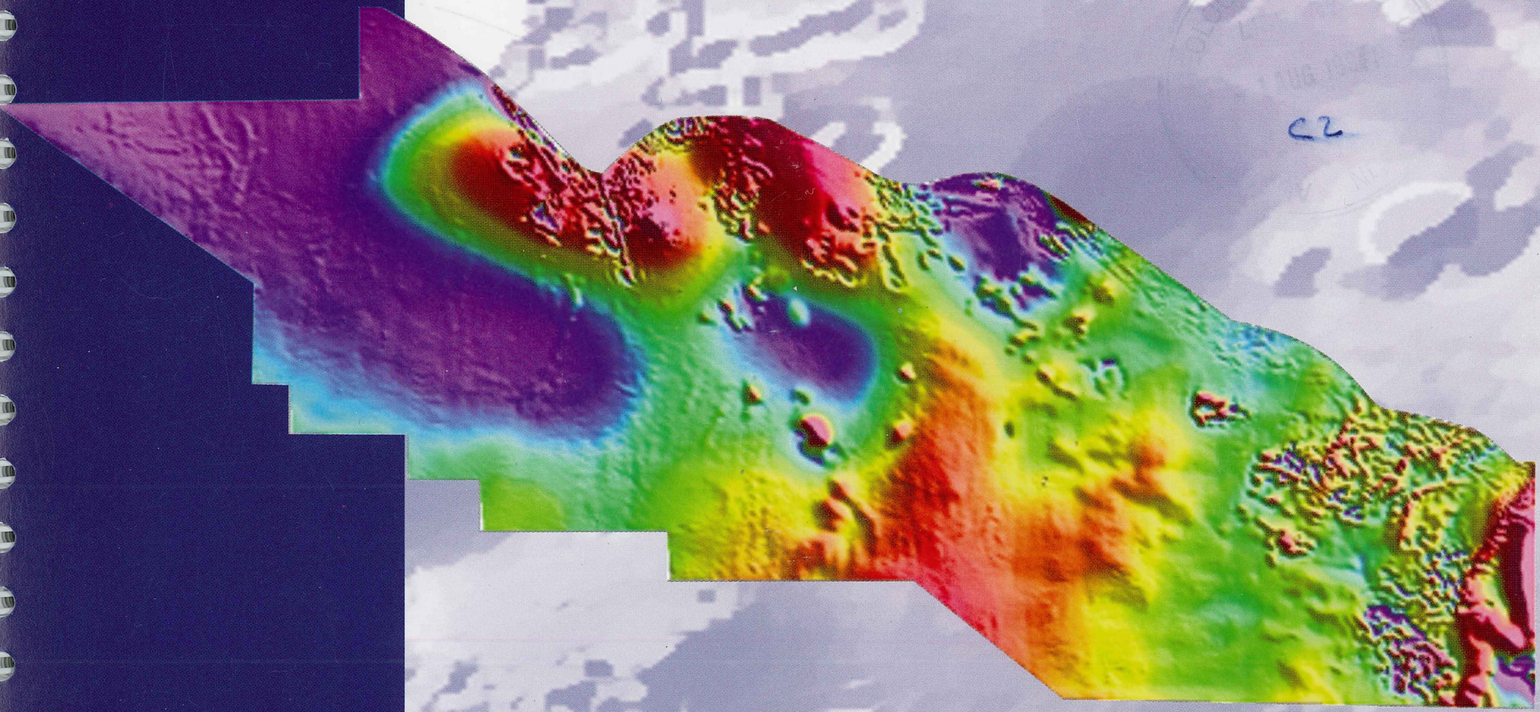
Offshore Otway Basin Aeromagnetic Interpretation



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P.J Gunn, T.E.Mackey, J.N. Mitchell

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OFFSHORE OTWAY BASIN AEROMAGNETIC INTERPRETATION

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DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

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Australian Geological Survey Organisation

Victorian Department of Natural Resources and Environment

Department of Mines and Energy, South Australia

BHP Petroleum

Bridge Oil

Mobil Exploration and Producing

Cultus Petroleum

SUMMARY

A detailed high sensitivity aeromagnetic survey flown with 500 m flightline spacings over the offshore Otway Basin between Cape Otway and the southeastern offshore portion of the basin in South Australia has provided considerable information on the distribution of structural elements and igneous features in the basin.

The Victorian portion of the offshore Otway Basin contains a broad irregular shaped area of relatively high magnetic intensity, which has been identified as originating from a sheet-like magnetic body occurring between depths of 2 and 10 km. It is thought that this unit is a large basic sill or extensive basalt flow. It is likely that it correlates with volcanic units in the Late Jurassic Casterton beds or with the Jurassic dolerite sills in Tasmania. It may also be a previously unknown volcanic unit within the volcaniclastic Eumerella Formation. Whatever its origin, this magnetic marker at the base of the Otway basin sequence greatly aids a structural analysis of the region because all of the deeper faults in the region which affect this magnetic marker have magnetic expressions.

The geometry of the deep magnetic sheet appears to reflect the extensional mechanism of the basin. This is particularly evident in "reduced to the pole" images of the magnetic data which remove asymmetry's due to the inclination of the earth's magnetic field and effectively adjusts magnetic anomalies to be vertically above their magnetic sources. Such an image shows sharp rectangular boundaries to the deep magnetic sheet which can be interpreted to indicate that after its initial formation the sheet was fractured by southwestward extension accommodated by a series of transfer faults trending at 210 degrees.

Many of the transfer faults are evident as narrow elongate weak linear magnetic features. Modelling suggests that such magnetic expressions of the transfer faults are due to a combination of magnetic material in the fault planes plus magnetic material deposited in channel systems, which appear to have developed along the transfer faults. Present day canyons developed along the continental slope align with the transfer faults. Linear features in detailed gravity surveys, as well as major gravity lineaments in gravity images of the southeastern continental margin derived from Geosat data confirm the trend direction of the transfer faults. The transfer faults can also be recognised in seismic data.

In the western portion of the survey area the extensional process has created two major "voids" or gaps in the magnetic sheet which are evident as major magnetic lows. These lows overlie depocentres known as the Eastern and Western Voluta Troughs and it thus appears that these troughs were formed by the same extensional episode that fragmented the magnetic sheet. The magnetic data appear to be giving an excellent image of the initial geometries of these troughs. Extension in the extreme eastern portion of the study area appears to have been more diffuse, however smaller equivalents of the Voluta Troughs are suggested by the magnetic data to exist southeast of Mussel 1 and in the vicinity of Eric the Red 1. An unfractured segment of the basal magnetic sheet, broadly corresponding in position to the Mussel Platform, occurs in the centre of the study area.

The 210 degree transfer fault direction can be recognised throughout the survey area, however, in the east the displacement along these faults appears to be relatively minor.

The magnetic data show evidence of features arising from a continuation of the onshore north-south trending Palaeozoic rocks beneath the Otway Basin. These manifest themselves as a series of subtle weak linear magnetic features trending in a direction of approximately 165 degrees. The lineaments appear to arise from faulting both in the magnetic sheet and the overlying sediments and are probably due to reactivations of deeper Palaeozoic faults. It is noted that the direction of these lineaments corresponds to the transform fault direction of the ultimate and actual splitting of the Australian and Antarctic continents which appears to have developed after an initial spreading in the 210 degree direction.

The magnetic data also shows a series of magnetic lineaments which are parallel to the present day continental margin. These are considered to result from down-to-the- basin listric and normal faults within the sedimentary section. A concentration of tilted block structures, bound by such faults, appears to occur in the southeastern sector of the survey area.

The 165 degree trending faults and the 230 degree trending faults appear to block out domains in which the structural style is relatively consistent and sometimes distinctly different from the structural style in adjacent domains.

The above structural picture remains consistent as far east as Cape Otway where a shallow ridge of basic rocks marks the boundary between the Otway Basin and the Torquay Embayment. This ridge may be a shallow portion of the basal magnetic sheet.

The magnetic data enable an excellent delineation of the distribution of Tertiary and Recent volcanics and igneous centres. Computer modelling allows a depth discrimination between the so called "Older Volcanics" of Palaeocene age and the "Newer Volcanics" of Neogene age. The igneous centres frequently occur on or adjacent to faults with the 230 degree and 165 degree directions. Many igneous centres appear to be at intersections of such faults.

The magnetic data also appear to be mapping depositional systems such as channels and barrier bar type sediments. The channels appear as forked images typical of drainage systems and tend to be focussed along the transfer fault zones. Modelling indicates that these features have depths of approximately 500 m. Their magnetic responses appears to arise from detrital magnetic minerals eroded from the Tertiary igneous material. A series of confused and irregular magnetic responses which have similar amplitudes to the channel systems and which parallel the continental slope at approximately the level where the dendritic nature of each of the channel systems changes to more linear character could possibly mark some type of strand line system such as an assemblage of barrier bars. The channels and bar systems are concentrated in the west of the survey area.

CONTENTS

LIST OF FIGURES

1. INTRODUCTION

This report presents an interpretation of high sensitivity, detailed aeromagnetic data over the offshore Otway Basin of southeastern Australia. These data resulted from a 44 379 km aeromagnetic survey flown by Kevron Geophysics Pty. Ltd. between 9 May and June 28 1994 on behalf of the Australian Geological Survey Organisation (AGSO), the Victorian Department of Natural Resources and Environment, the Department of Mines and Energy, South Australia and a consortium of exploration companies consisting of BHP Petroleum, Bridge Oil, Mobil Exploration and Producing and Cultus Petroleum. The location of the aeromagnetic survey is shown in Figure 1.

The objectives of the survey were to delineate structural, sedimentary and igneous features in the basin and to produce an interpretation relating the results to the evolution of the basin and its hydrocarbon prospectivity.

The project was managed by AGSO on behalf of the other participants AGSO's role has been to design the survey, let tenders for the data acquisition, and to supervise the data acquisition and processing through to the stage of located, levelled data. AGSO subsequently gridded the data received from the contractor and produced various map, image and interpretation products which were integrated into an interpretation of the complete dataset.

Maps, images and interpretation products are included in this report at 1:1 000 000 scale. 1:250 000 versions of the key hardcopy products available for sale via the AGSO Sales Centre.

2. GENERAL REVIEW OF THE GEOLOGY OF THE OTWAY BASIN AND THE SURVEY OBJECTIVES

As outlined recently by O'Brien *et al.* (1994), the Otway Basin, located on the south-eastern Australian margin, has been an area of active hydrocarbon exploration since the late 1950's. In fact, the western onshore Otway Basin was the site of Australia's first oil well, which was drilled in 1866 at Alfred Flat, near the Coorong in South Australia (Sprigg, 1986). In spite of this activity, success within the basin has been relatively limited. In the onshore Otway Basin, sub-commercial gas was encountered in Port Campbell 1 (Victoria) in 1959, while in 1967 a small commercial carbon dioxide (C02) discovery was made in South Australia at Caroline 1 (Mulready, 1977). More recently, exploration resulted in the discovery of commercial gas accumulations at North Paaratte (1979), Katnook (1987) and Ladbrook Grove (1989; see Parker, 1992), and Iona (1988; see Miyazaki *et al.*, 1990).

In the offshore basin, the only significant hydrocarbon show recorded between 1967 and 1993 was in Pecten IA, which flowed about 90 000 cubic feet of gas per day. However, a recent upsurge in offshore exploration activity has been rewarded by two large gas discoveries in early 1993 namely the Minerva and La Bella accumulations off Port Campbell in western Victoria.

These recent discoveries, as well as previous finds in the onshore basin, have established the Otway Basin as a potential major gas province and have ensured the continuance of high levels of exploration activity.

The Otway Basin extends along the southern coast of Australia for 500 km, from Cape Jaffa in the northwest to the Mornington Pensile in the east, and as far south as King Island. It has an average width of 200 km including the continental slope. The onshore basin and the continental shelf part of the offshore Basin make up about half its area.

As outlined by O'Brien *et al.* (1994), the Otway Basin initially developed along Australia's southern margin in the Late Jurassic to Early Cretaceous as part of the Bassian rift system that formed in response to rifting between Australia and Antarctica, and continued eastwards into the Bass and Gippsland Basins. Its major structural components are outlined in Figure 2. The basin west of the Torquay sub-basin has a fill of more than 10 km of sediments in places. The axes of the depocentres tend to parallel the present coastline but have moved around over time (Megallaa, 1986). The Early Cretaceous depocentres were in the inner Voluta Trough and westward of the Sorell Fault, beneath the outer part of the present shelf; the Late Cretaceous depocentre was about 50 km further offshore, beneath water now 1000-2500 m deep; and the Tertiary depocentre lies inshore, beneath the present shelf. The nature of the tectonic processes that formed this rifted system, dominated by steeply dipping northwesterly trending faults, are still uncertain. One view is that the basin is essentially extensional, and the other is that it is essentially strike-slip.

Etheridge *et al.* (1985, 1987) proposed that the Bassian rift was produced by NNE-SSW lithospheric extension, largely during the Early Cretaceous. This extension led to the extensional faults and orthogonal, steeply-dipping, transfer or accommodation faults. In this scenario, the tectonic evolution proceeded smoothly from rift initiation, to active rifting and finally to sea-floor spreading and associated post-rift subsidence. In their model, this basic architecture was reactivated during the Tertiary by compressive stresses.

More recently, Willcox and Stagg (1990) discussed the evolution of the Great Australian Bight basins. Whilst their study did not deal directly with the Otway Basin, it has potentially profound implications for understanding its tectonic development. They proposed that the initial rifting between Australia and Antarctica, which led to the formation of the Bassian Rift system, was more complex than proposed by Etheridge *et al.* (1985, 1987). They suggested that the development of the rift system in the Bight took place in two distinct stages.

During the first stage, which spanned the Late Jurassic to Early Cretaceous (ca.153-122 Ma), the margin was extended by about 300 km; the extensional transport direction was NW-SE, oblique to the ENE-SSW orientation proposed by Etheridge *et al.* (1985, 1987). Extrapolation of this stress regime to the southeastern Australian margin suggests that the Otway Basin lay within a regime of left-lateral strike-slip in this period, and thus that extension may have been oblique. Etheridge *et al.* (1989) supported the idea of such an extensional transport direction in the Bight basins.

A second phase of tectonism may have occurred in the Early Cretaceous (ca. 122-100 Ma), and would have consisted of only 120 km of extension along a NNE-SSW azimuth, identical to that proposed by Etheridge *et al.* (1985, 1987), and consistent with the normal fault directions which now dominate the Otway Basin (WNW-ESE). In this model the second extension event in the Otway Basin was oblique to the earlier event but would have led to major reactivation of older structures.

However, most recently, Willcox et al. (1992) interpreted deep seismic data from the Gippsland Basin, and suggested that it is of similar age and origin to the Great Australian Bight basins (Late Jurassic-Early Cretaceous), and that it formed over a deep detachment by left-lateral NW-SE oblique extension.

It is obvious from these varying opinions that the structure and origin of the Otway Basin is still being disputed. Despite the uncertainties surrounding the early rift tectonics, it appears that continental break-up (i.e. the initiation of seafloor spreading) took place off the Otway Basin at about 96 Ma (Veevers, 1990; Veevers *et al.*, 1991) and a general sequence for its stratigraphic development can be outlined.

The history of the Otway Basin reflects the rift-to-drift transition discussed above. Onshore, the basin consists of a series of predominantly southeast-trending Early Cretaceous troughs or half-grabens separated by basement highs. Offshore, the basin can be subdivided into three distinct structural provinces: the Crayfish Platform in the west, the Voluta Trough (western and eastern), and the Mussel Platform in the east. These three structural provinces have existed since at least the beginning of the Late Cretaceous, and have closely controlled the sedimentary facies developed throughout the basin.

A stratigraphic column for the Otway Basin is illustrated in Figure 3. The oldest sediments known from the Otway Basin belong to the Casterton Group, a latest Jurassic/Early Cretaceous sequence of interbedded non-marine siltstones, mudstones, minor coals and volcanics (Wopfner *et al.*, 1971; Dettmann and Douglas, 1976). Lacustrine sediments with good source rock potential have also been reported from this unit (Knopsen and Scholefield, 1990). The Casterton Group is only known from the onshore part of the basin.

Overlying the Casterton Group is the Early Cretaceous Crayfish Group, principally high energy fluviatile sands. The Crayfish Group appears to be particularly thick in the western Otway Basin, with over 1500m drilled in the Crayfish Platform, and up to 4700 m in the onshore Robe Trough. A brief period of block faulting and erosion appears to have ended deposition of the group at about 120 Ma., when it was extensively faulted, particularly on the Crayfish Platform (Williamson *et al.*, 1987, 1988, 1990). Deposition of the group may well have been controlled by the initial oblique separation of Australia and Antarctica, and the faulting at 120 Ma may be related to the change in extensional direction from NW-SE to NNE-SSW in the basins flanking the Otway Basin.

Deposition of the Eumeralla Group commenced in the Early Cretaceous (ca. 117 Ma), and it largely blanketed the underlying Crayfish Group. It consists of shales and claystones, with minor coals, argillaceous sands and sandstones. Volcanogenic detritus is common offshore.

Early Cretaceous sedimentation ended with a mid-Cretaceous period of block faulting, differential uplift, and erosion (100-95 Ma), which was probably related to continental breakup and the initiation of seafloor spreading. Offshore, the basin became subdivided into the slowly subsiding Crayfish and Mussel Platforms, and the rapidly subsiding western and Eastern Voluta Trough. Deposition of the Late Cretaceous Sherbrook Group commenced in the Cenomanian. The margin continued to subside throughout the Tertiary, with detrital sedimentation giving way to widespread carbonate deposition in the Neogene.

Volcanic rocks form numerous magnetic anomalies, and occur in two distinct phases in the Otway Basin (Megallaa, 1986). The "Older Volcanics" are Palaeocene, whereas the extensive basaltic "Newer Volcanics" in central and western Victoria are Neogene.

Prior to 1992 the only aeromagnetic coverage of the offshore Otway Basin in Victoria consisted low sensitivity surveys with flight line spacings greater than or equal to 1.5 km. These surveys consisted of the Bass Strait Encounter Bay Survey (BMR, 1965), Otway Basin Survey (Shell, 1970), Portland 1:250 000 Sheet (BMR, 1989a) and the Colac 1:250 000 Sheet (BMR, 1989b).

In order to assist the on-going exploration effort in the western Otway Basin, and to fill in a gap in the national aeromagnetic coverage, AGSO acquired 14,200 km of high resolution aeromagnetic data in November and December 1992 (O'Brien *et. al.*, 1994). These data were collected in the South Australian portion of the Otway Basin, mostly over the onshore Penola 1:250 000 Sheet area, but extending offshore to the 1000 m isobath. These results, although acquired at the relatively wide line spacing of 1.6 km provided confirmation of the applicability of aeromagnetic data to the resolution of basement and intra-sedimentary features as well as the mapping of igneous material in the Otway Basin.

The results of the new survey flown with a flightline spacing of 500 m provide a set of continuous high resolution images of a large portion of the offshore basin. The results of previous high sensitivity surveys in the Otway Basin area and elsewhere indicate that interpretations of the data could be capable of indicating:

- the depth and structure of pre-Mesozoic basement under the basin
- the outlines and depths of Mesozoic and Cainozoic volcanics and intrusives
- a detailed definition of intra-sedimentary fault systems
- palaeodrainage systems containing magnetic minerals
  major basement faults and trends which typically control the position and orientation of transfer faults and
- basement lithologies.

The identification and mapping of the above features together with a synthesis of the results with relevant geological, drill, seismic, gravity and bathymetric data to assist with the assessment of the hydrocarbon prospectivity of the area is the prime objective of the current survey.

3. SURVEY DETAILS

Survey location:	see Figure 1
Survey duration:	9 May - 28 June 1994
Kilometres flown:	44 379 km
Survey design:	AGSO
Contract:	specification and supervision by AGSO
Contractor:	Kevron Geophysics Pty. Ltd.
Flightline direction:	north-south
Flightline spacing:	500 m
Tieline direction:	east-west
Tieline spacing:	5 km
Flight height:	130 m above sea and above land
Magnetometer:	0.01 nT resolution
Sample interval:	8 m
Navigation:	GPS (better than lO m)
Processing:	contractor produced levelled, located data with IGRF removed AGSO gridded data to 100 m grid and produced contours and images
Interpretation:	performed by AGSO

A logistics report of the survey has been provided by Kevron Geophysics (1994). In general the field acquisition of the data was satisfactory although the contractor had to abort 14 days of operations due to high winds which were abnormal even for the offshore Otway Basin during May-June. This delayed survey production. The contractor was unacceptably slow in delivering the processed data which eventually arrived on 23 July, effectively five weeks after completion of flying. This was despite a contract clause specifying delivery within 3 weeks of completion of flying and repeated requests to the contractor to fulfil this condition. This late delivery combined with the delays due to weather have retarded AGSO's delivery of interpretation products.

The main operational problem however, which was outside the contractors control, originated from magnetic noise due to the magnetic fields resulting from the movement of conductive seawater in oceanic swell moving through the Earth's magnetic field. Although some geophysicists still dispute the existence of such effects, their existence is well documented in research literature. The theory of this effect has been fully described by Weaver (1965) and field confirmation of the magnitude of the effects predicted by Weaver have been observed by Ochadlick (1989). Ochadlick demonstrates that a 3.3 metre swell with a period of 12 seconds can generate an effect of 0.08 nanotesla 100 metres above the ocean. More recently Heath et al. (1993) report noise due to 2-4 m oceanic swells having amplitudes of +/- 0.8 nanotesla at 100 m above sea surface in the offshore Perth Basin. This noise was observed to have a wave length of approximately 500 m and to exhibit a frequency shift depending on the flying direction relative to the direction of advancement of the oceanic swell.

As a check on the existence of oceanic swell in the offshore Otway Basin data from the AGSO 1992 aeromagnetic survey which covered both the onshore and offshore Otway basin in South Australia (Reeves *et al.*, 1993) was examined. These data were acquired with a surface clearance of 80 m and contain a semiperiodic noise exhibiting an amplitude of approximately +/- 0.25 nT. The wavelength averages approximately 500 m and is shorter when the flight direction was towards the oncoming waves. The phenomenon disappears for the onshore portions of the flightlines. These results appear to confirm the existence of swell noise in the offshore Otway Basin. These survey data were acquired during early December when swell conditions are probably quieter than the May-June period of the current survey.

At the commencement of the current survey the swell phenomenon was checked by flying the same lines both into and with the swell direction at altitudes of 100, 130 and 150 m. Periodic noise was observed with wavelengths of 500 m when flying into the swell and 700 m when flying with the swell. At 100 m the amplitude of the wave noise approximated +/- 0.8 nT, at 130 m it approximated +/- 0.2 nT and at 150 m it approximated +/- 0.1 nT. This drop off in amplitude accords well with the predictive theory of Weaver (1965).

As a compromise between flying the survey as low as possible to enhance the responses of magnetic sources and as high as possible to minimise swell noise a survey altitude of 130 m was selected for the survey. A justification for this decision is that the real noise level of most aeromagnetic acquisition systems is +/- 0.2 nT which is the noise level observed at 130 m.

The observed swell noise for the entire survey was generally less than +/- 0.2 nT and on many flights was not evident. However on some flights in rougher weather it did slightly exceed the +/- 0.2 nT level.

The periodic nature of the swell noise and the fact that its short wavelength differs markedly from the magnetic responses of anomalous sources within the sedimentary section simplifies its removal from the data. The swell noise was removed by the application of a high cut filter. Checking of the filtered results indicated that the filtering process was not removing features that could be considered as "geological signal".

4. INTERPRETATION METHODOLOGY

4.1 Data Verification

Field acquisition of the data was checked by on site visits of AGSO staff to verify that the acquisition procedures conformed to tender specifications. The basic processed data provided by the acquisition contractor consisted of located, levelled, total magnetic intensity data with the Earth's main magnetic field (IGRF) removed. The contractor provided stacked profiles of the results together with an image of the data as evidence of quality control procedures. After this the data were quality controlled by inspecting the profile values for noise and gridded using AGSO proprietary software. The gridded dataset was imaged to confirm that levelling routines involving removal of the magnetic diurnal and adjustment between flightlines and tie lines had been correctly performed.

4.2 Creation of Interpretation Products

After AGSO was satisfied with the standard of the delivered product, production of final interpretation quality products commenced. These consisted of:

- a 100 m grid of the total magnetic intensity produced using the AGSO minimum curvature routine (Briggs, 1974) which is incorporated in the AGSO in-house **INTREPID** system for processing aeromagnetic data.

- a 1:250 000 contour map of the total magnetic intensity produced using the in-house **INTREPID** contouring routine.

- a **MAPINFO** GIS of the relevant geographic information such as coastlines, permit boundaries, bathymetry, and well locations for overlay where appropriate on the various map and image products generated.

In order to facilitate the quantitative 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** and output using a **Novajet** colour plotter and an **Oce** electrostatic plotter. These included:

- colour image of the total magnetic intensity with northeast gradient
- reduction to the pole of the total magnetic intensity (colour image) to eliminate the effects of the inclination of the earth's magnetic field (i.e. to relocate anomalies to positions directly above their sources).
- calculated the first vertical gradient (contour map and colour image) of the total magnetic intensity in order to remove the effects if the deeper anomalies and to enhance the imaging of more subtle intra-sedimentary features. This was done with both highpass convolution filters and Fast Fourier transformations.
- matched filtering based on an inspection of the computed logarithmic energy spectrum to give on optimal separation between magnetic sources at different depths.
- sun angle illuminated version of various images to enhance the visibility of features with different strike directions.
- colour and grey scale versions of the above together with combinations of images to maximise the process of information extraction.
- automatic gain control images that give equal emphasis to weak and strong magnetic markers.

The qualitative 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.

- 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.

All of the above products were examined to produce the composite interpretation map of Figure 4. It should be appreciated that no one map or image displays optimally all the features in magnetic data sets and any processing of magnetic data sets eventually results in a compromise in the number of images produced and the scales at which the maps and images ultimately produced. The maps and images that were found to display virtually all of the significant magnetic effects and which are included in this report are:

Figure 5	Total magnetic intensity contours 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 6	Total magnetic intensity colour image 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 7	Stacked profiles of the magnetic data 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 8	Reduction to the pole of the total magnetic intensity 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 9	Bathymetric contours superimposed on total magnetic intensity 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 10	Computed vertical gradient contours 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 11	Colour image of computed vertical gradient with northeast illumination 1:1 000 000 scale (hard copy at 1:250 000 available)
Figure 13	High pass matched filter image 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 14	Lowpass matched filter image 1:1 000 000 scale (hard copy at 1:250 000 available through Sales Centre)
Figure 15	Regional gravity image
Figure 16	Euler deconvolution used to map magnetic source outlines 1:1 000 000 scale

4.3 Otway Basin Aeromagnetic Project Team Members

The AGSO personnel who have contributed to the Offshore Otway Basin Aeromagnetic Project and their responsibilities were:

Project Leader:	Dr Peter Gunn
Co-Project Leader:	Dr Geoff O'Brien

Survey Design and Contract Specification:	Ian Hone, Ivan Zadoroznyj
Field Supervision:	Murray Richardson, Ivan Zadoroznyj
Data Checking:	Tim Mackey
Processing and Imaging:	Tim Mackey, Dr Peter Milligan
Computer Modelling:	Jane Mitchell
Correlation with Seismic Data:	Donna Cathro
MapInfo Database:	Frank Simonis
Interpretation Synthesis:	Peter Gunn assisted by other team members

5. INTERPRETATION

5.1 Interpretation Philosophy

Aeromagnetic interpretation consists of combining a visual analysis of various map and image products to identify the lateral positions of magnetic sources and any structures which affect these sources with quantitative modelling to determine the depths and shapes of these sources and a collation with other relevant information to produce a three dimensional geological explanation for the observed magnetic responses. Ideally the person performing such an interpretation has considerable knowledge of which rock types cause observable magnetic responses and how these responses can vary with the depth and geometry of the sources and also how they may vary according to the inclination of the earth's magnetic field in the study area. Aeromagnetic interpretation is thus a combination of the skills of imaging and modelling which are relatively quantitative processes with the qualitative conceptual processes of the interpreter.

The application of high resolution aeromagnetic surveys with close line spacing to the study of sedimentary basins has only recently been attempted and methodologies for interpreting such datasets have not been standardised. The following sections describe how various methods from the armoury of processing and interpretation techniques have been applied in the study area. Each technique has aided the extraction of information from the data set. Figure 4 illustrates a synthesis of all the features interpreted.

5.2 Inspection of the Total Magnetic Intensity Contours and Images

A line contour map of the total magnetic intensity, as recorded, and after the appropriate compilation techniques were applied, has been produced (Figure 5). Such maps were traditionally the standard products for aeromagnetic surveys but they have been largely superseded by colour images. Contour maps still have the advantage that they can be used to obtain precise magnitude values of the field; they also give a clearer depiction of contour gradients which are sometimes necessary to estimate the depth and forms of magnetic sources.

The colour total magnetic intensity image of the survey data (Figure 6) however is a much more useful product for a visual impression of the survey data. The colour representation allows immediate recognition of relative highs and lows. The example shown has had various sun angle illuminations applied which by virtue of the "shadows" created emphasise the more subtle magnetic features.

A stacked profile representation of the magnetic data set is shown in Figure 7. This provides a good representation of the relative anomaly strengths.

While images of the total magnetic intensity have been used in the interpretation process it must be appreciated that because the Earth' s magnetic field is inclined at 65 degrees, in the survey area, an asymmetry has been induced into the magnetic image which causes an offset of the magnetic anomalies from their sources. A transformation process called "reduction to the pole", which can correct for this, has been applied to the dataset and this reduced to the pole image has been used for the main regional analysis of the dataset. It must however be mentioned that a slight risk exists with the application of the 'reduction to the pole' technique because, if a rock unit has a significant component of permanent magnetisation in a direction other than that of the Earth's field then, the results can be misleading. The probability of this occurring are generally low and can in many cases be recognised. Such effects do not appear to be significant in the 'reduced to the pole' version of the Otway Basin dataset.

5.3 Interpretation of the 'Reduced to the Pole' Image

The most striking feature of the entire reduction to the pole image (Figure 8) is the intense irregular shaped semi-contiguous magnetic high which covers the central two thirds of the survey area. The source of this anomaly has been interpreted as a sheet-like igneous body emplaced as a sill or as a basalt flow. A primary reason for this identification is that the anomaly has no obvious gravity expression either on regional AGSO data sets or on a detailed gravity survey recorded along seismic lines in 1980 by GSI in Permit VIC P14 which occupies the same area as Blocks V94-1 and V94-2 (AGSO has only been able to obtain a paper copy of these results). The lack of a gravity high discounts the likelihood of this magnetic anomaly having an intra-basement or a stock like intrusion source. Magnetic modelling results presented in Appendix 1 for Profiles B - M indicate that the anomaly can be explained by a sheet-like source at a depths varying from 2 - 10 km. Such depths suggests that the igneous mass occurs at the base of the Otway Basin sequence and may correlate with the Jurassic volcanics in the Casterton Beds and the Jurassic dolerites of Tasmania both of which appear to be associated with the initial stages of extension which led to the separation of the Australian and Antarctic continents. The magnetic sheet could also occur in the Eumerella Formation which is known to have a significant volcaniclastic component. The irregular outlines of the magnetic anomaly associated with the sheet are consistent with it being a sill or basalt flow.

Whatever its origin, this magnetic sheet, which occurs at or near the base of the Otway Basin sedimentary sequence, provides magnetic anomalies associated with all faults which have affected this portion of the section. This phenomenon significantly aids the structural analysis of the region. The interpreted outlines of the sheet are shown on the interpretation map of Figure 4.

The geometry of the deep magnetic sheet appears to reflect the extensional mechanism of the basin. Rectangular boundaries on the western side of the magnetic sheet are interpreted to indicate that, after its initial formation, the sheet was fractured into fragments by southwestward extension accommodated by a series of transfer faults trending at approximately 210 degrees.

Many of the transfer faults are evident as narrow, elongate weak linear positively magnetic features. Most of these are visible to varying degrees in the reduction to the pole image but are even more obvious in the various derivative and high frequency images described below. Modelling (Appendix 1) suggests that the magnetic expression of the transfer faults is due to magnetic material in the fault planes plus magnetic material deposited in channel systems which appear to have developed along the transfer faults. The tops of these "magnetic" channels model at about 400 - 500 m below sea level. Present day canyons developed along the continental slope which are evident in bathymetric contours (Figure 9), align with the transfer faults suggesting that they have a topographic expression. Weak linear trends in the GSI gravity results of VIC P14 correlate with the interpreted positions of the transfer faults. Major lineaments in gravity images of the southeastern continental margin derived from satellite Geosat data (Finlayson et al.,1994) and shown in Figure 3 confirm the trend direction of the transfer faults and may actually be continuations of the same features.

In the western half of the study area the extensional process has created two major "voids" in the magnetic sheet which are evident as major magnetic lows. These lows overlie depocentres known as the Eastern and Western Voluta Troughs. It appears that these troughs were formed by the same extensional process that fragmented the magnetic sheet. The magnetic data appear to be giving an excellent image of these troughs. The magnetic sheet in the northern portions of Block V94-2 has a sharp southern edge consisting of two segments each of which parallels the present day continental slope. These boundaries probably mark normal faults, where the magnetic sheet ruptured in a direction normal to the transfer faults in order to be able to accommodate the southwestern extension.

The continuation of the magnetic sheet into the eastern extremities of the study area is obscured by the magnetic effects of shallow Tertiary volcanics. "Stripping" of these magnetic effects to reveal deeper structures has been achieved by means of a matched filtering process described in Section 5.5. The interpretation of the probable eastward continuation of the magnetic sheet is discussed in Section 5.5.

The semi-continuous extension of the magnetic sheet over the eastern half of the study area is broadly coincident with the Mussel Platform as depicted in Figure 2. It is possible that the unfragmented portions of the magnetic sheet outline a relatively stable platform area which has undergone less subsidence than adjacent areas.

The 'reduction to the pole' image also gives an excellent representation of the distribution of igneous intrusives and lava flows. These are also well imaged on the various derivative maps and highpass image products discussed below. The computer modelling presented in Appendix 1 gives the depths and forms many of the intrusives.

The most intense anomaly of the entire survey area which occurs on the headland south east of Portland is due to the Portland Aluminium Refinery.

5.4 Interpretation of "High Pass" Images

While the total magnetic intensity and 'reduction to the pole' images give an excellent picture of the main magnetic units in the survey area, the more intense and larger magnetic features in these images obscure weaker but nevertheless significant detail. The low amplitude anomalies can be enhanced by illuminating these images with a variety of sun angles, each of which enhance weak features with different trends. This process however is not guaranteed to reveal all significant detail and it is normally advisable to apply some type of highpass filtering which suppresses regional trends and enhances narrower, more subtle, magnetic lineaments.

The following images of this variety were produced:

- first vertical derivative (greyscale and colour) with and without southwest and southeast illumination

- second vertical derivative (greyscale) with and without southwest and southeast illumination

- automatic gain control of the first and second vertical gradients

- highpass convolution filter (greyscale) with and without southwest illumination. The response of this filter is similar to that used to produce the vertical gradient image.

- automatic gain control of the highpass convolution filter

- highpass results of a matched filtering process (described in Section 5.5)

Most of these images were produced as hard copy although some were simply inspected with the **ER Mapper** viewer. To a large extent all images contain the same information although different images show some features more clearly than others. Figure 11 which shows the colour vertical gradient results illuminated from the northeast contains most of the detail of the other images. The following interpretations are based on a visual assessment of all of the above images including those of the total magnetic intensity and the reduction to the pole. It is important to appreciate that while the images show subtle features the sun angle illumination process used to create the majority of the images tends to give a false indication of the positions of anomaly peaks and gives virtually no indication of true contour gradients that indicate depths and body edges. For this reason care has been taken to examine the contour representations of the total magnetic intensity and computed vertical gradient when interpreting the geological sources of the various magnetic effects.

No magnetic features can be identified as obviously arising from a continuation at depth of the onshore north trending Palaeozoic rocks beneath Blocks V94- 1 and V94-2 however a series of subtle weak linear magnetic features are evident trending in a direction of approximately 165 degrees. These lineations are probably not optimally imaged because of their acute angle relative to the north south flight line direction. They nevertheless definitely exist and appear over extensive portions of the entire survey area. These lineaments appear to arise from faulting both in the magnetic sheet and the overlying sediments. These features are most likely reactivations of deeper Palaeozoic faults. It is noted that the direction of these lineaments corresponds to the direction of the ultimate and actual, splitting direction of the Australian and Antarctic continents as is clearly illustrated in Figure 3 of Finlayson et al. (1994). This 165 degree direction appears to have developed after an initial spreading in the 210 degree direction. It is possible that the 165 degree fault direction is a propagation of the later more southerly transform direction combined with a reactivation of Paleozoic faults.

Many igneous centres occur on the intersection of faults with the 210 degree and 165 degree directions.

The magnetic images also contain a series of extremely weak magnetic lineaments which are parallel to the present day continental margin. These are considered to result from down-to-the basin normal and listric faults within the sedimentary section. Many such faults are dislocated by the transfer fault zones and this is further evidence of the compartmentalisation of the area by the transfer faults. It is not clear if these intra-sedimentary faults arise from magnetic minerals in fault planes or from the effects of faults cutting magnetic layers. The assemblage of intra-sedimentary faults which parallel the continental margin are probably best interpreted in detail by correlations with seismic data using large scale images. It is possible that superposition of the effects of the same fault at different levels are actually being imaged. AGSO has completed a separate report which uses the seismic from this study area in an attempt to calibrate these responses (Cathro, 1995). It has been shown that some faults do produce distinct magnetic responses although many faults do not appear to be associated with any observable magnetic effect.

All magnetic responses arising from faults within the sedimentary section appear to be extremely weak unless enhanced by faulting of magnetic units within the sediment section or infill of magnetic material in channels following fault planes.

Intense faulting parallel to the continental margin appears to be clearly indicated in the magnetic data in the eastern half of the study area, particularly so in the immediate vicinity of La Bella 1. The total magnetic intensity contours and image (Figures 5 and 6), the vertical gradient contours and images (Figures 10 and 11) and the high pass matched filter image (Figure 13) all show a series of magnetic ridges trending at approximately 130 degrees. These magnetic ridges have been interpreted as arising from faulting in the magnetic sheet occurring at the base of the sediment section. This qualitative interpretation on the source of these anomalies is supported by computer modelling on Profiles 20, 22, 28, 30 and 35 (Appendix 1). It appears that significant oceanward extension has fractured the magnetic sheet (and most probably a large part of the overlying sedimentary section) to create a series of rotated fault blocks with major bounding faults on their southwestern sides.

A transfer fault zone has been interpreted to occur immediately to the east of La Bella 1 and Mussel 1. The existence of this zone is more conjectural than the transfer zones evident in the west of the study area. Its existence has been inferred from alignments of linear discontinuities having the same trend direction as the transfer faults in the west. The extension to the east of La Bella 1 appears to be more diffuse than that which has apparently occurred in the Eastern and Western Voluta Troughs. Instead of being accommodated by a small number of major faults in the 210 and 130 degree directions the extension east of La Bella 1 appears to have produced numerous faults of limited strike length having these directions. This process appears to have fragmented the magnetic sheet into numerous tilted blocks trending at 130 degrees. The extension appears to have progressed to such a degree in two areas that slices of the magnetic sheet may be separated by several kilometres. These two areas (shown on Figure 4) are located to the southeast of Mussel 1 and in the vicinity of Loch Ard 1. It appears likely that localised extension in these areas has produced localised subsidence relative to adjacent areas. These two areas may be localised depocentres which are in effect less developed versions of the Eastern and Western Voluta Troughs. This interpretation is supported by the lowpass matched filter image of Figure 14 which suggests the absence of, or extreme thinning of, the magnetic sheet in these areas.

The extreme east of the study area, directly south of Cape Otway, contains an intense contorted magnetic ridge which modelling of Profiles W, X and Z shows to be explained by a steeply dipping magnetic sheet occurring at the relatively shallow depth of 2 km. The intensity of the anomaly suggests that its source is a basic rock unit. It is possible that this magnetic unit is a portion of that basal magnetic sheet which lies beneath so much of the study area. If this so there are two possible explanations for it occurring at a significantly shallower depth than elements of the sheet occurring immediately to the west. The magnetic unit immediately south of Cape Otway may be occurring at approximately the depth of its original emplacement. The depth of the more westerly magnetic sheet may merely reflect greater subsidence to the west of what was originally part of the same magnetic sheet. Alternatively the compressive inversion episode which caused the uplift of the Otway Ranges immediately to the north of Cape Otway may have also caused an uplift of the magnetic sheet to the south of Cape Otway.

The 165 degree trending faults and the 230 degree trending faults appear to block out domains in which the structural style is relatively consistent and .sometimes distinctly different from the structural style in adjacent domains. This is probably a reflection of the different competencies of the Palaeozoic basement rocks underlying each compartment and the different degrees of extension occurring between each pair of transfer faults.

The magnetic data also appear to be mapping depositional systems such as channels and barrier bar type sediments. This has been confirmed by correlations with seismic data (Cathro, 1995). The channels appear as forked images typical of drainage systems and tend to be focussed along the transfer fault zones. Magnetic modelling and depth estimates from seismic stacking velocities indicate that many of these features have depths of approximately 500 m. Their magnetic responses probably arise from detrital magnetic minerals eroded from the Tertiary igneous material. This phenomenon appears to be convincingly demonstrated by the channel system near the Bridgewater Bay 1 which appears to have its source at the volcanic sheet to the north. A series of confused and irregular magnetic responses which have similar amplitudes to the channel systems and which parallel the continental slope at approximately the level where the dendritic nature of each of the channel systems changes to more linear character could possibly mark some type of strand line system such as an assemblage of barrier bars. Tertiary barrier bars can be recognised in seismic data from the area (Cathro, 1995). These are best imaged in Figure 11. The anomalies due to the channels and "barrier bar" systems overly and in some cases obscure the weak responses due to the intra-sedimentary faults.

5.5 Interpretation of Matched Filtering Images

Matched filtering as applied to aeromagnetic data is the process of designing and applying filters to separate the magnetic effects of different magnetic markers by inspecting the frequency content of the logarithmic radial energy spectra of magnetic survey data. The theory of the method has been described by Spector and Grant (1970) and AGSO has been able to apply the process to the Otway Basin data by virtue of an algorithm in the Intrepid processing software. In very simple terms, magnetic markers at different depths are evident as straight line segments of logarithmic radial energy spectra and identification of these straight line segments enables the design of filters to separate the magnetic effects of the different markers. It should be appreciated that because of a general overlap in the frequency content of magnetic anomalies it is never possible to achieve a perfect separation. The method does however work reasonably well when the effects being separated arise from magnetic markers at significantly different depths. This the problem occurring in the Otway Basin data where the two main magnetic markers are the deep magnetic sheet and the near surface Tertiary volcanics. As is obvious in the total magnetic intensity image of Figure 6, the effects of the Tertiary volcanics obscure the deeper markers in many parts of the survey area, particularly in the eastem extremities. The logarithmic energy spectrum of the data which is shown in Figure 12 indicates both the deep and shallow sources whose effects are identified on Figure 12 by the two straight lines. The imaged results of the matched filtering process are shown in Figure 13 which shows a "highpass matched filter image" and Figure 14 which shows a "lowpass matched filter image".

The lowpass matched filter image portrays the magnetic data free from the magnetic effects of the Tertiary Basalts and localised structural relief on the top of the deep magnetic sheet. In effect Figure 14 shows a smoothed version of the distribution of the deep magnetic sheet. The Eastern and Western Voluta Troughs are well defined as is the extent of the magnetic sheet beneath the western extremity of the Mussel Platform. What is most significant about this image however is its indication that a fragmented continuation of the sheet extends to the eastern extremity of the study area. The image supports the existence of the depocentres southeast of Mussel 1 and in the vicinity of Loch Ard 1 that were postulated in Section 5.4. It is not immediately apparent if the magnetic lows northwest and northeast of Pecten 1 are the result of extensional processes or simply the natural termination of the magnetic sheet northwest and northeast of Pecten 1. Either possibility could mean that localised depocentres occur in these regions.

The highpass matched filter image shows the magnetic field components that have been subtracted from the total magnetic intensity to produce the lowpass matched filtered image. The highpass matched filtered image emphasises fine structural detail, in particular, structure on the top of the deep magnetic sheet and the distribution of the Tertiary igneous rocks. The process appears to be most successful in the eastern half of the study area where it images the 130 degree trending magnetic ridges interpreted in Section 5.4 as due to tilted fault blocks. A certain amount of low frequency response is visible in the west of the study area and this is probably due to the matched filtering method being unable to completely eliminate the large intense low frequency anomalies that occur in this area. This is probably a result of the relatively shallow depth of the magnetic sheet in this area causing its magnetic effects to contain a greater proportion of the frequencies associated with shallow markers. It is difficult to design a truly optimal matched filter over such a large area as the Otway Basin which contains such a variety of magnetic responses.

Figure 13 has clarified the existence of many features trending at 165 degrees. In accordance with the explanations given in Section 5.4 these are interpreted as due to a combination of deep Palaeozoic features or reactivations above zones of Palaeozoic weakness.

5.6 Interpretation of Gravity Images

Figure 15 is an image representation of the regional gravity field over the study area and adjacent regions. The pixel size of the image is 5 km. The onshore gravity results come from the AGSO database. The offshore gravity values were obtained by Geosat (Finlayson *et al.*, 1994). Although this is large scale data, it clearly shows the main tectonic framework of the area. Onshore, the northerly Palaeozoic trend is obvious. The study area is dominated by at least 5 linear features trending at 230 degrees. They correlate with interpreted positions of transfer faults and, by implication, are expressions of these transfer faults. The edge of the present day continental slope is marked by a major lineament trending at 130 degrees and a second parallel lineament several tens of kilometres to the southwest (marking the southern boundary of the purple area on the image) marks a major discontinuity to the south of which a series of major north south trending lineaments are obvious. The north south lineaments correspond to present day transform faults. This image appears to provide convincing evidence for an initial spreading of the Otway Basin in the 210 degree direction followed by an ultimate continental separation in the north south direction. Intriguingly, some of the 210 degree trends appear to continue into the southwestern corner of Figure 15. These may be relicts of earlier transform faults.

5.7 Automatic Depth Determination using the Euler Method

The in-house AGSO **INTREPID** software incorporates the Euler automatic depth determination algorithm (Reid et al., 1990) which, on the basis of simple assumptions such as approximating magnetic sources by assemblages of magnetic "poles", can produce credible estimates of magnetic source positions and depths. The results can be presented as a series of crosses where the centre of the circle denotes a body edge and the diameter of the circle corresponds to the source depth. Larger crosses denote larger depths. Figure 16 shows an example where the method was tuned to interpret "lines of magnetic poles". All circles of this process have been illustrated with the same diameter. This product is extremely useful for mapping trends, the outlines of magnetic sources and for locating faults. It also gives generalised, relative indications of depths. Experience has shown that the method does not give exactly the same body boundaries as modelling. The method can also give erroneous results when superposition of magnetic effects from different sources occurs.

5.8 Computer Modelling

ModelVision software has been used to model various magnetic features and there by provide a quantitative basis for the interpretation. **ModelVision** has the ability to access the gridded survey data stored in **ER Mapper** format and to select and model arbitrary profiles and local grids of the magnetic data. The locations of the profiles modelled are shown on Figure 17. The modelling results are presented in Appendix 1. It must be appreciated that in many cases virtually equally good model fits may be obtained to the observed data for a variety of model shapes. In other words magnetic modelling does not necessarily provide a correct and unique solution. Despite this incertitude the models do give good indications of likely explanations for the various anomalies modelled. The results of the modelling have been mentioned, where appropriate, in the previous sections.

5.9 Integration with Seismic Data

As far as the author is aware no detailed studies have been published which calibrate the subtle low amplitude magnetic responses arising from intra-sedimentary sources with actual features observable on high quality seismic reflection data. Such a study has been carried out as an adjunct to the aeromagnetic interpretation of the Otway Basin data. The study was restricted to using lines from the OP80 survey shot in 1980 over what are now Blocks V94-1 and V94-2. The lines actually used were reprocessed by GSI in 1986 and Geco Prakla in 1993. Convincing examples relating the magnetic and seismic responses of faults, channels, bars systems and igneous intrusions were identified. These have been referred to, where appropriate, in the previous sections. The results are presented in a separate report by Cathro (1995).

5.10 Interpretation Summary

The principal findings of this interpretation of the aeromagnetic results over the offshore Otway Basin are concisely presented in the Summary given at the beginning of this report. The actual positions of the interpreted features are shown on the interpretation may (Figure 4). The outlines of the interpreted features have in general been determined by subjective visual estimates. If precise outlines of the geometries of these features are required reference should be made to the detailed computer models included with this report or, where necessary, further computer modelling should be undertaken.

6. FUTURE PROGRAM

It should be appreciated that this interpretation was produced using 1:250 000 scale maps and images. Detailed interpretation for problems at exploration prospect scale require checking of the interpretations using primarily 1:100 000 scale of 1 50 000 scale datasets. AGSO considers that such work is the role of organisations with commercial interests in the study area. These organisations will most likely have access to ancillary information not available to AGSO and are thus likely to be better placed to do such detailed works.

The usefulness of the data could be significantly improved by estimating the depth of every single magnetic feature. This is impractical with modelling software such as **ModelVision** however it is possible with other software.

Noddy modelling software developed at Monash University which is capable of modelling the magnetic response of a folded and faulted magnetic sheet would be ideal for modelling the exact geometry of the basal magnetic sheet occurring in the study area. Such a project would probably require at least two months to achieve realistic results. AGSO has a copy of the Noddy software and may be able to organise such a project if sufficient interest exists.

An algorithm for analysing profiles of magnetic data to estimate magnetic source depths was developed by Naudy (1971). The results of this method are accurate but require correction for source length and source strike direction plus editing out of sources which cannot be approximated by simple tabular shapes. The method in its present form is tedious to use particularly as existing versions of the software only treat individual profiles. AGSO is pursuing the possibility of developing a version of the software that can produce verified, edited, plan representations of the depth estimates. This new software could be operational by March 1995.

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APPENDIX 1

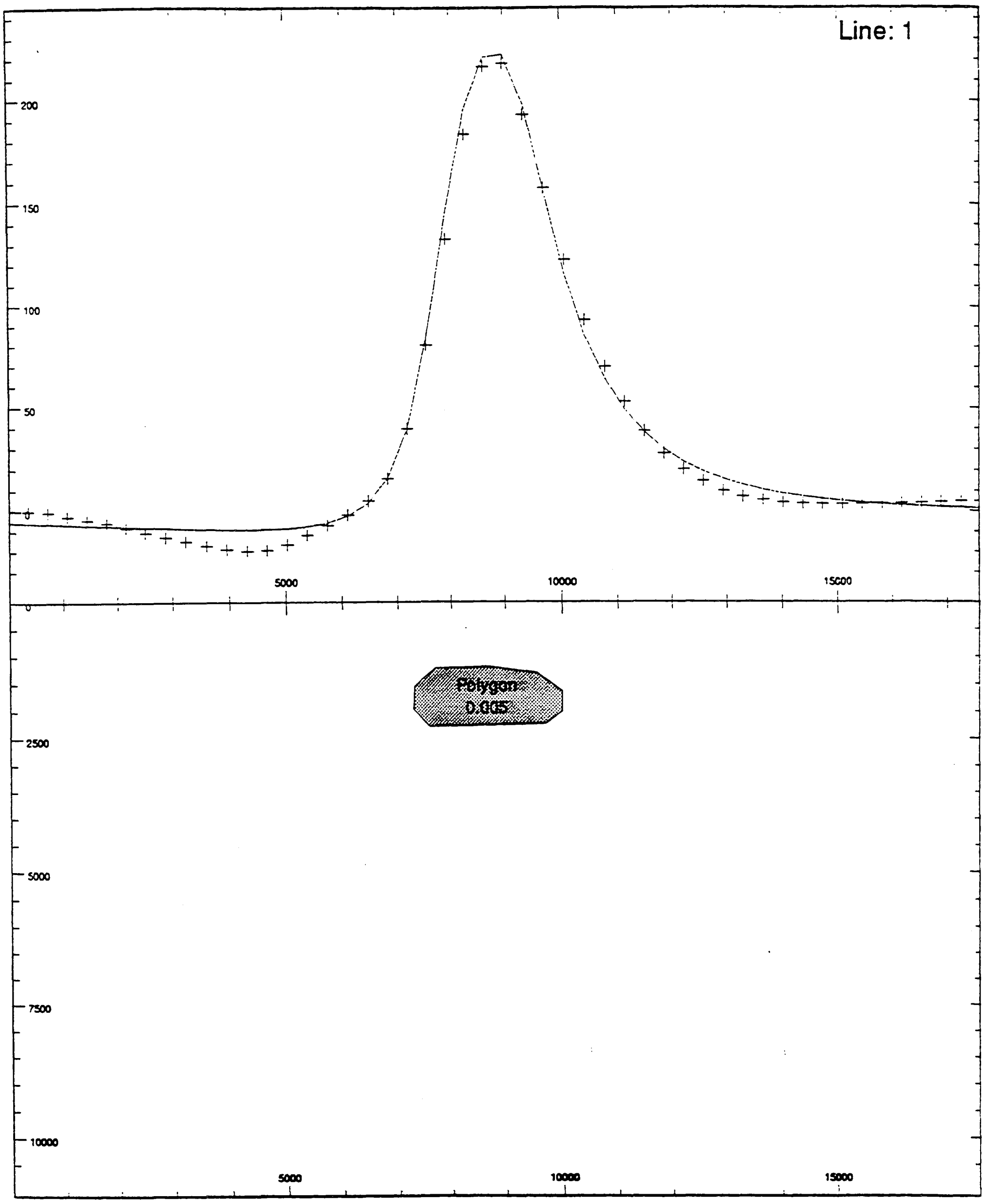
COMPUTER MODELLING RESULTS

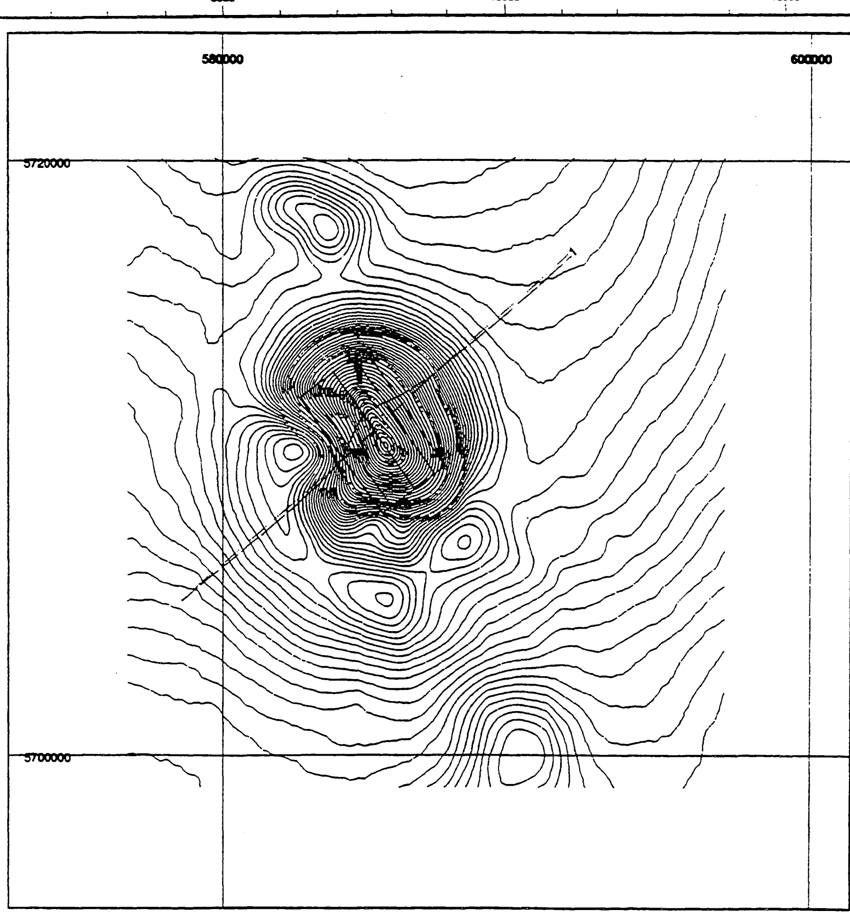
The locations of the profiles modelled are shown on the images of the following pages. For elongate magnetic anomalies where two dimensional approximations are valid only profile results are presented. For sub-circular and strike limited features a central profile has been modelled using finite length source bodies.

All intensity units are in nanoteslas and all distance units are in metres. Susceptibilities are in c.g.s. units.

While the depths on the two dimensional models should be approximately correct the relief and thicknesses of the bodies is indicative only. This is because precise values of susceptibility are required to be known to model relief unambiguously. In the case of bodies with vertical elongation it is only possible to determine the product of the thickness and the susceptibility when the depth is greater then the thickness. The general forms and depths of such bodies will however be correct. Unless modelled profiles are perpendicular to the contour trends of the anomaly being modelled the depth modelled must be multiplied by the cosine of the angle between the profile and the direction normal to the contour trends.

All model result depths are relative to the survey flight height which was 130 m above sea level.


Line: 1
200
150
100
50
0
5000
10000
15000
Polygon
0.005
2500
5000
7500
10000
5000
10000
15000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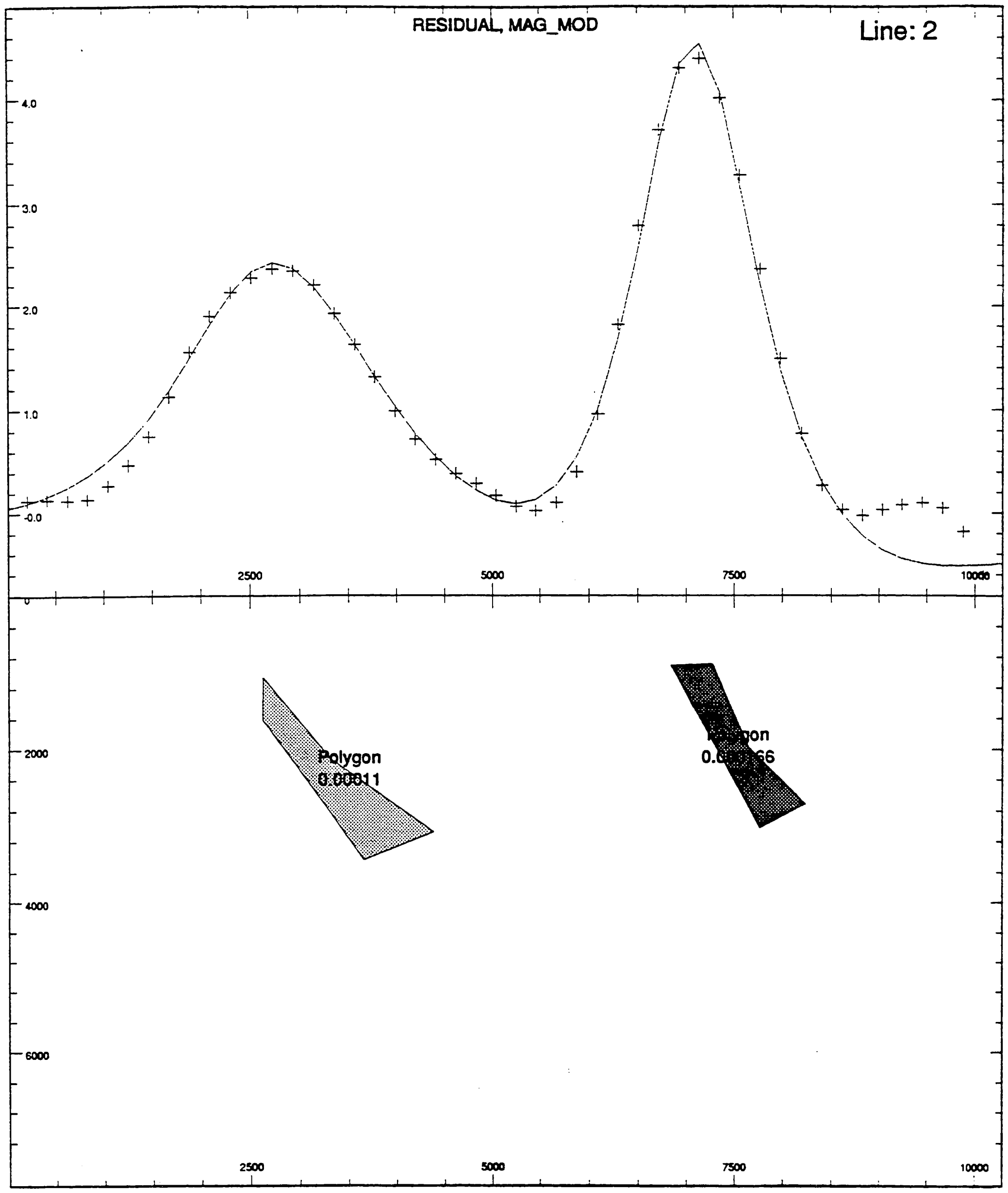
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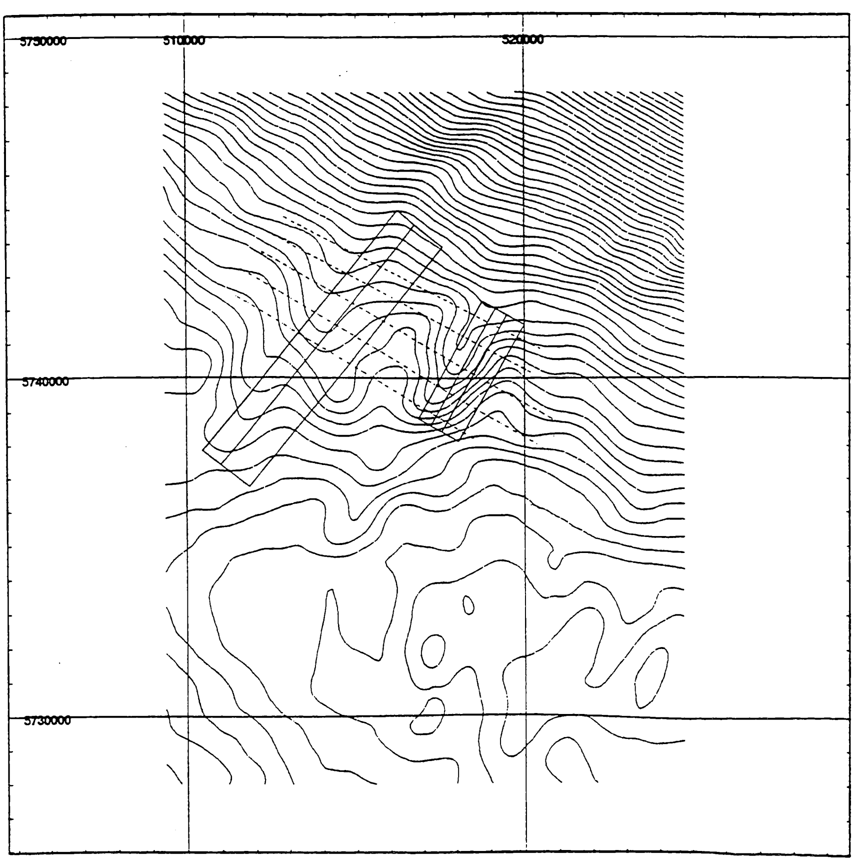
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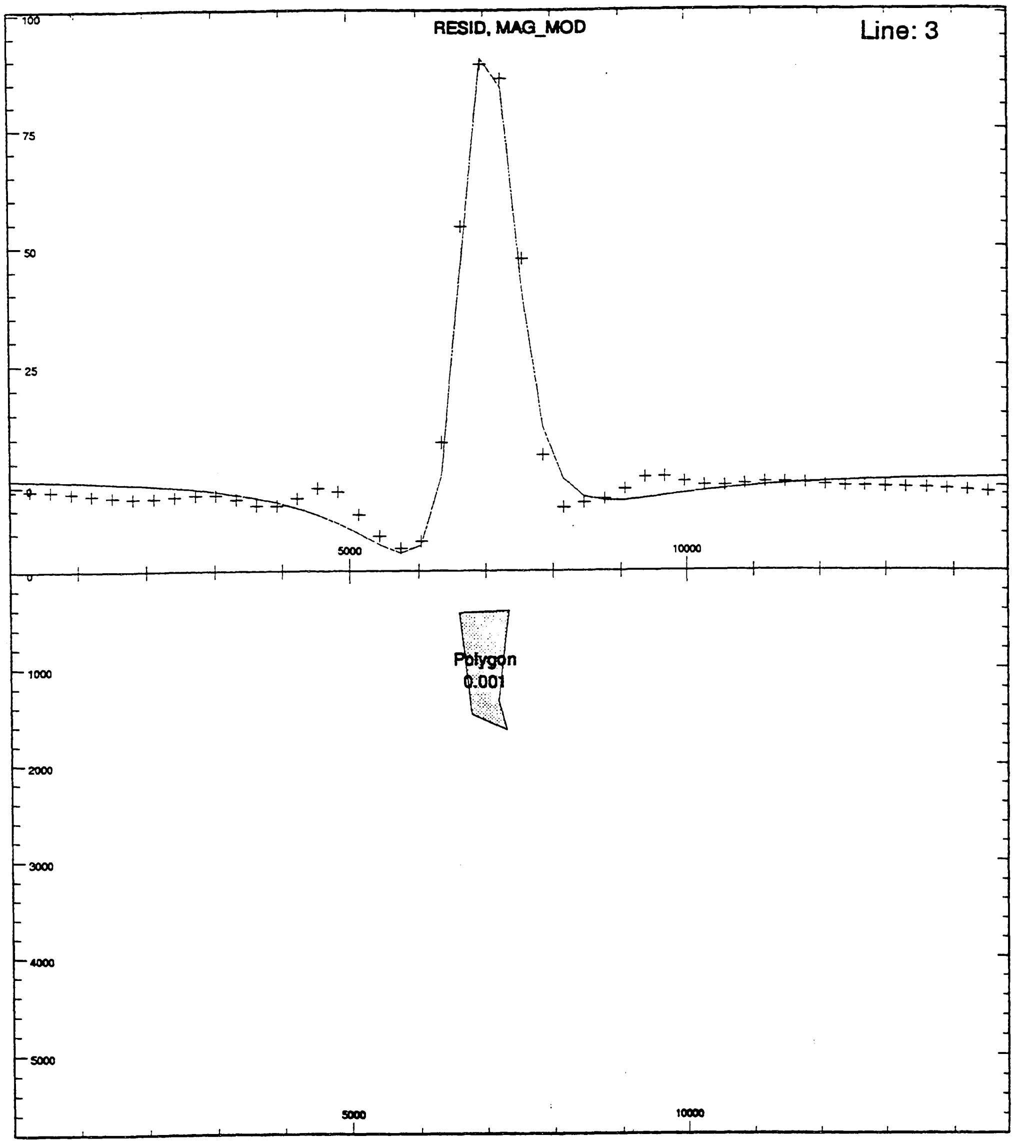

RESID, MAG_MOD
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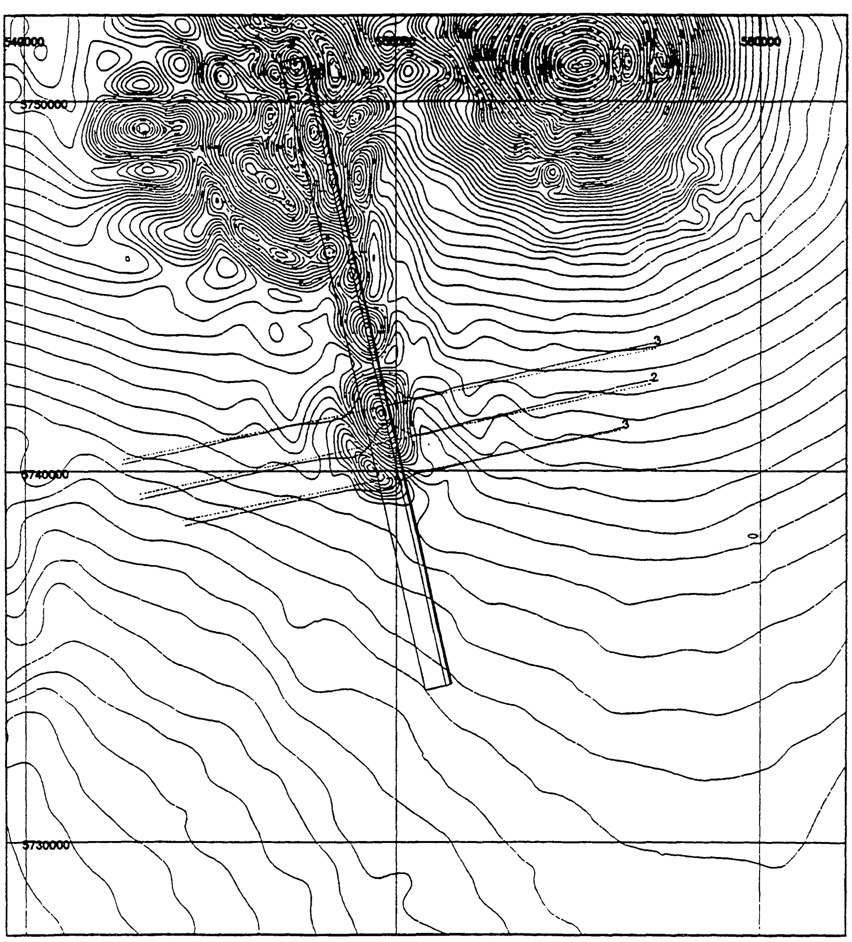

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2
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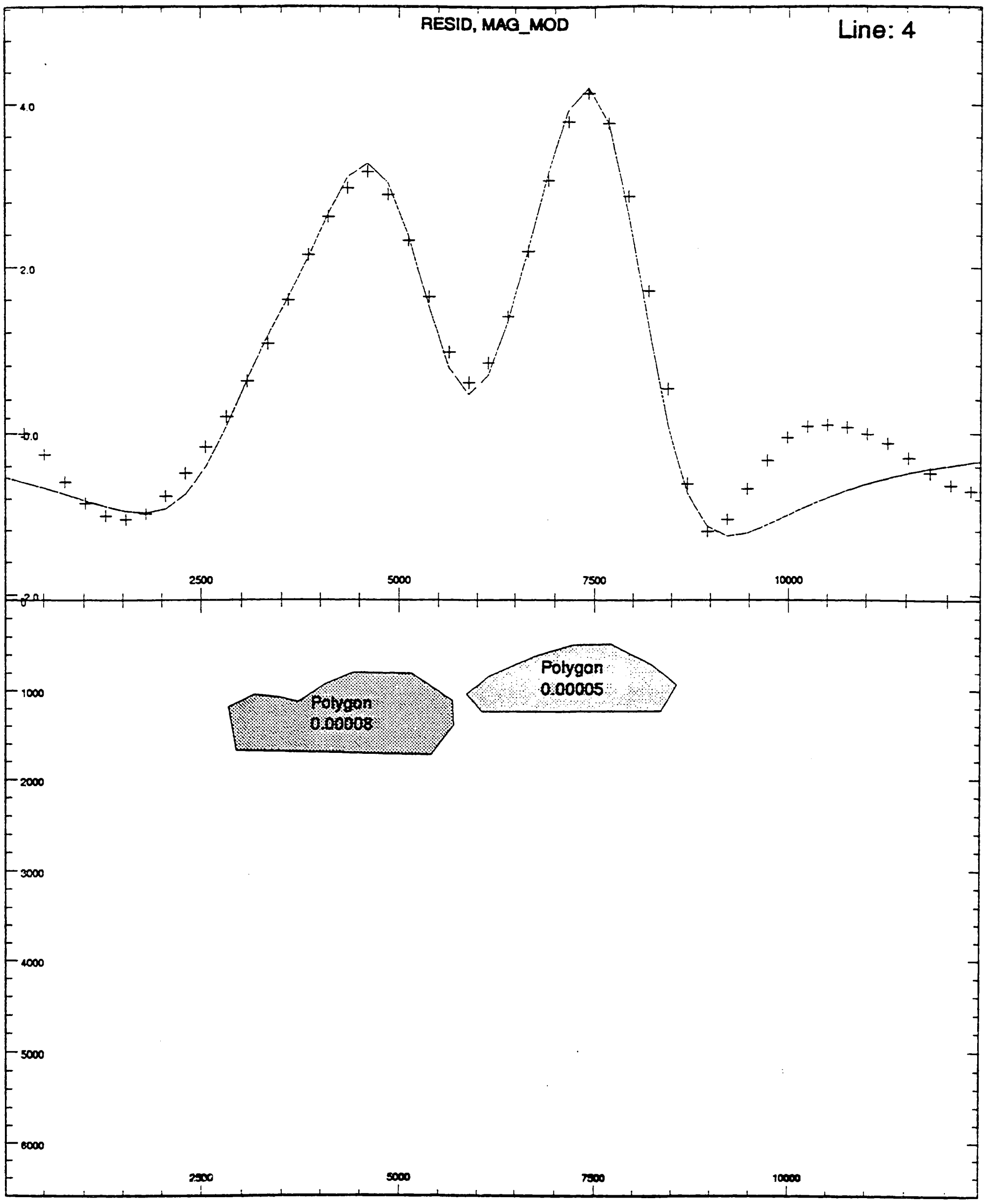
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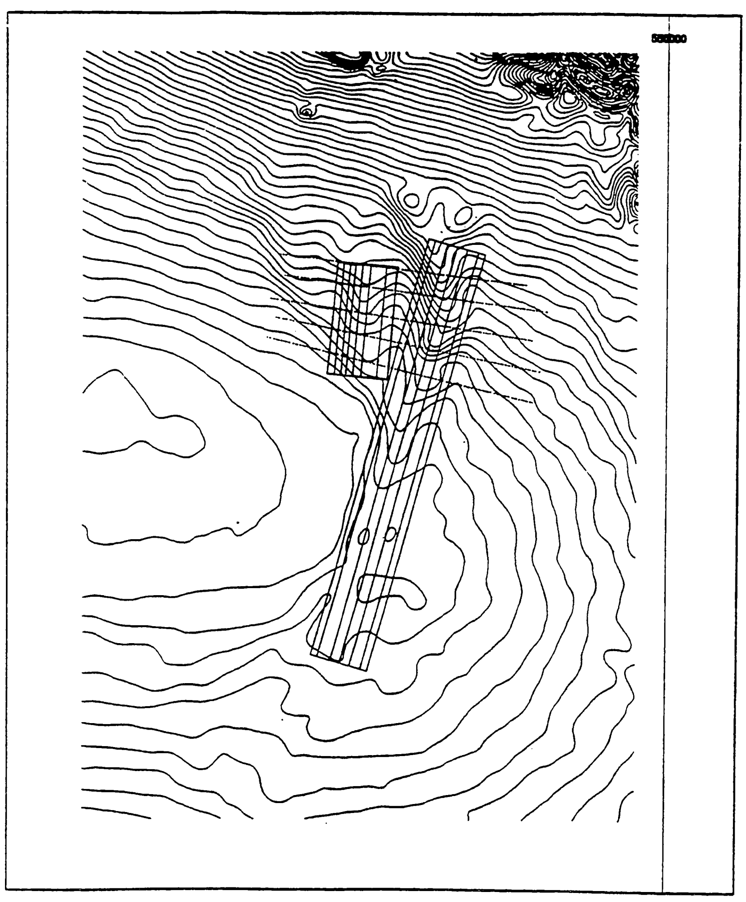

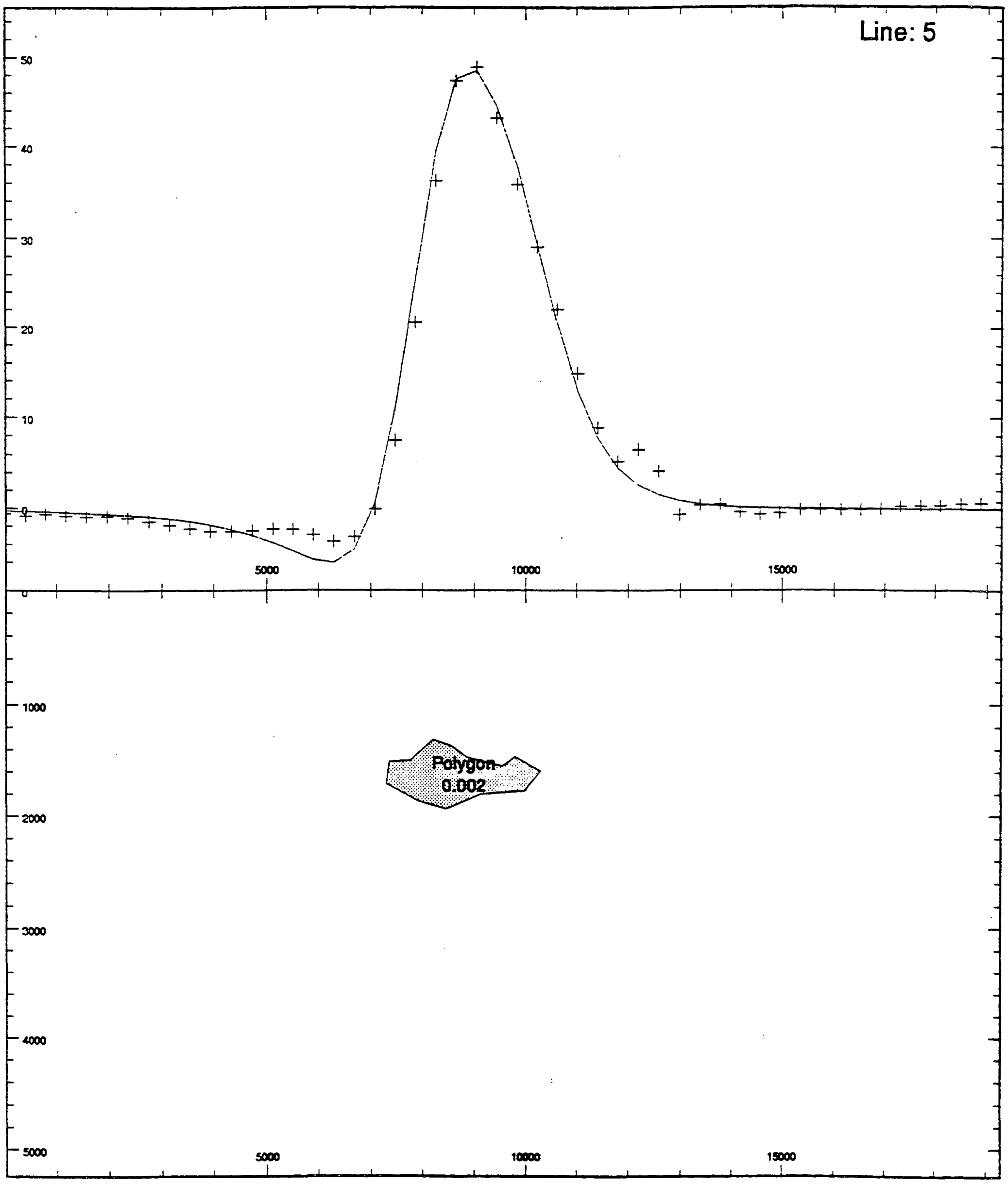
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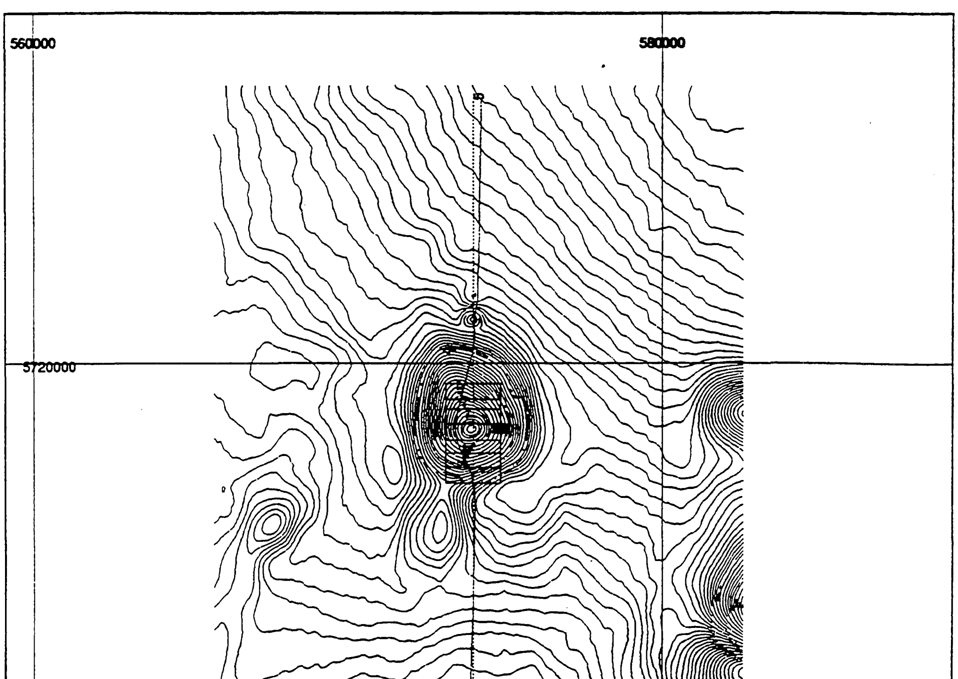
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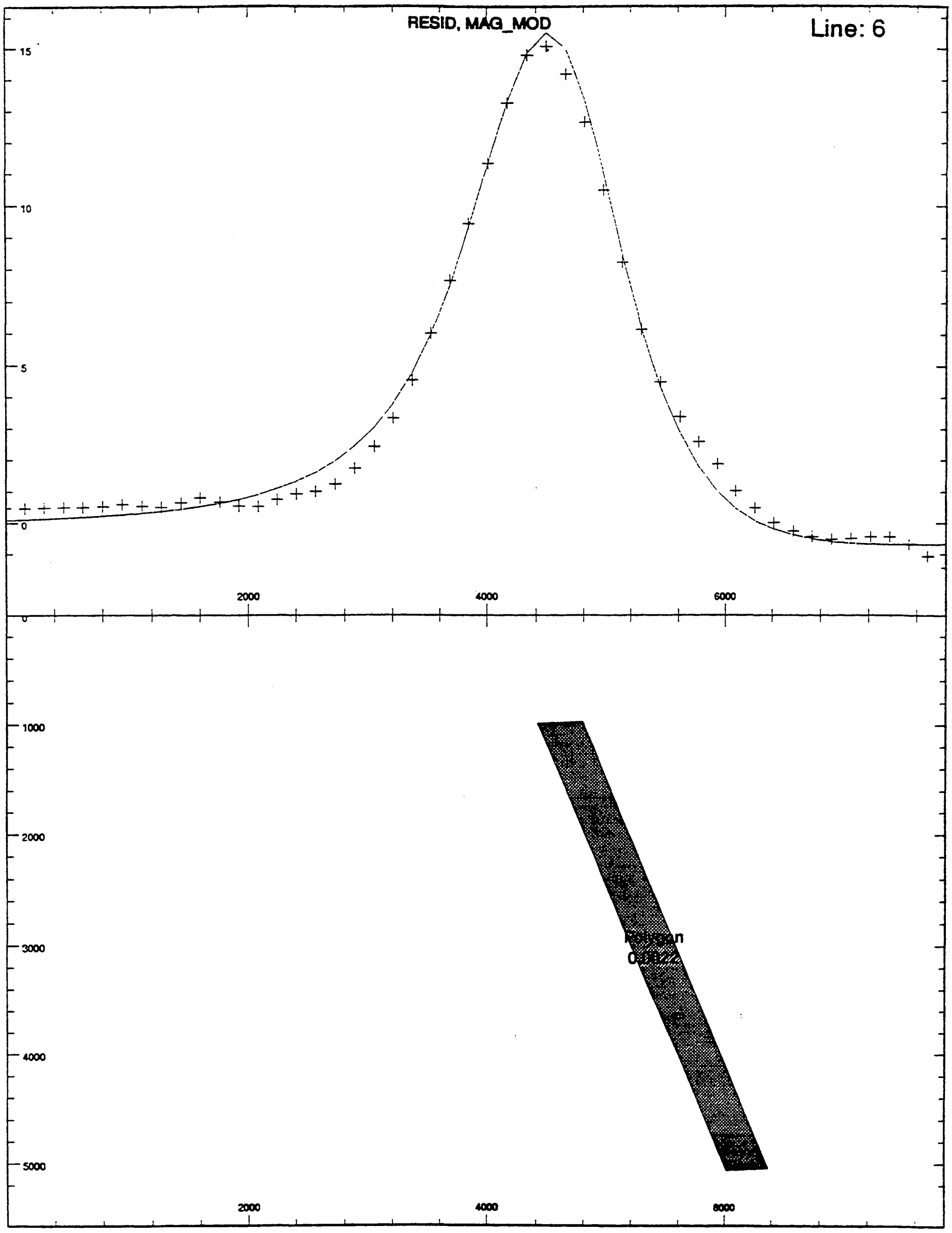

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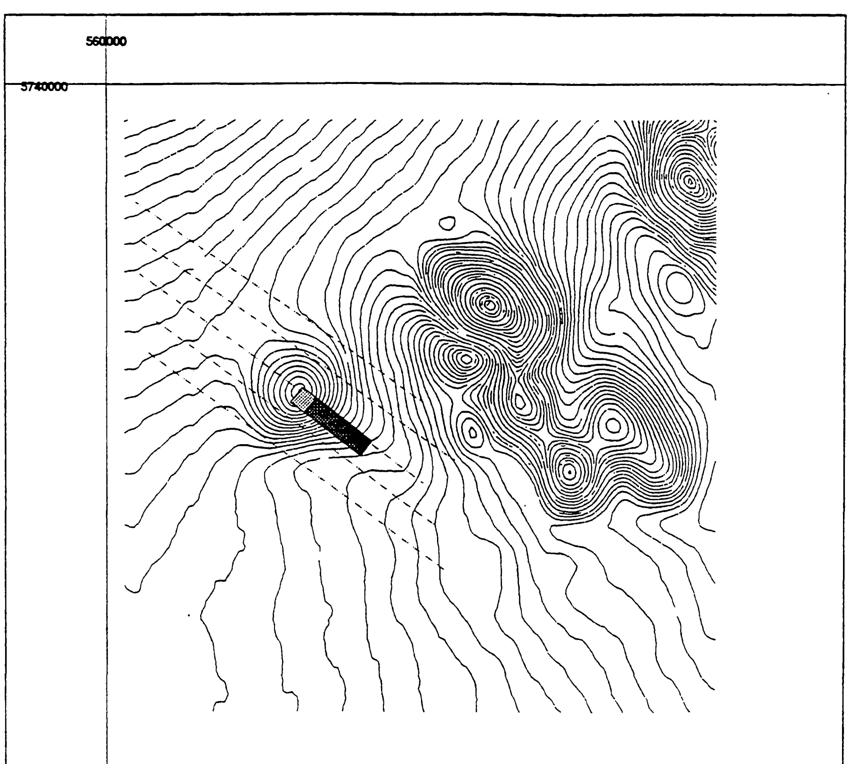

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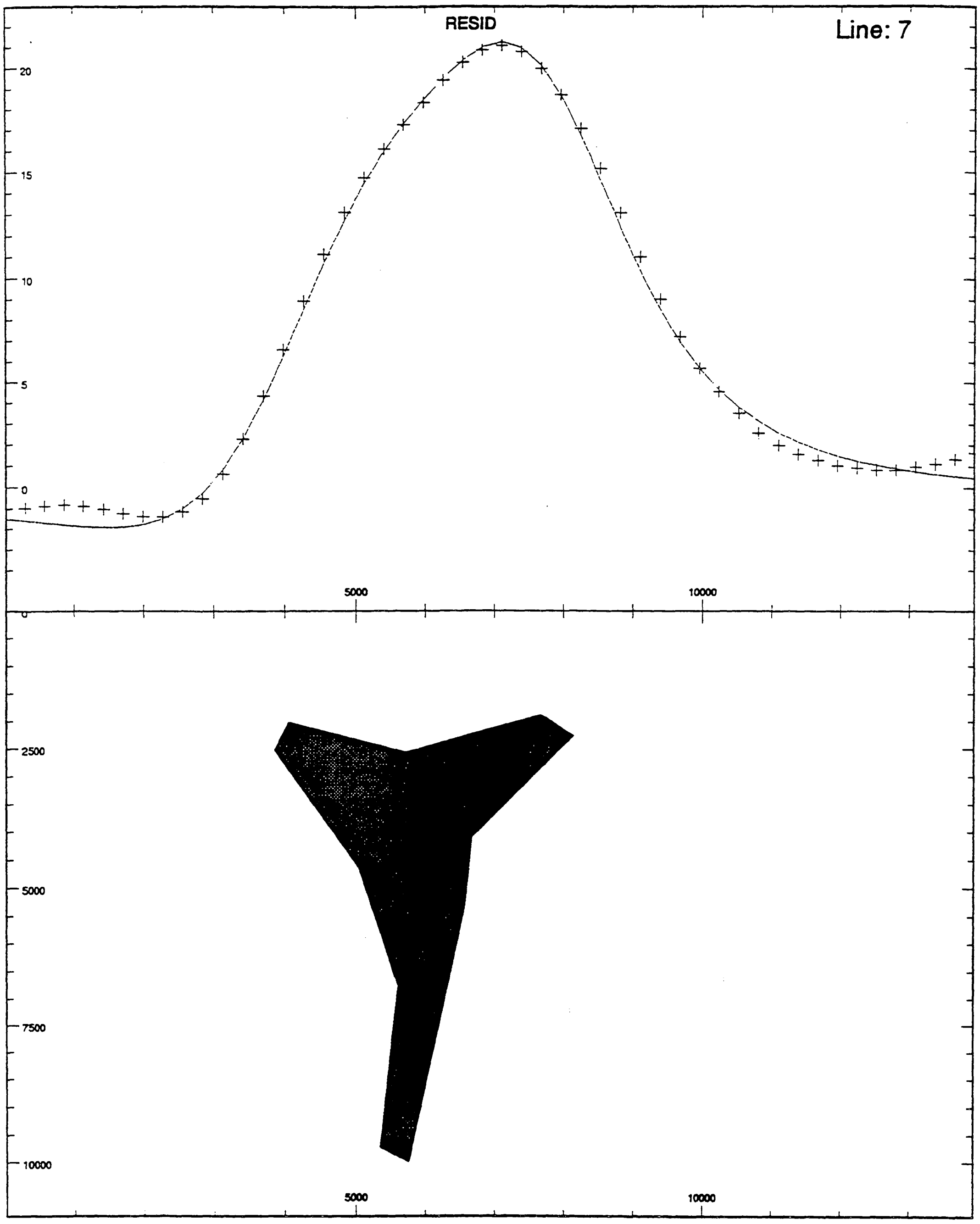
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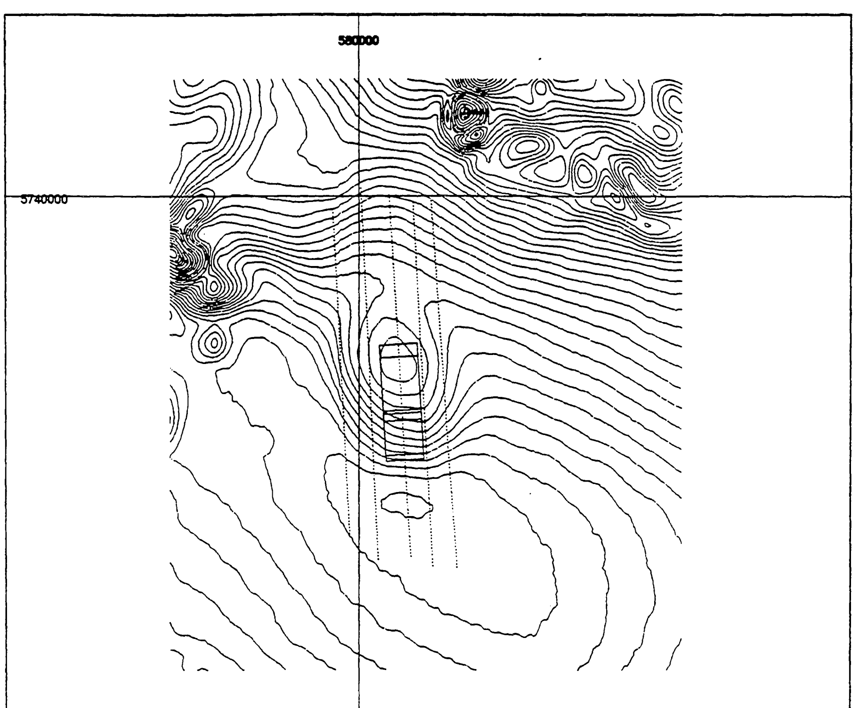
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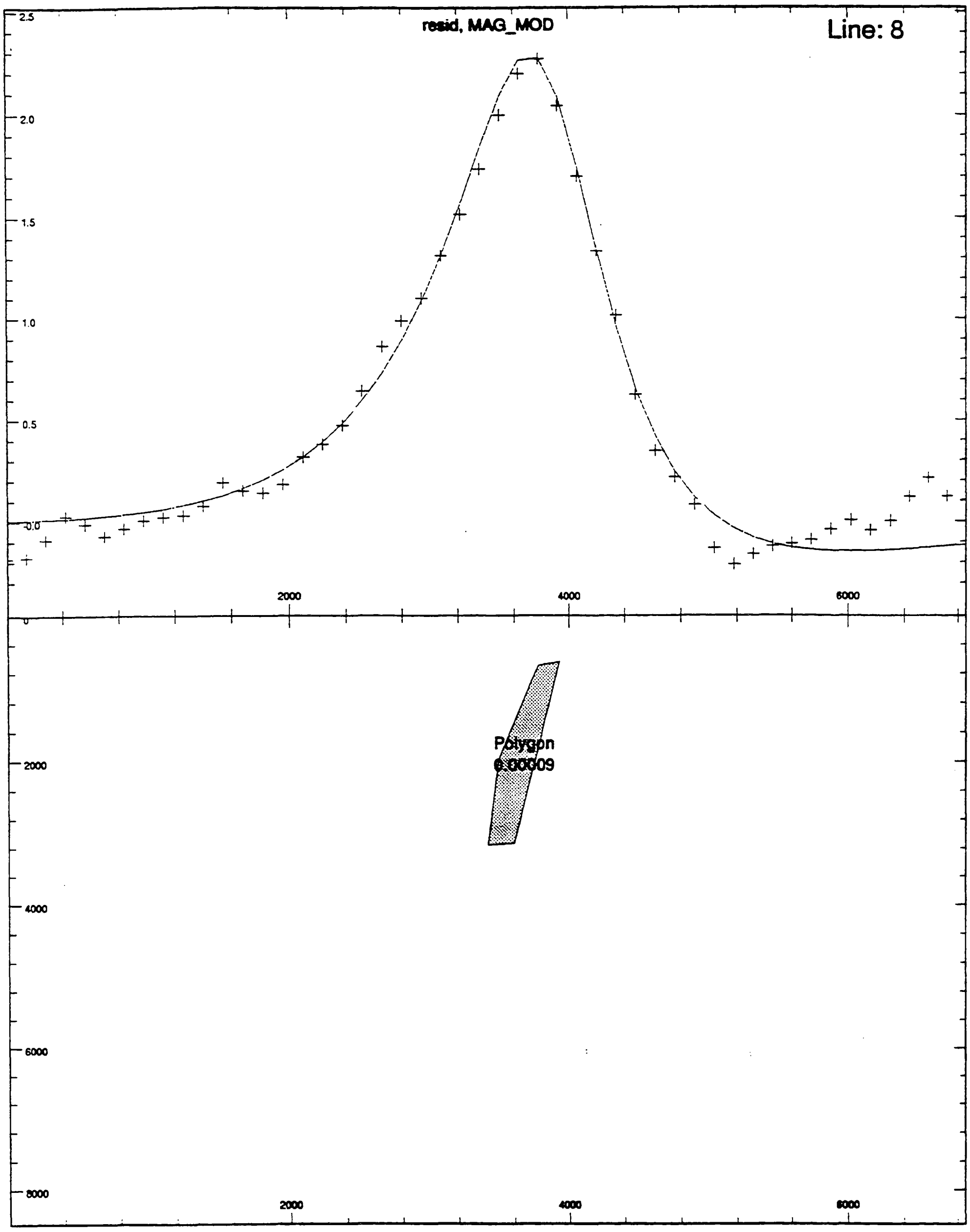
resid, MAG_MOD
Line: 8
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2.0
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Polygon
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4000
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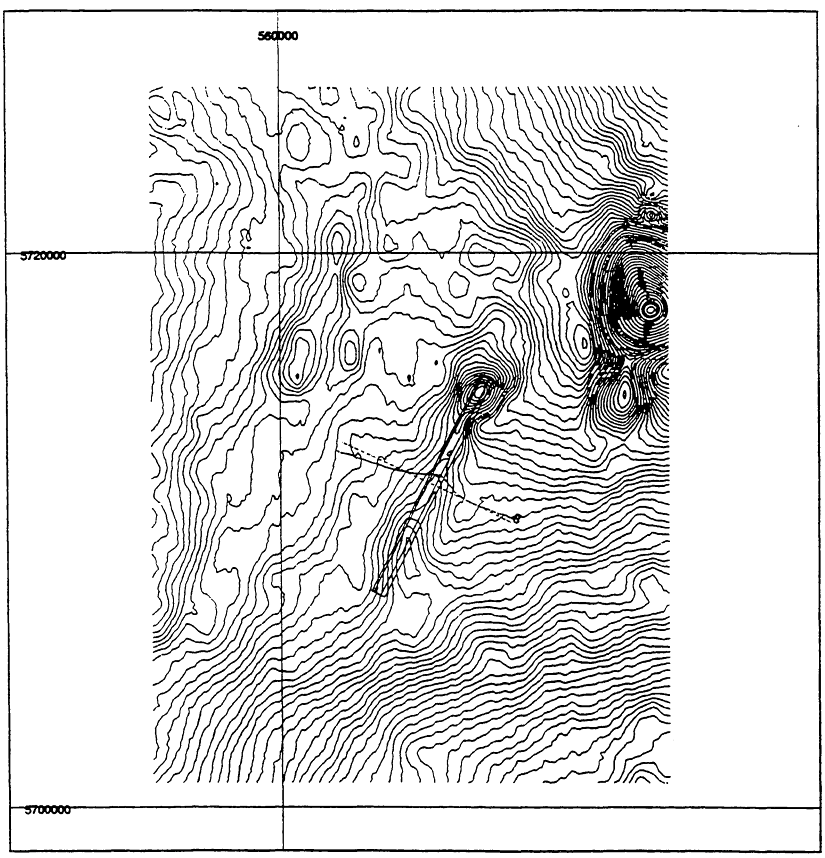
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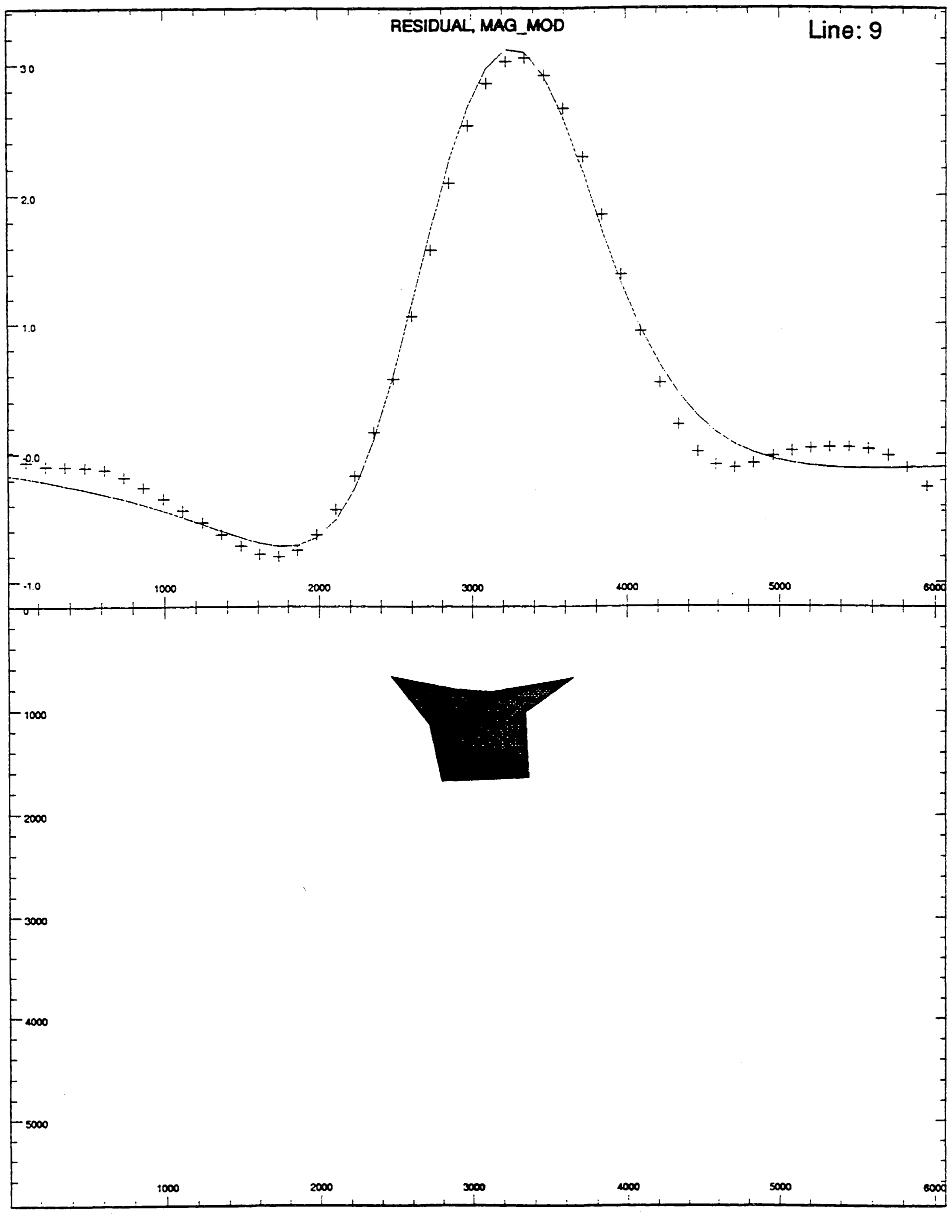
RESIDUAL, MAG_MOD
Line: 9
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2.0
1.0
0.0
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4000
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1000
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3000
4000
5000
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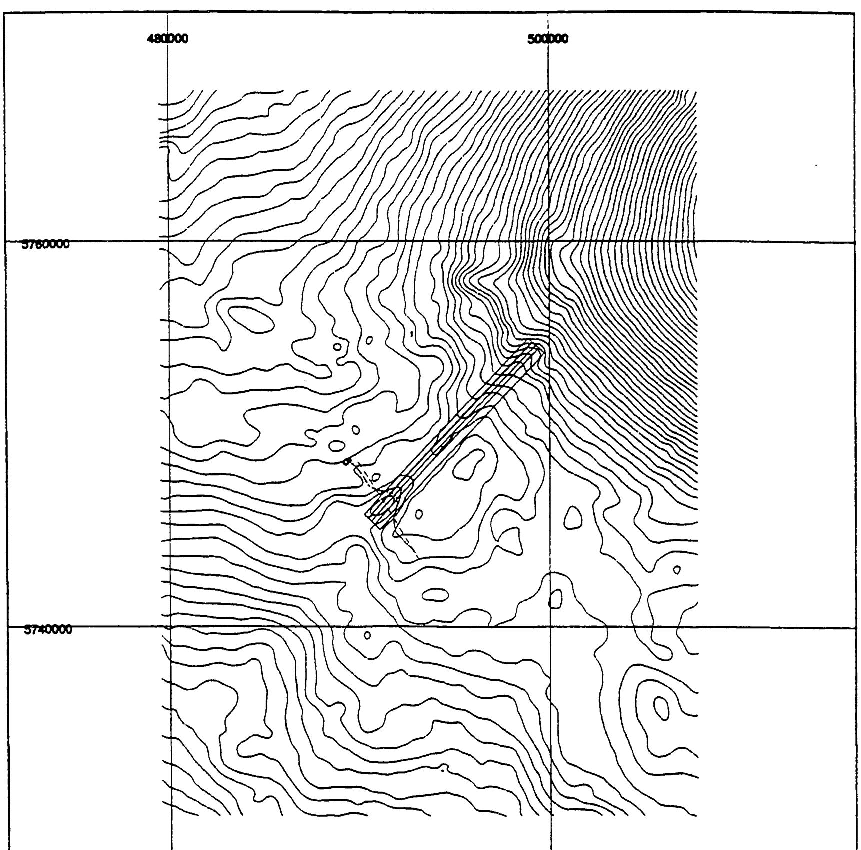
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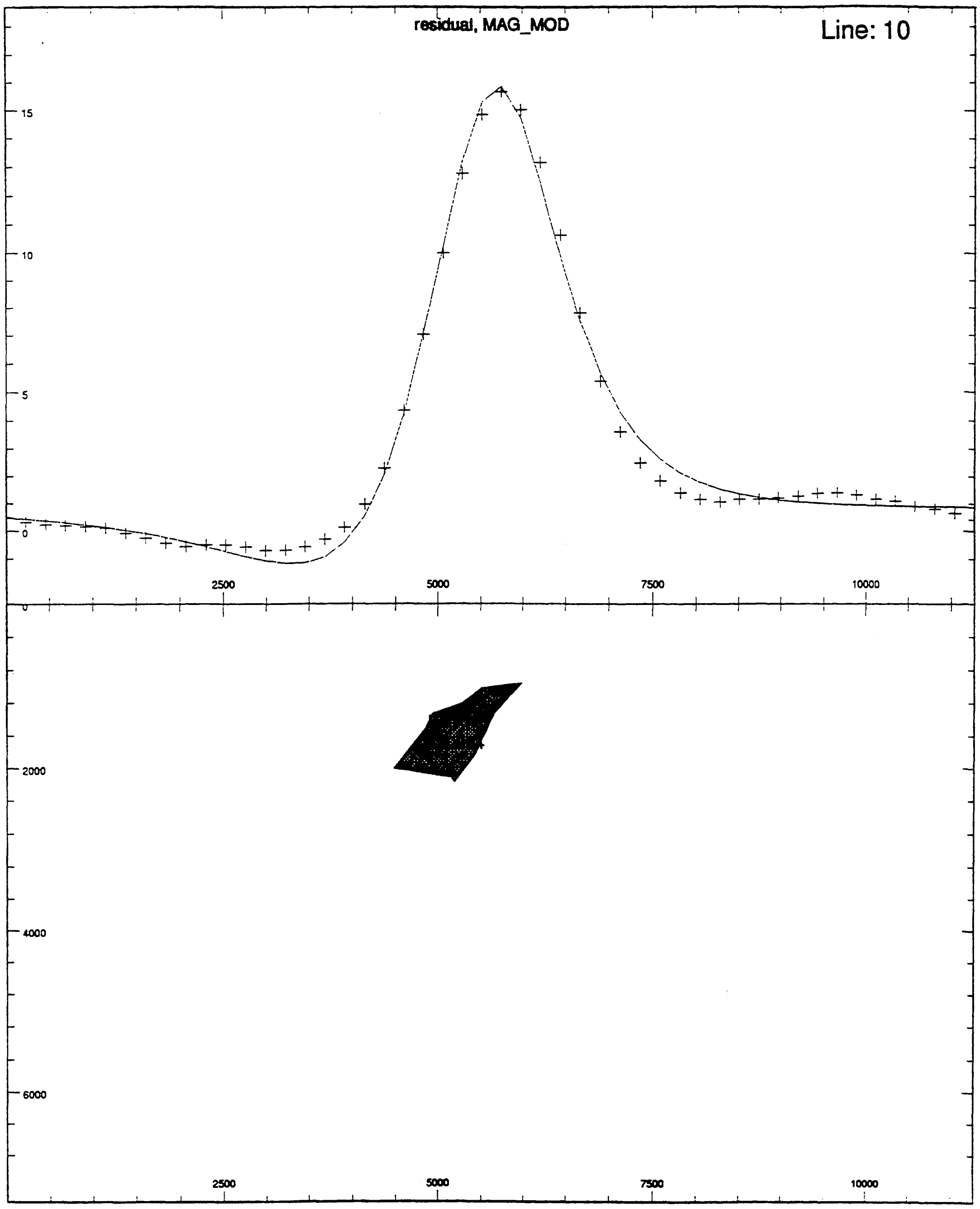

residual, MAG_MOD
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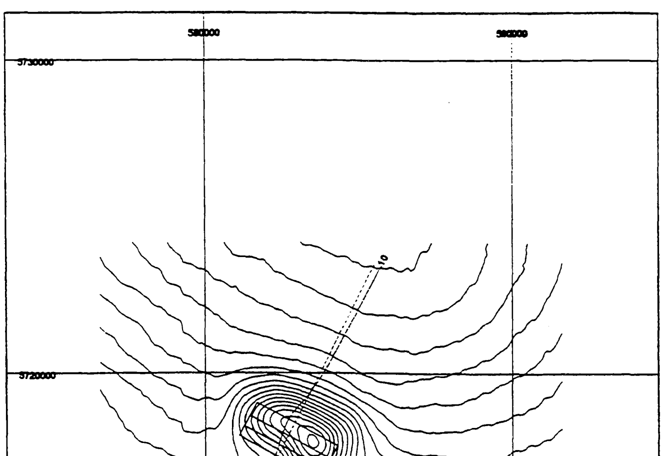
2500
5000
7500
10000



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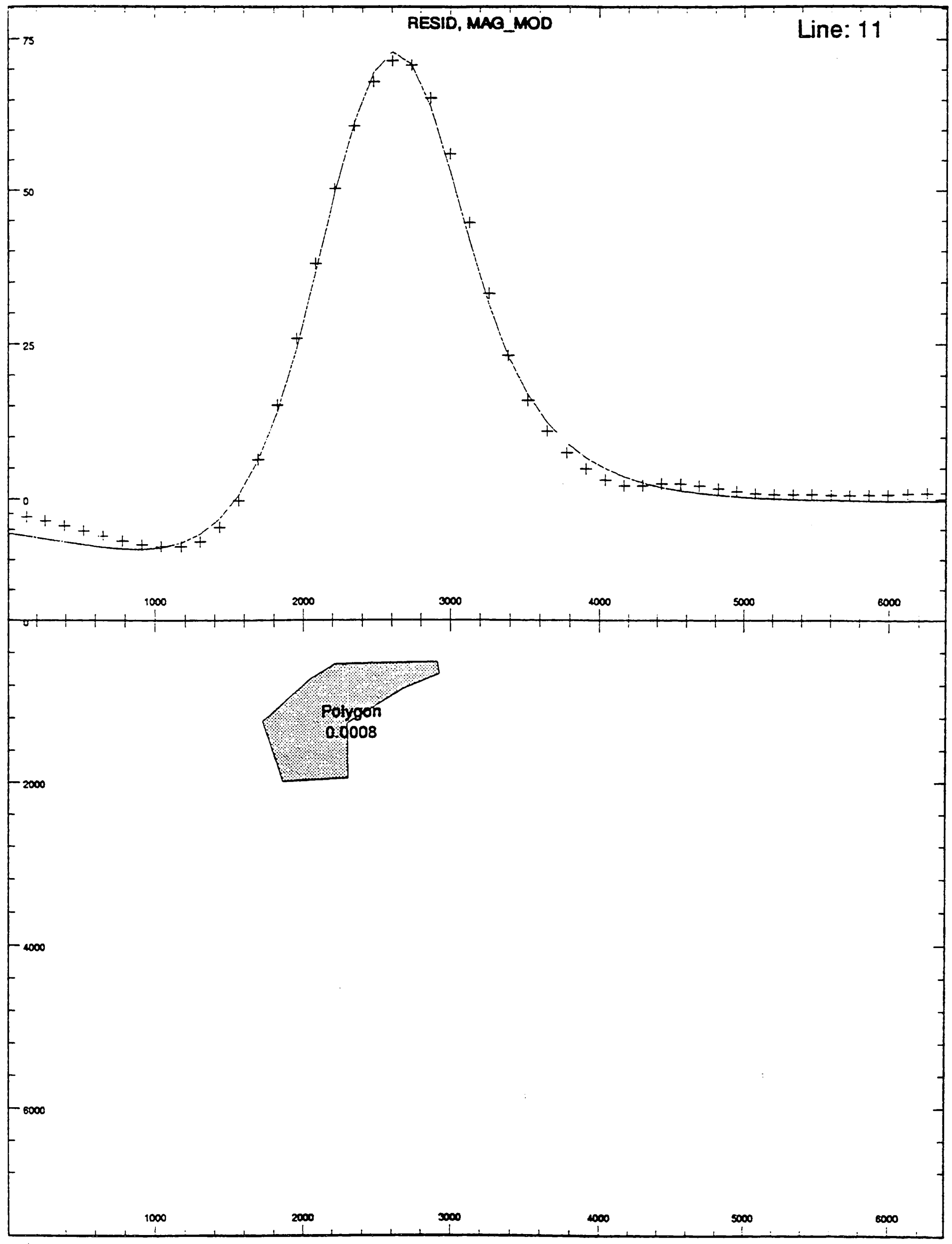

RESID, MAG_MOD
Line: 11
75
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6000
Polygon
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4000
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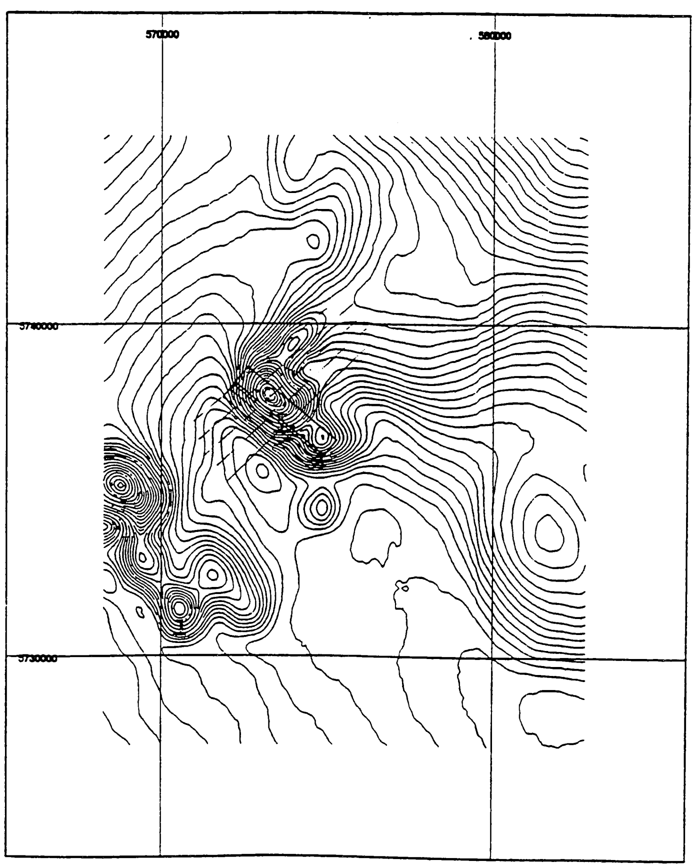
2000
3000
4000
5000
6000



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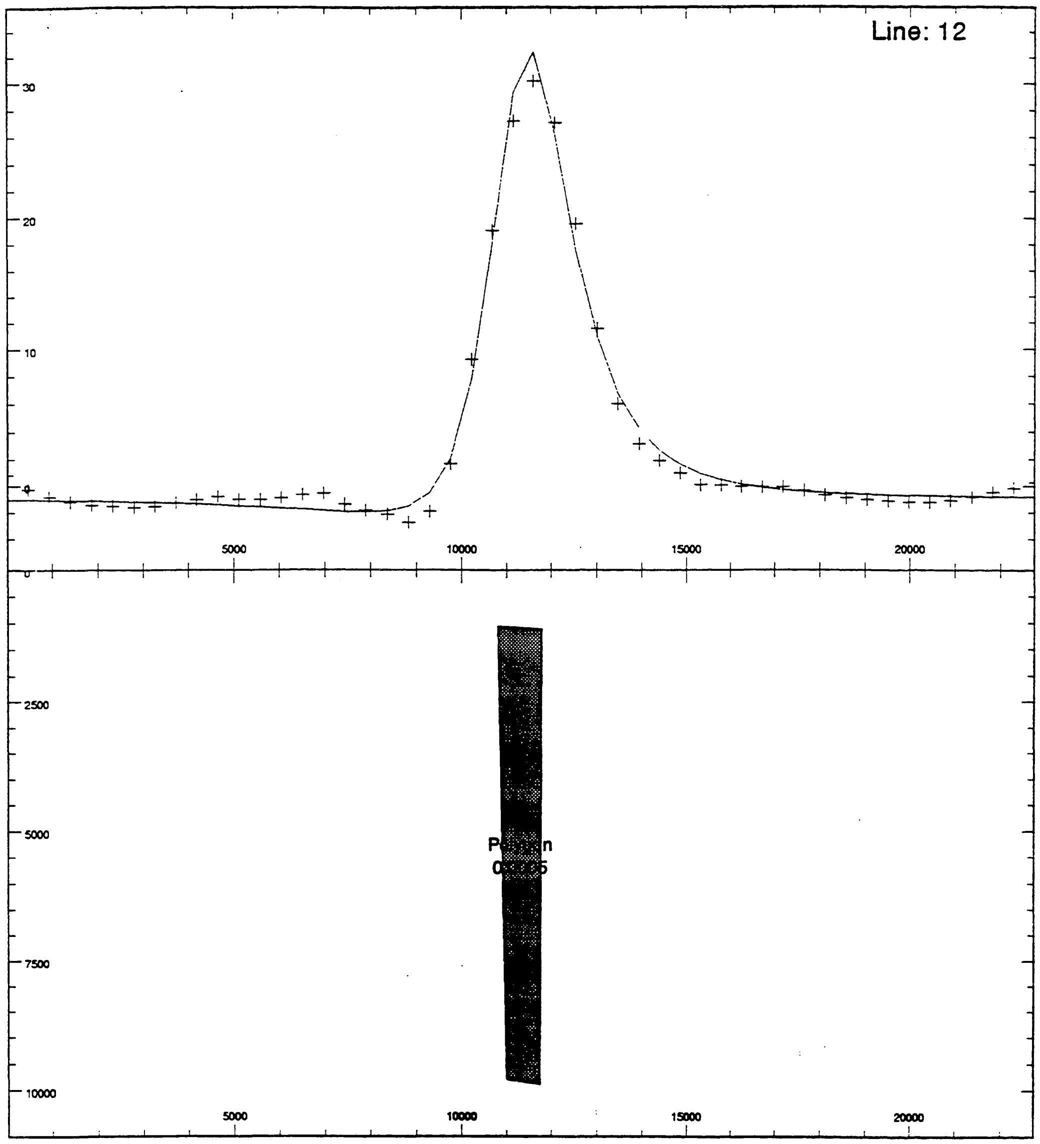
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7500
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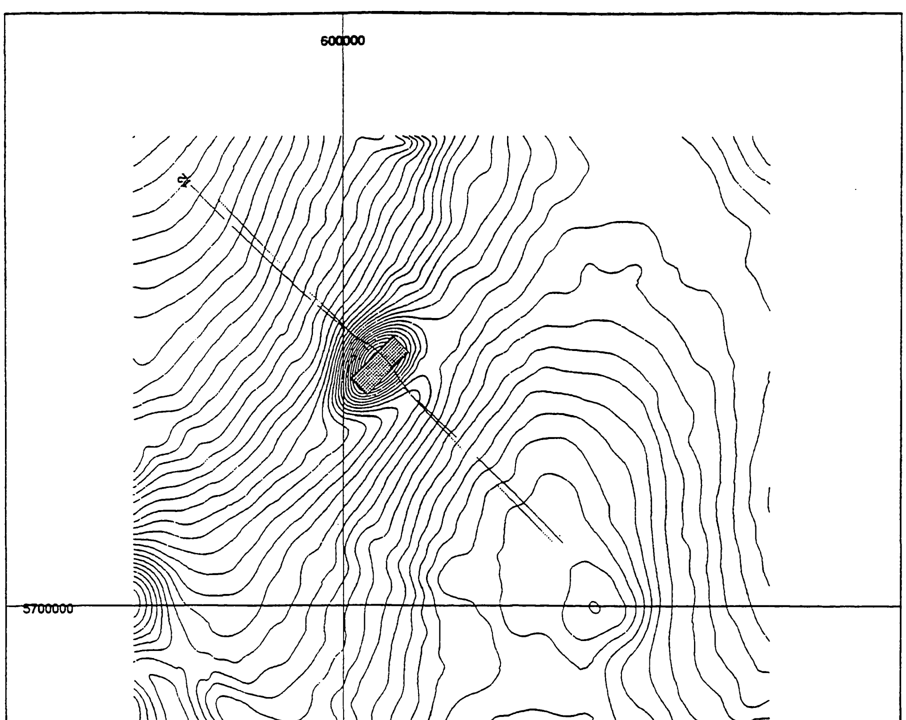
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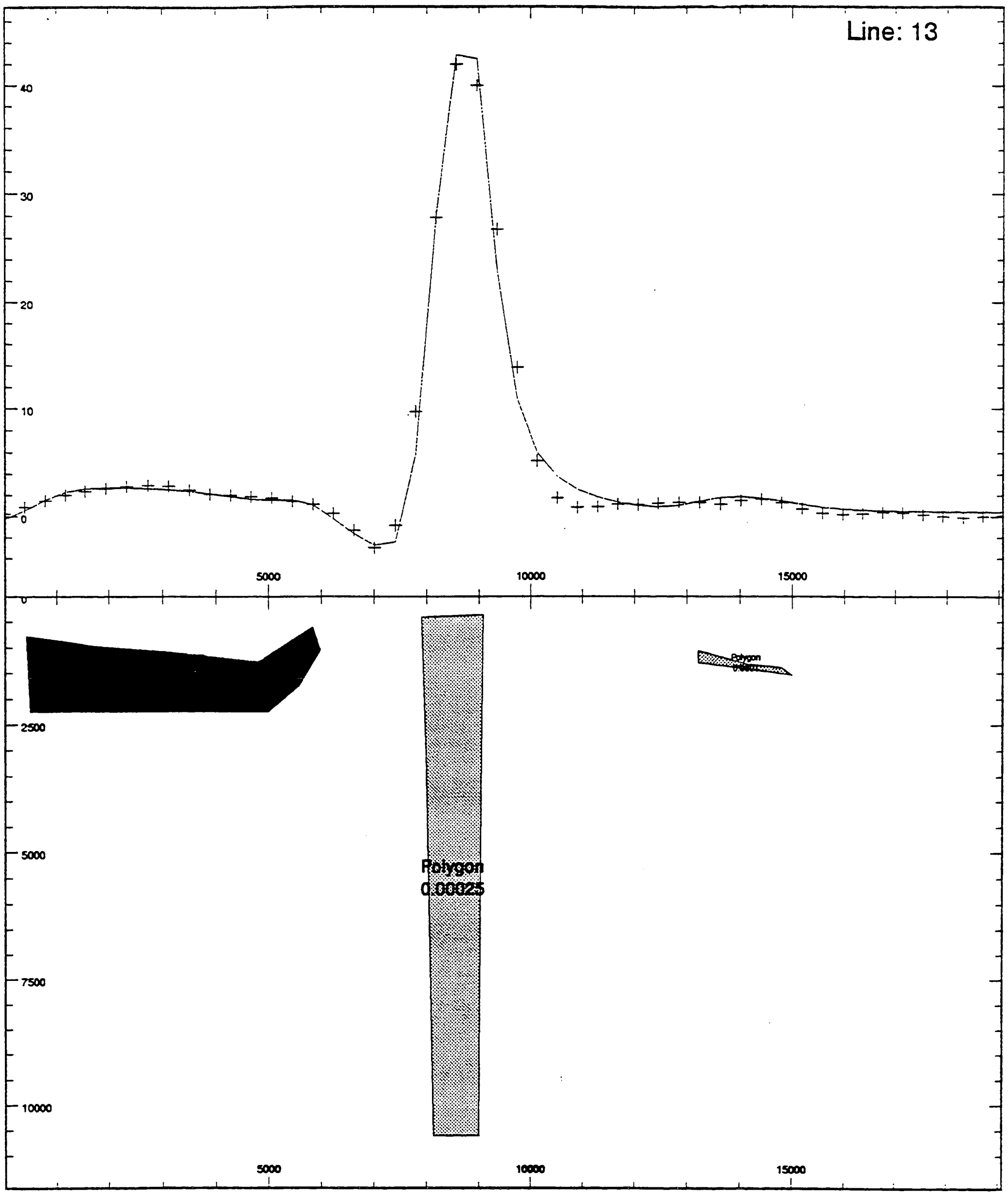

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0
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10000
15000
2500
5000
7500
10000
Polygon
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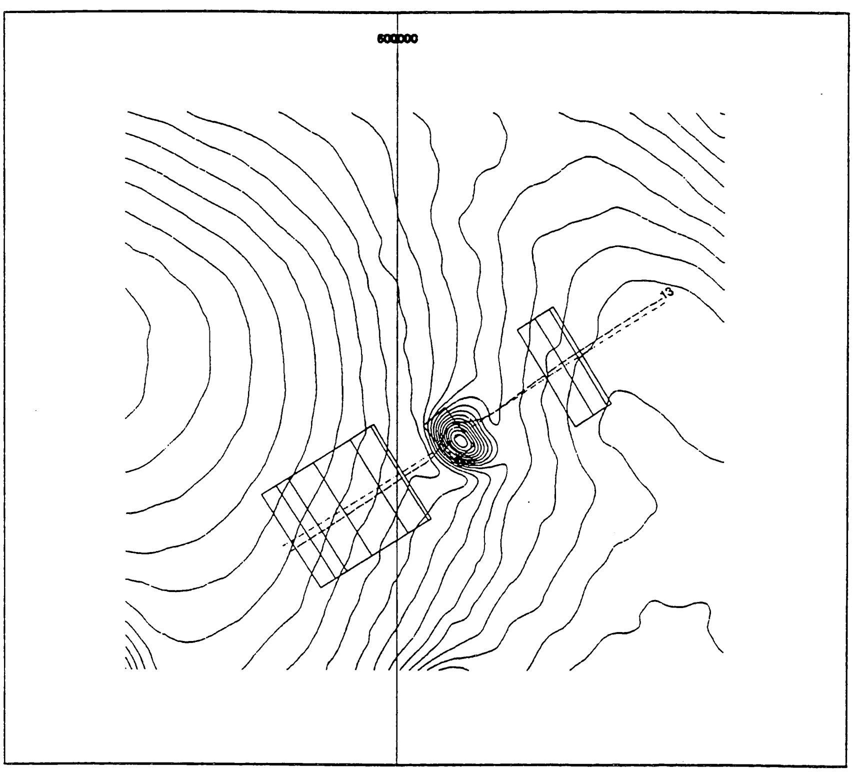
5000
10000
15000



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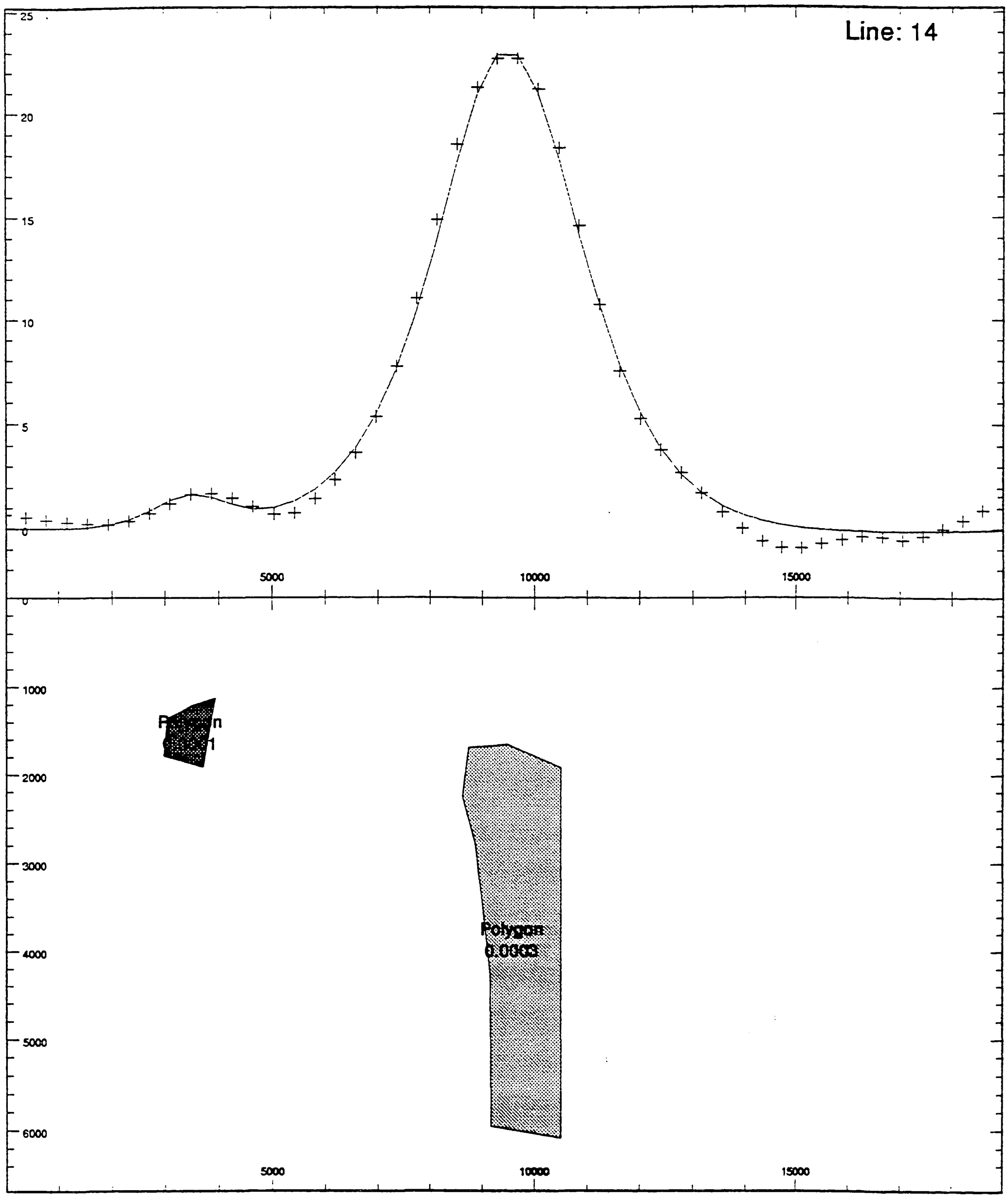

Line: 14
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5000
6000
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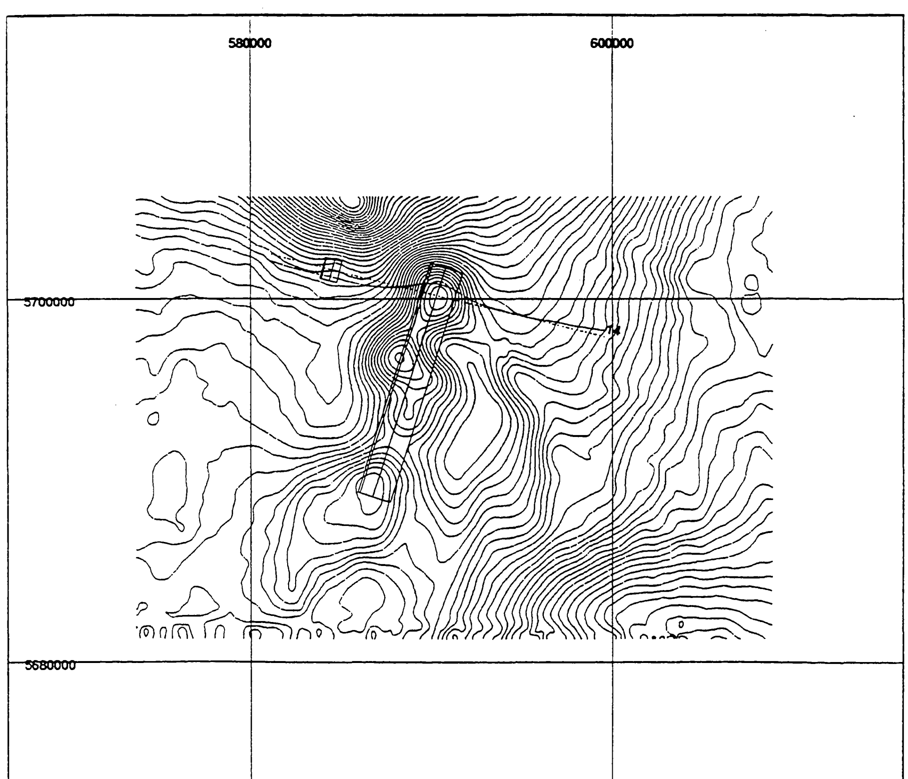
10000
15000



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600000
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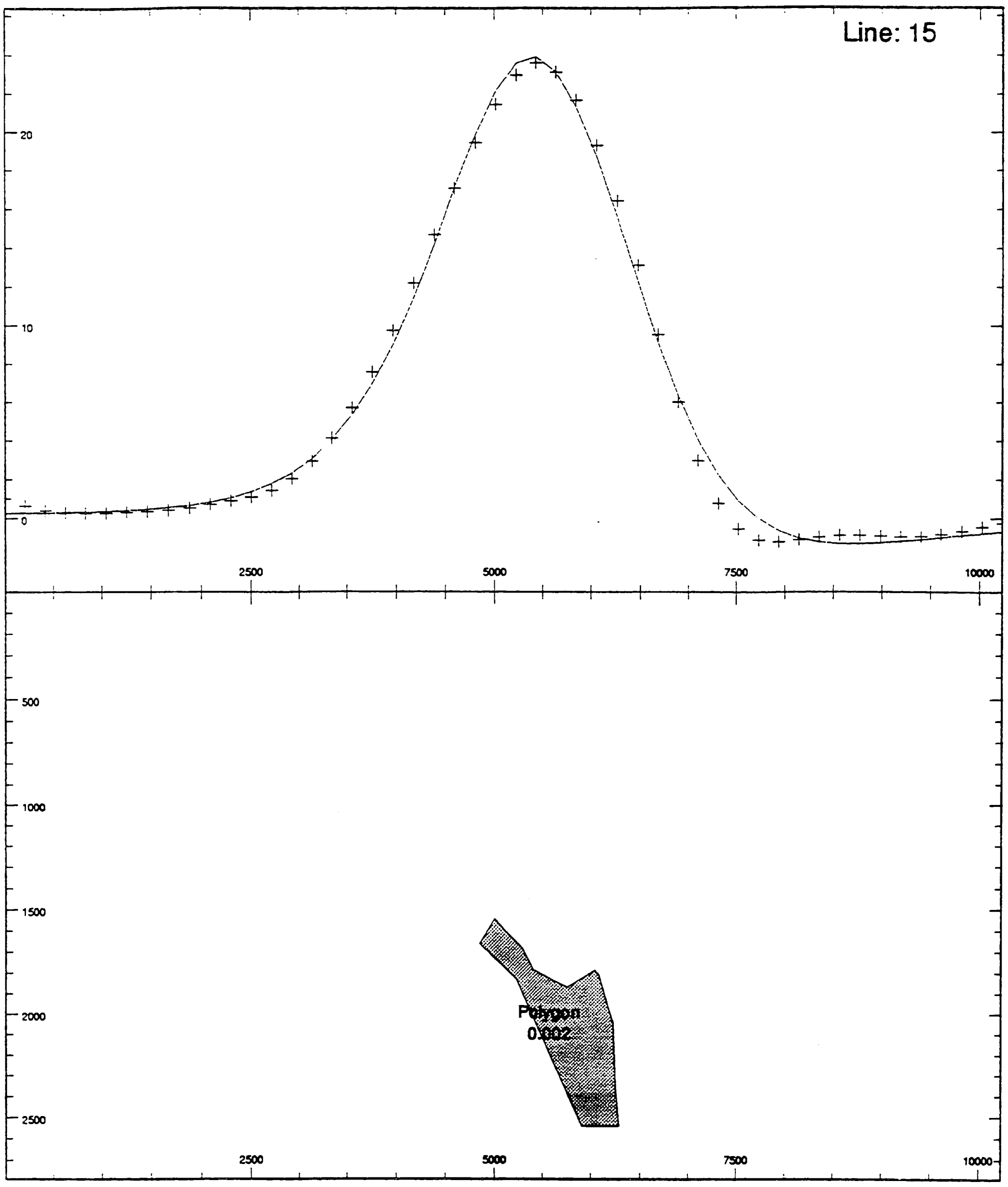
5680000
14


Line: 15
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7500
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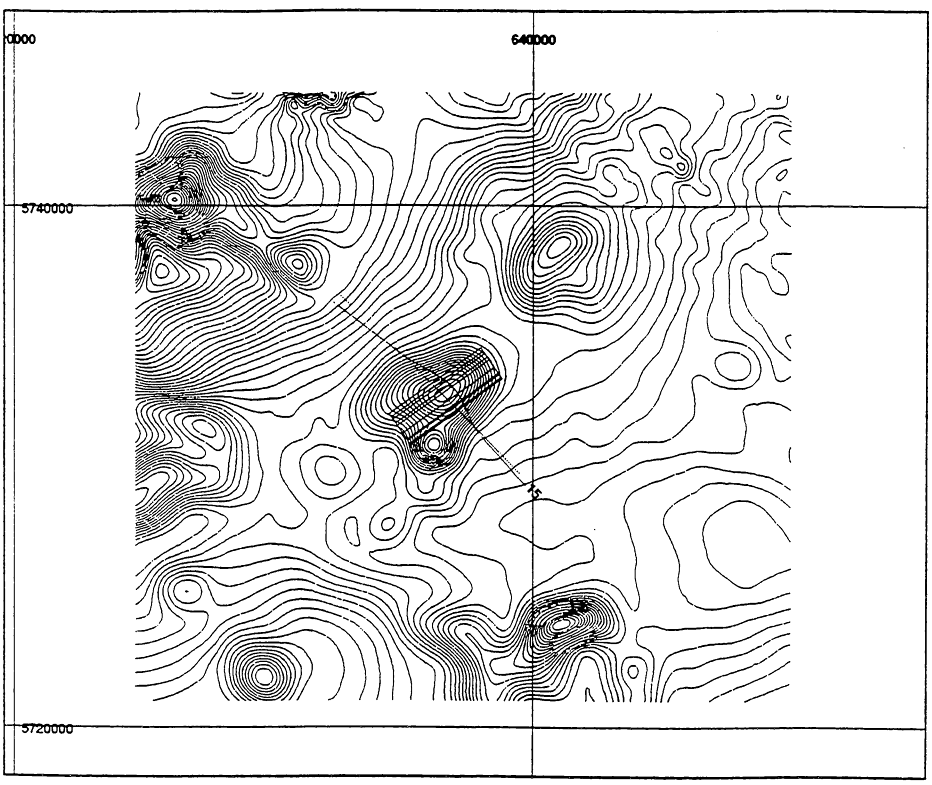
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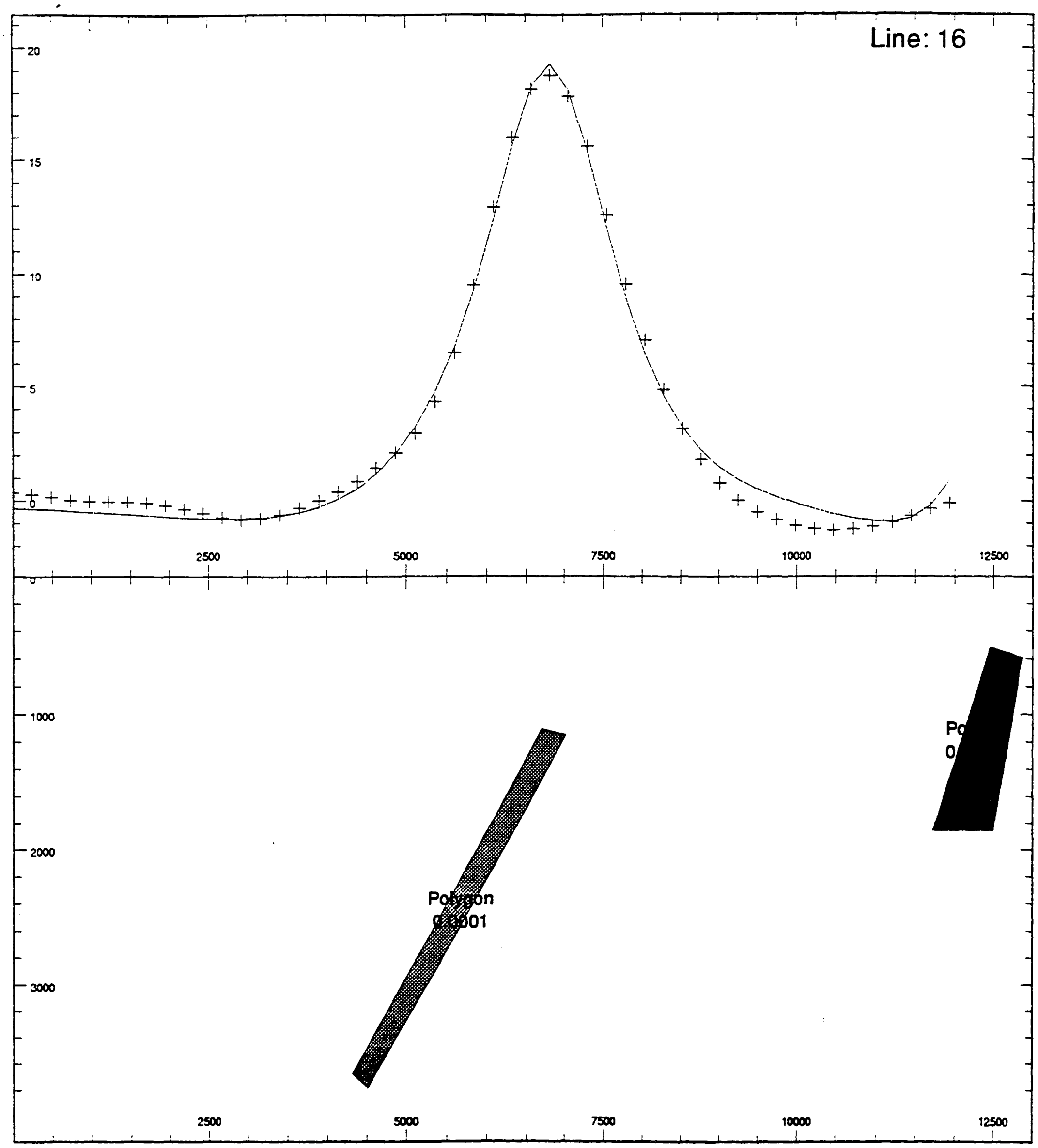

Line: 16
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15
10
5
0
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7500
10000
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Polygon
0.0001
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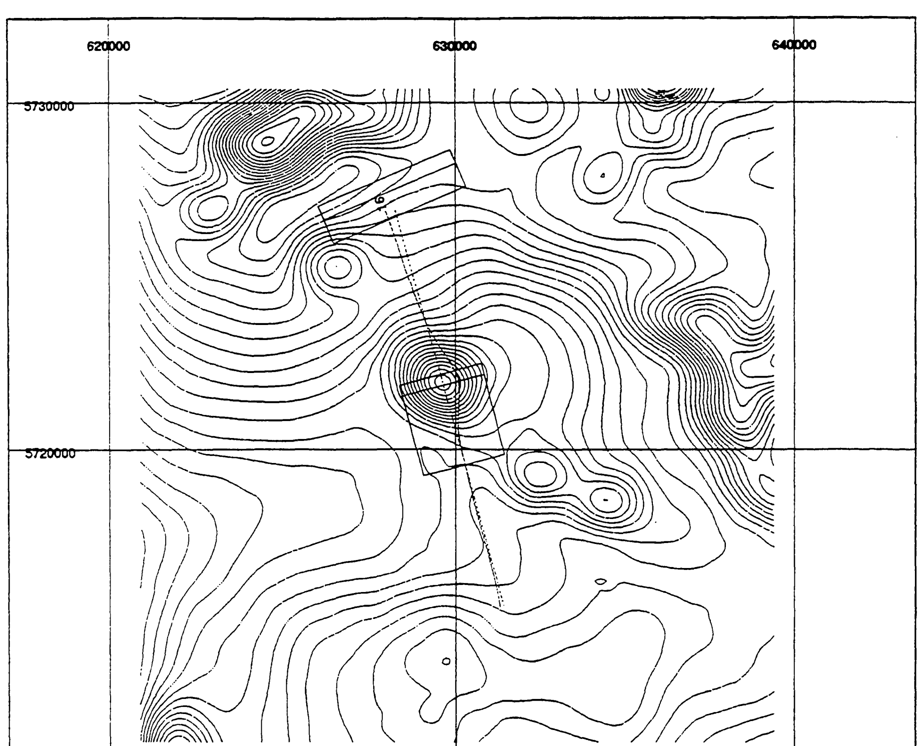
7500
10000
12500



620000
630000
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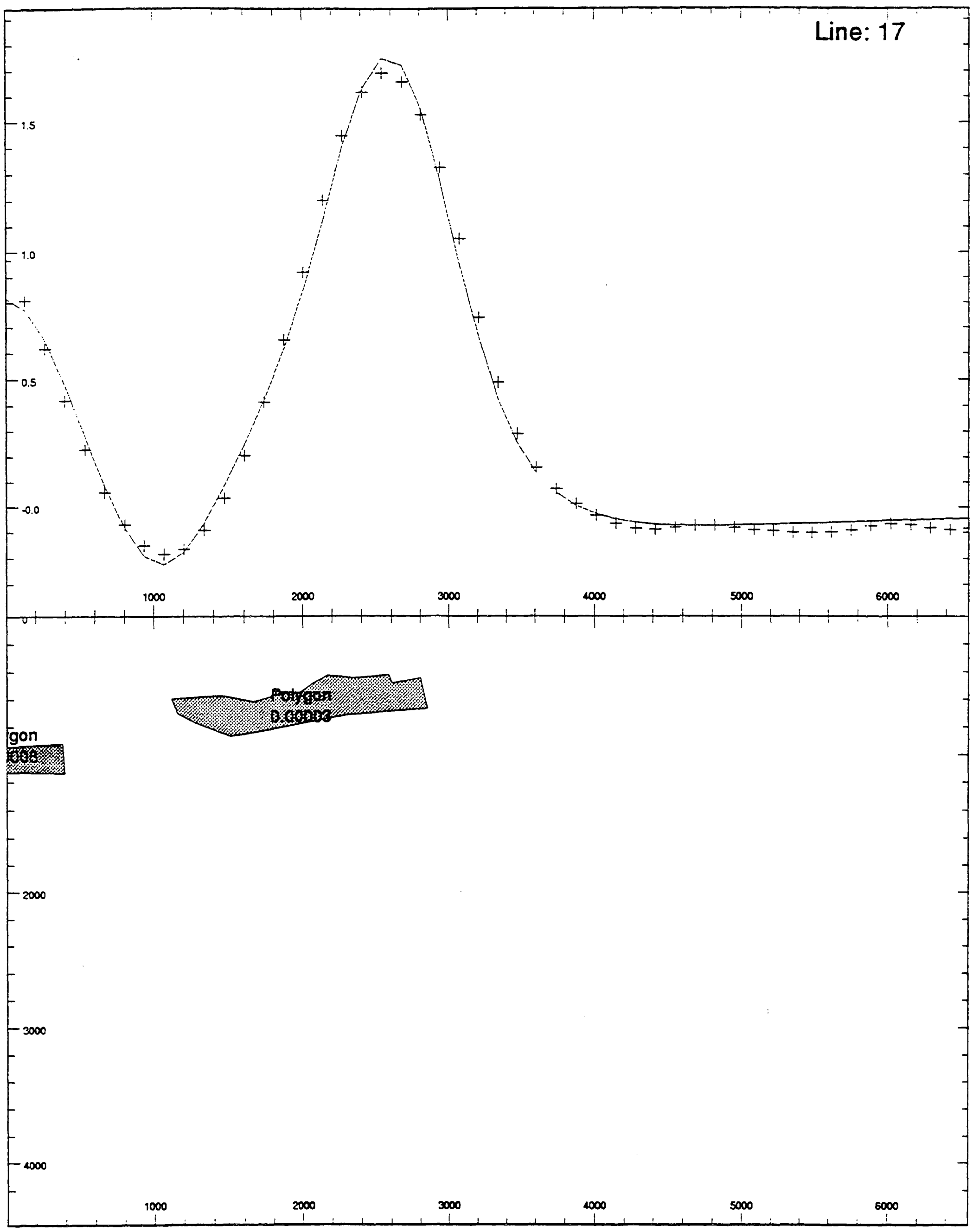
Line: 17
1.5
1.0
0.5
-0.0
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4000
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3000
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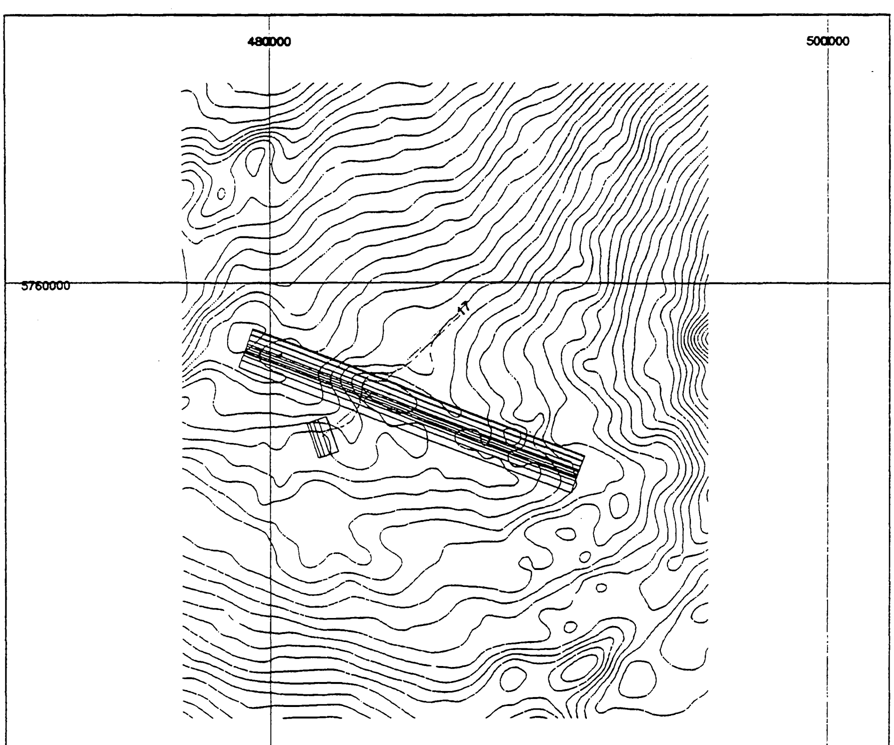
4000
5000
6000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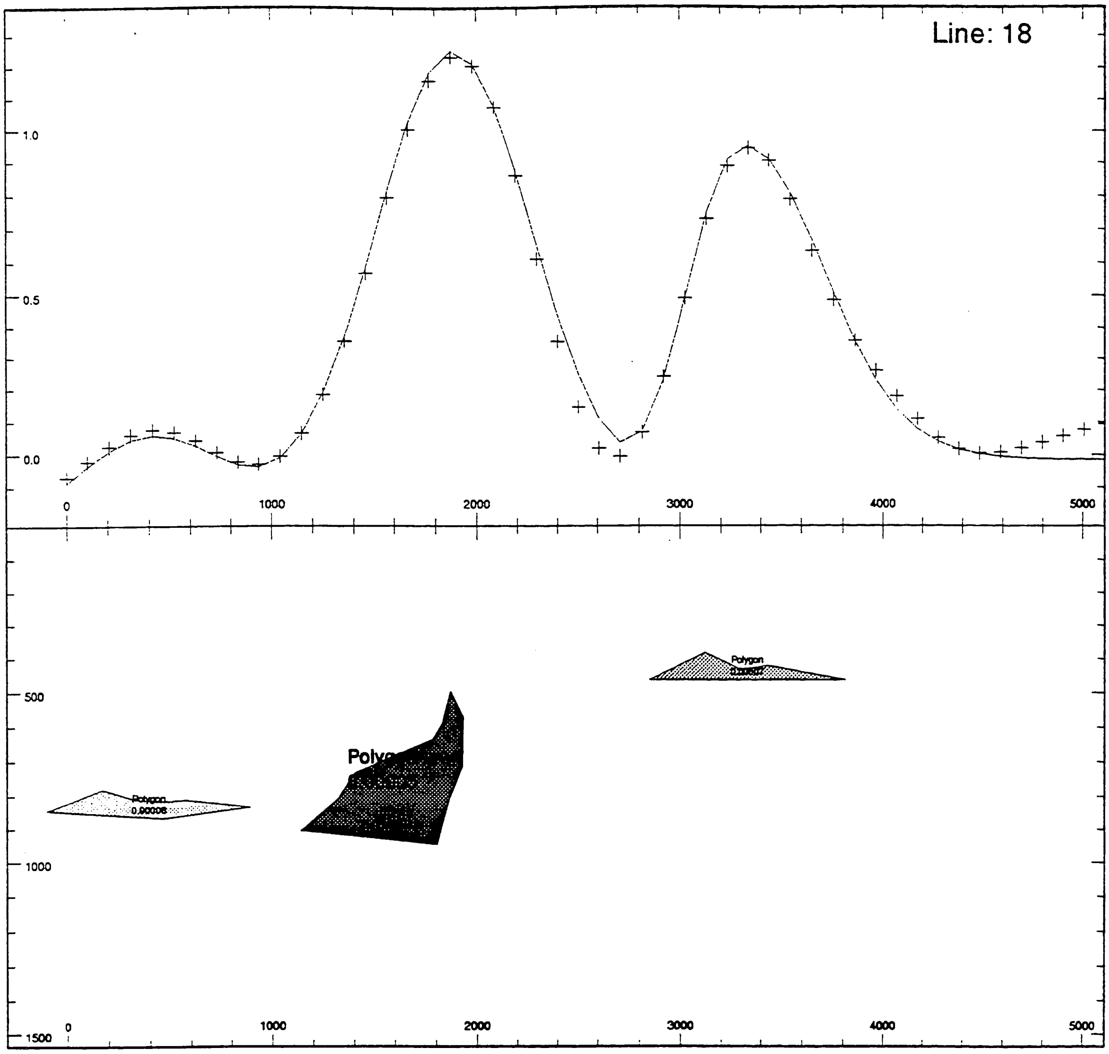
17


Line: 18
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0.5
0.0
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Polygon
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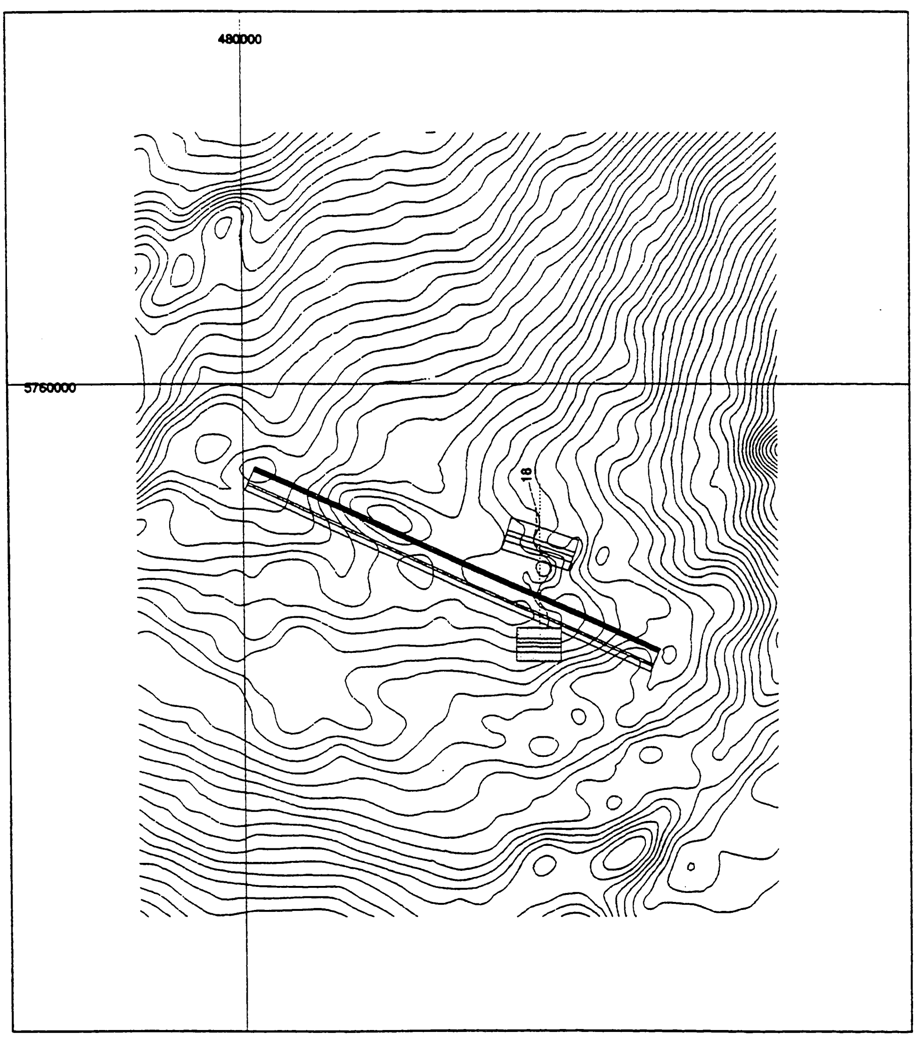
4000
5000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5760000
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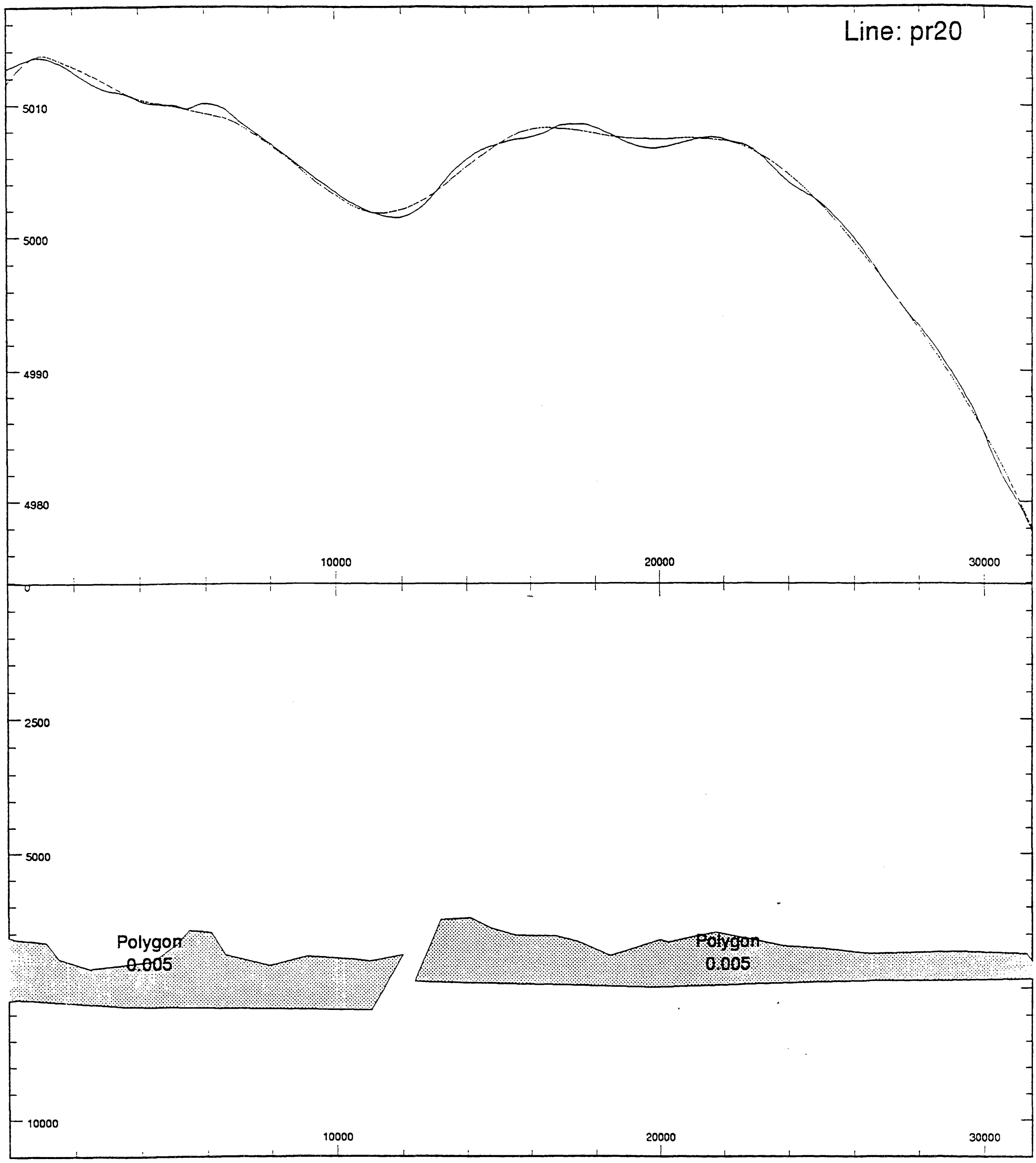

Line: pr20
5010
5000
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30000
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2500
5000
Polygon
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Polygon
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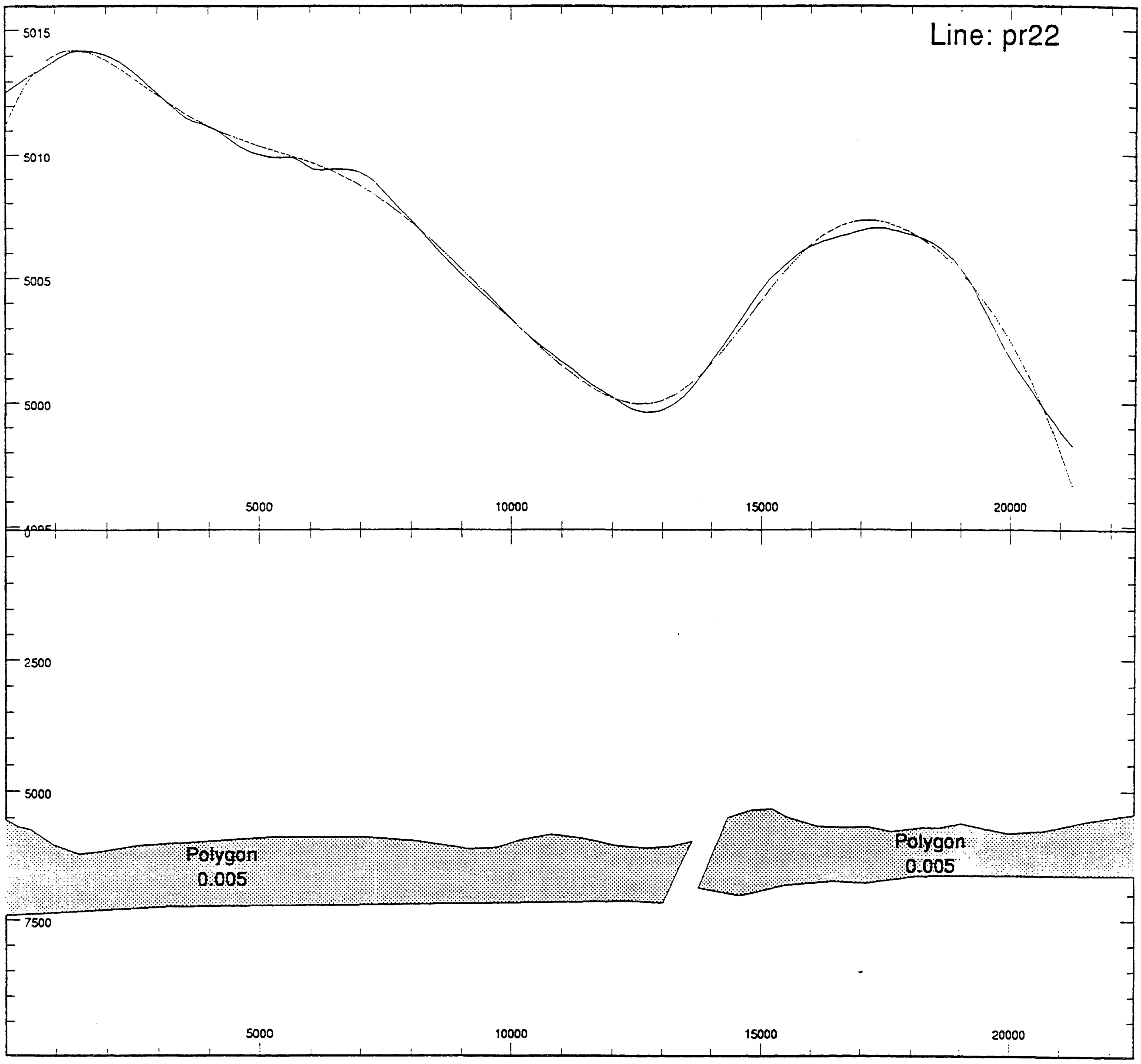
10000
10000
20000
30000



Line: pr22
5015
5010
5005
5000
5000
10000
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20000
2500
5000
7500
Polygon
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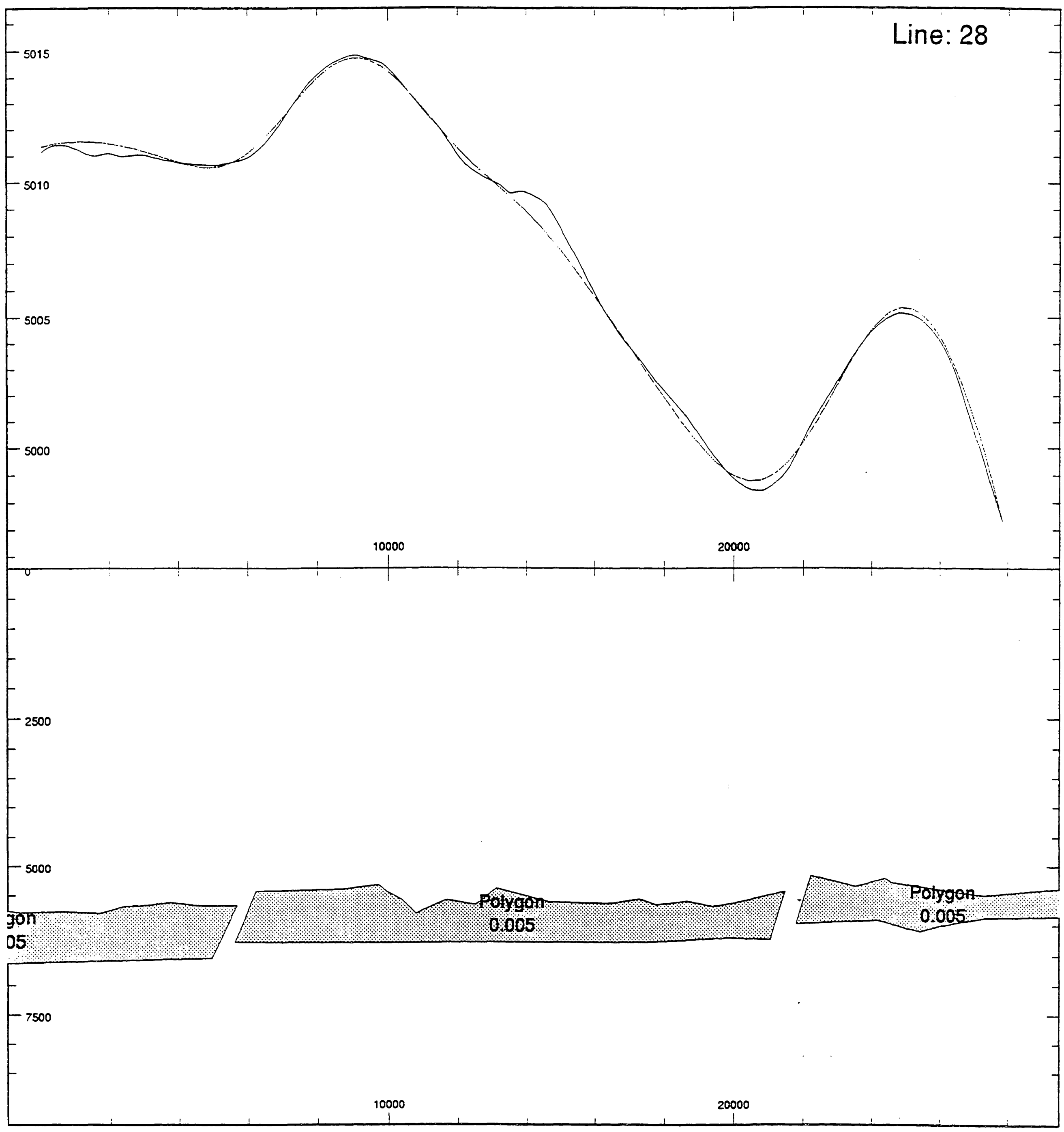
Polygon
0.005
5000
10000
15000
20000



Line: 28
5015
5010
5005
5000
10000
20000
0
2500
5000
7500
Polygon
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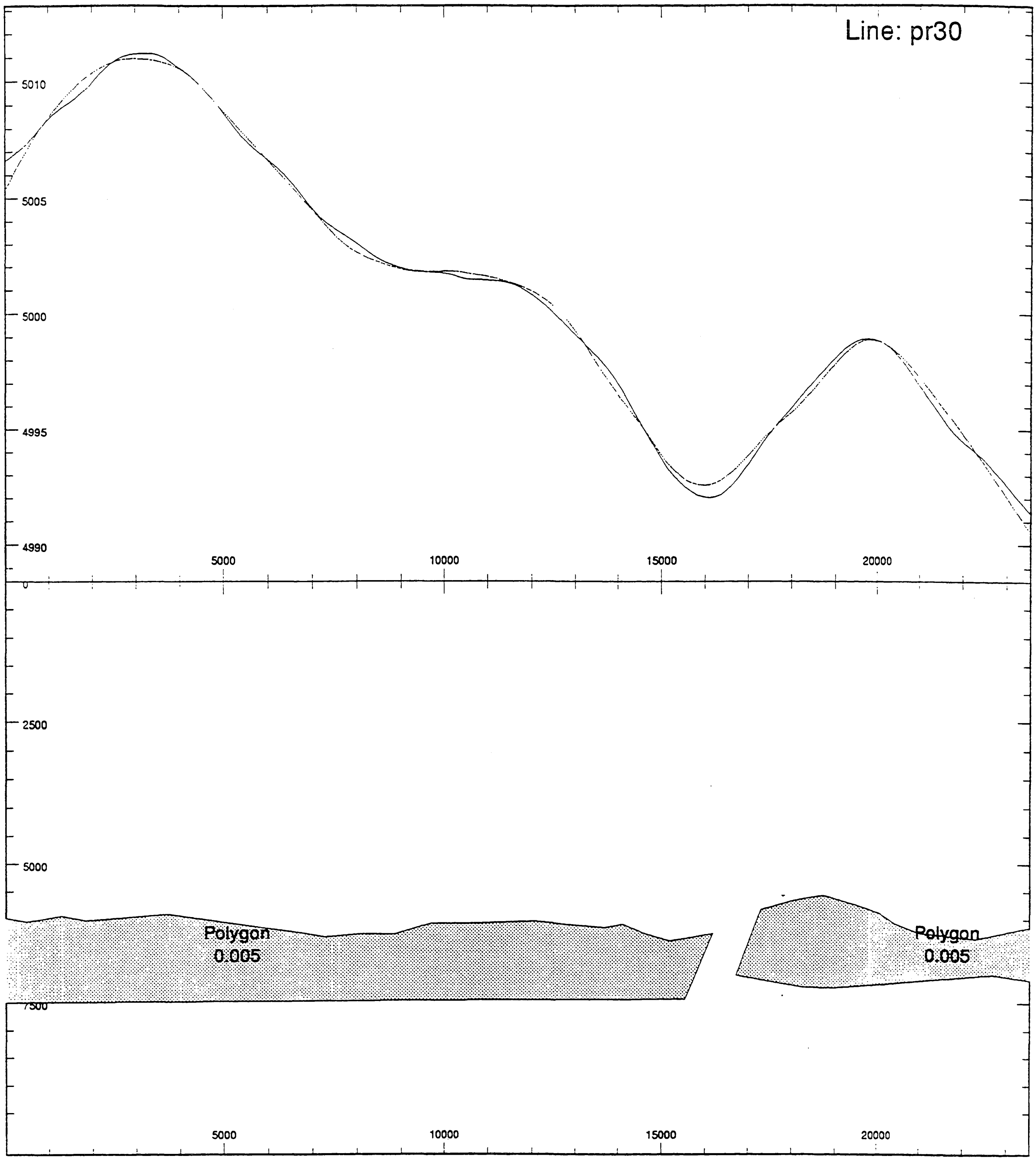
Polygon
0.005
gon
05
10000
20000


Line: pr30
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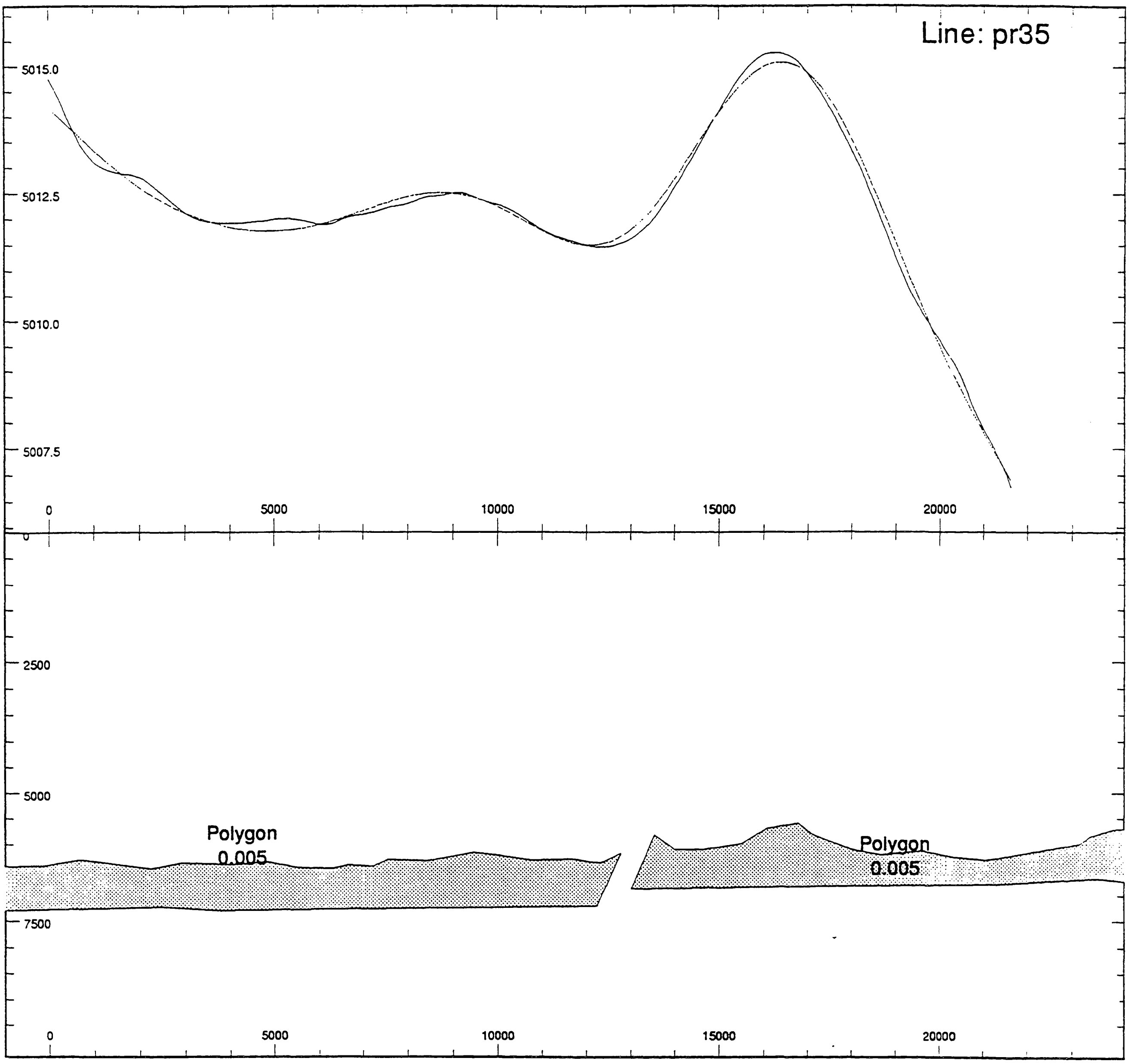
5005
5000
4995
4990
5000
10000
15000
20000
0
2500
5000
7500
Polygon
0.005
Polygon
0.005
5000
10000
15000
20000



Line: pr35
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5012.5
5010.0
5007.5
0
5000
10000
15000
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0
2500
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Polygon
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Polygon
0.005
0
5000
10000
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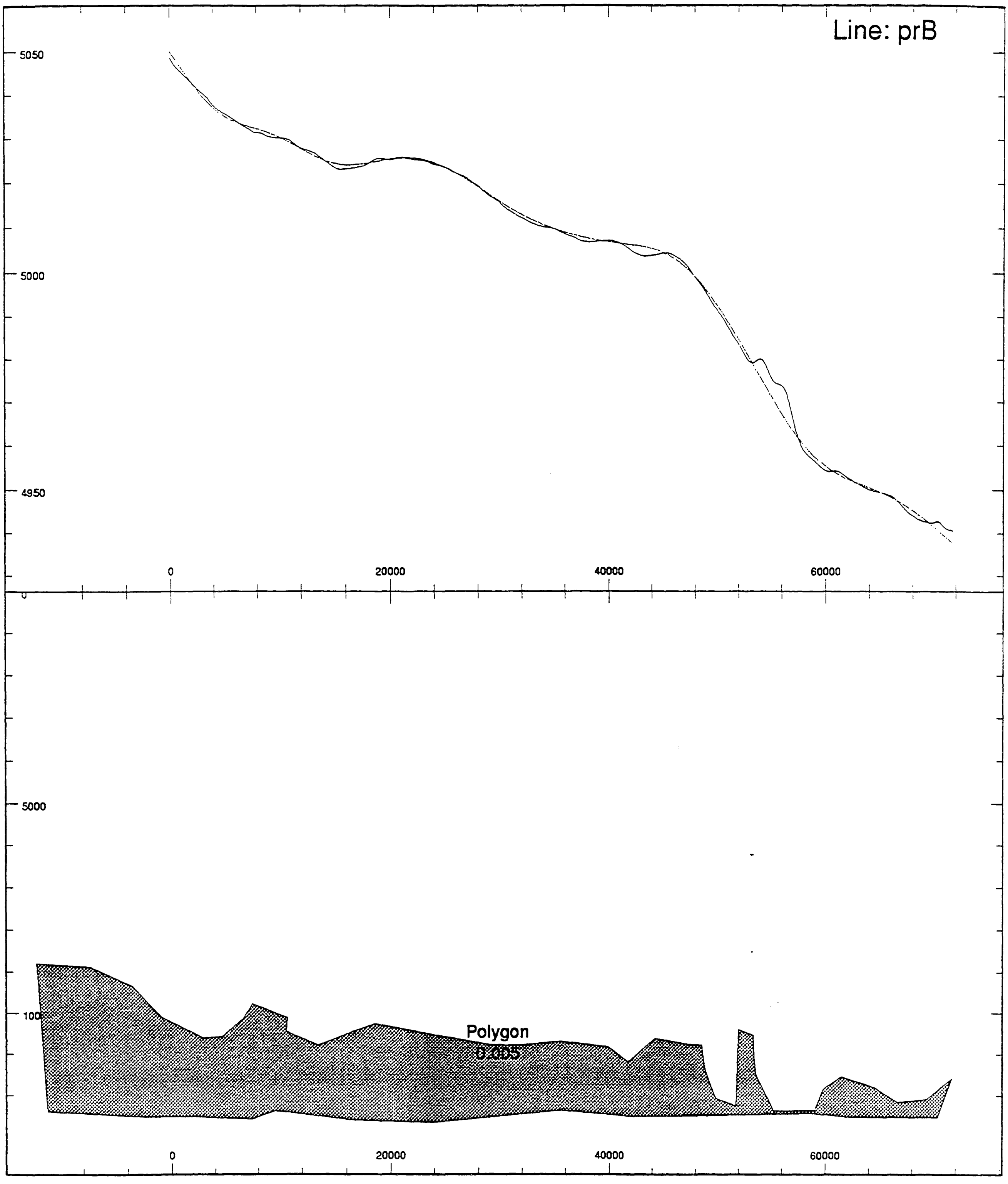
20000



Line: prB
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4950
0
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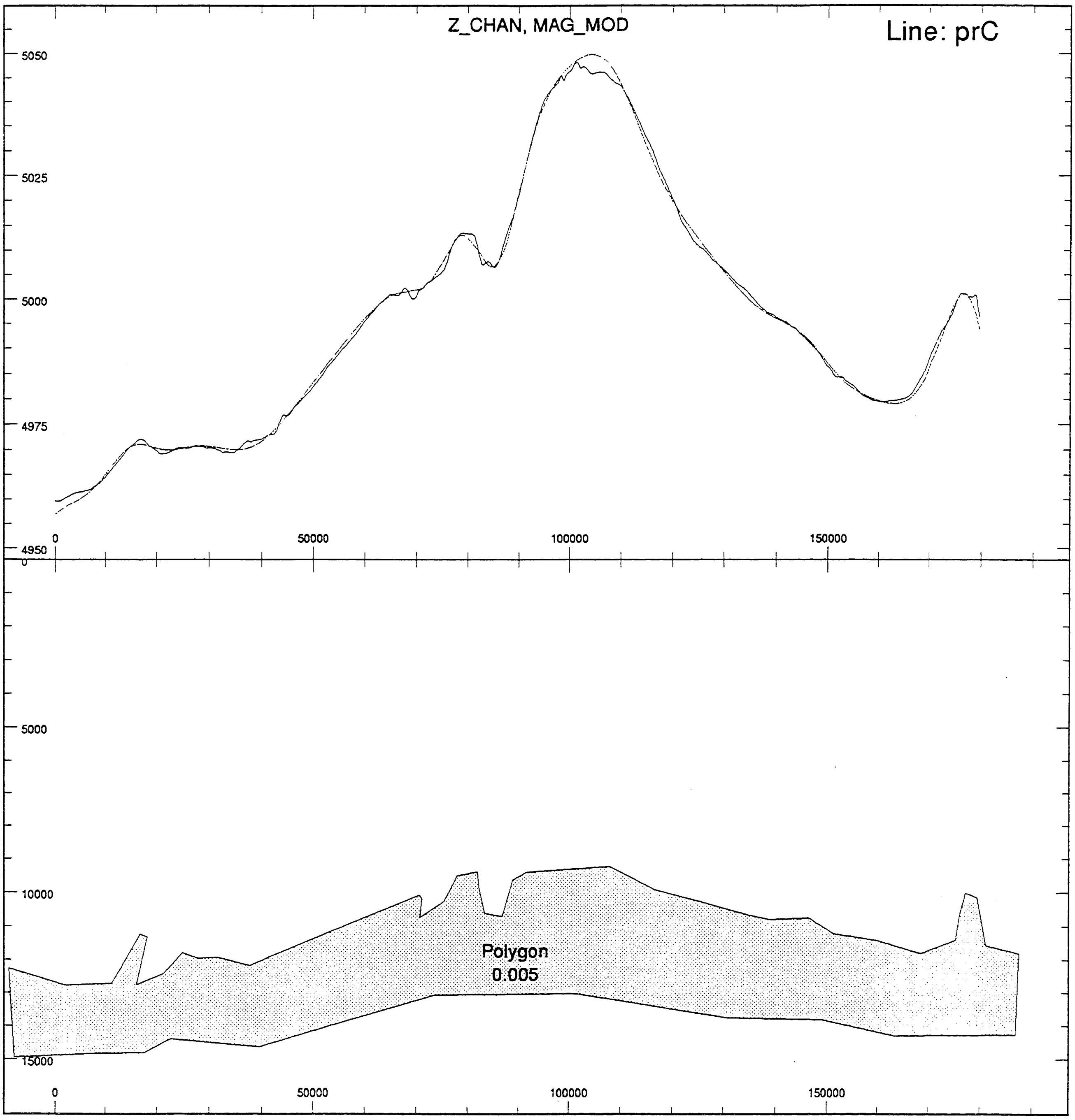
40000
60000
0
5000
Polygon
0
20000
40000
60000



Z_CHAN, MAG_MOD
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100000
150000
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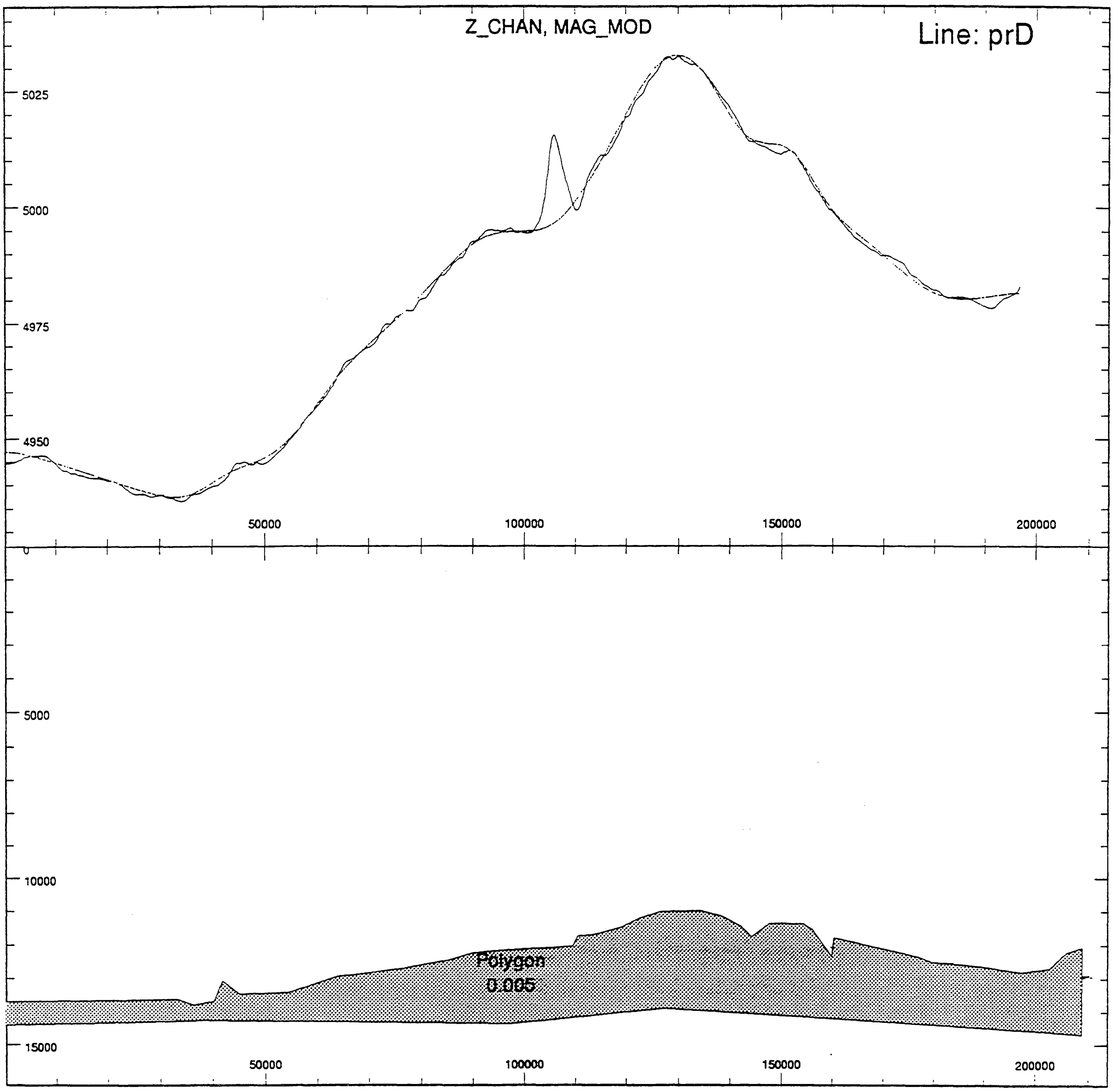
10000
15000
Polygon
0.005



Z_CHAN, MAG_MOD
Line: prD
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4950
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100000
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5000
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Polygon
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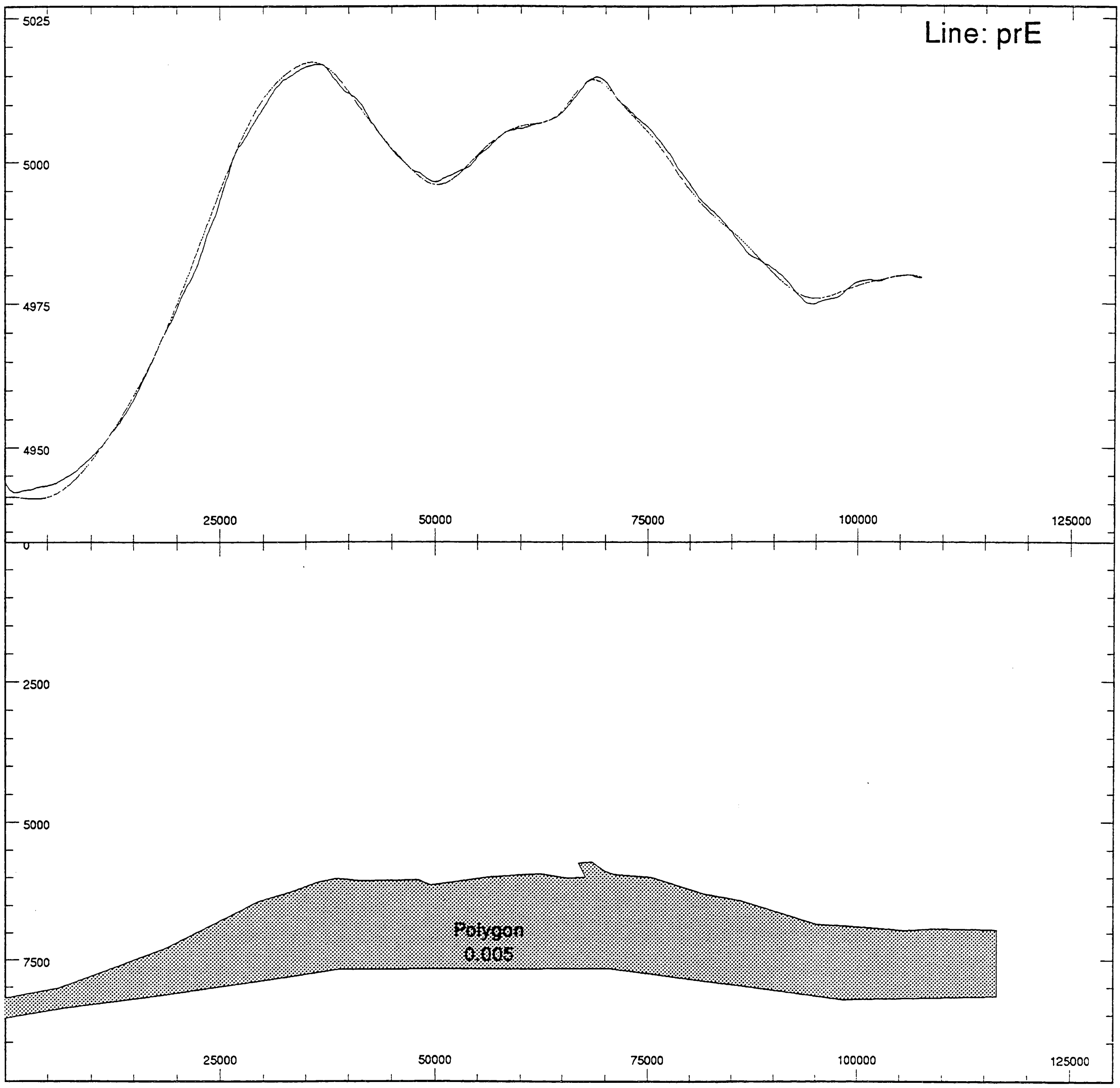
100000
150000
200000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4950
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100000
125000
0
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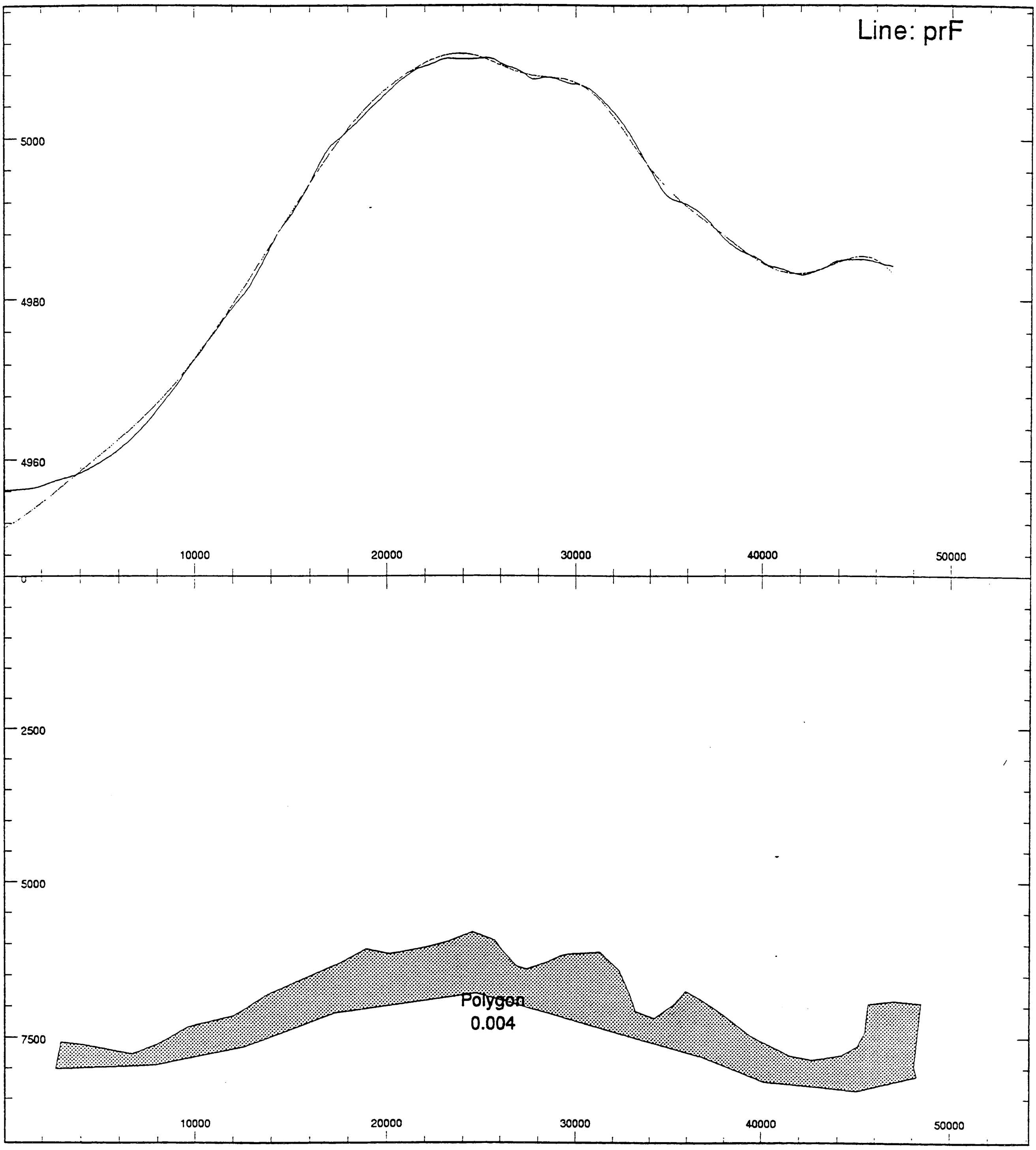
5000
7500
Polygon
0.005



Line: prF
5000
4980
4960
10000
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50000
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5000
7500
Polygon
0.004
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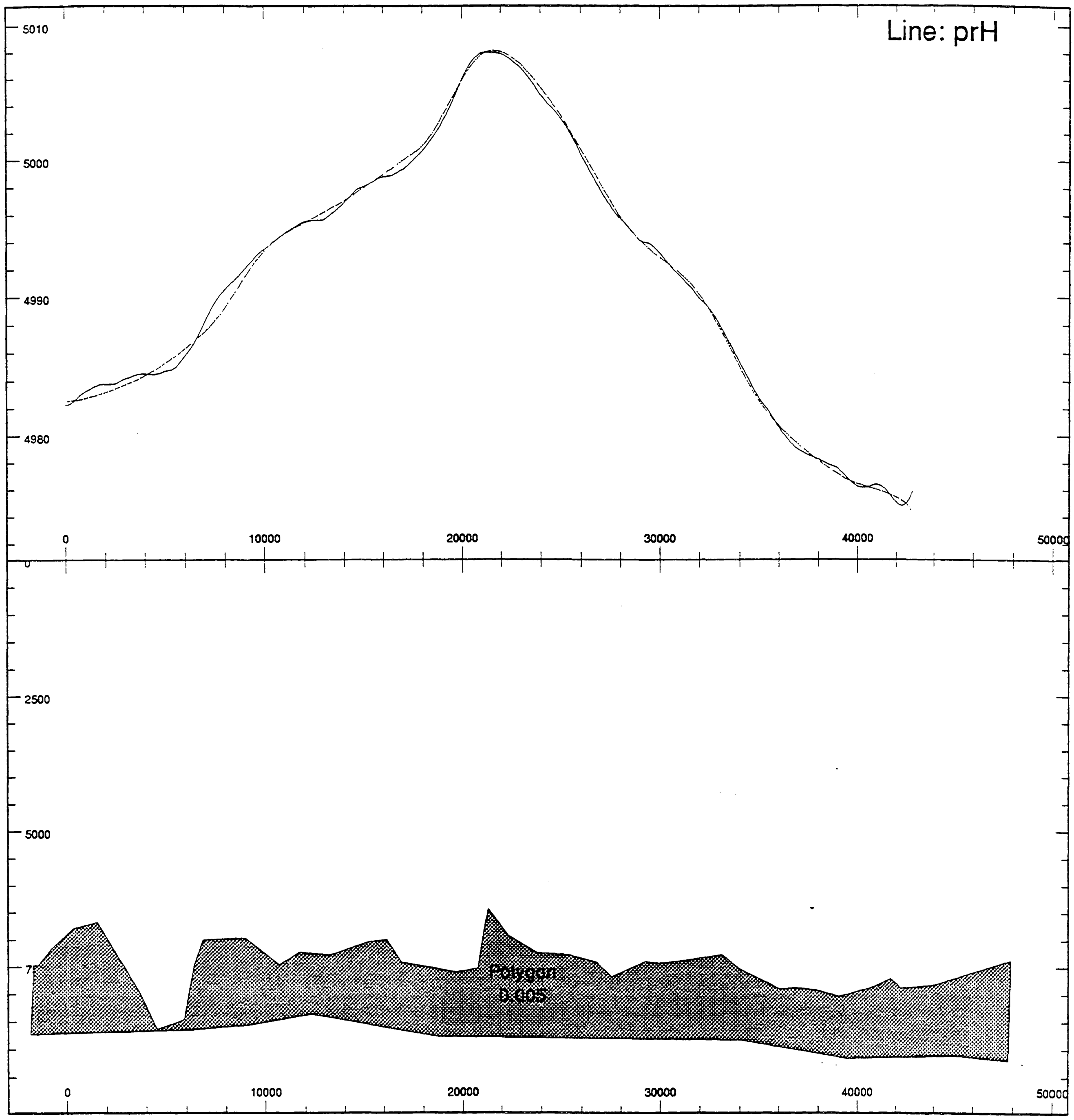
20000
30000
40000
50000



Line: prH
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5000
4990
4980
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40000
50000
0
2500
5000
Polygon
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0
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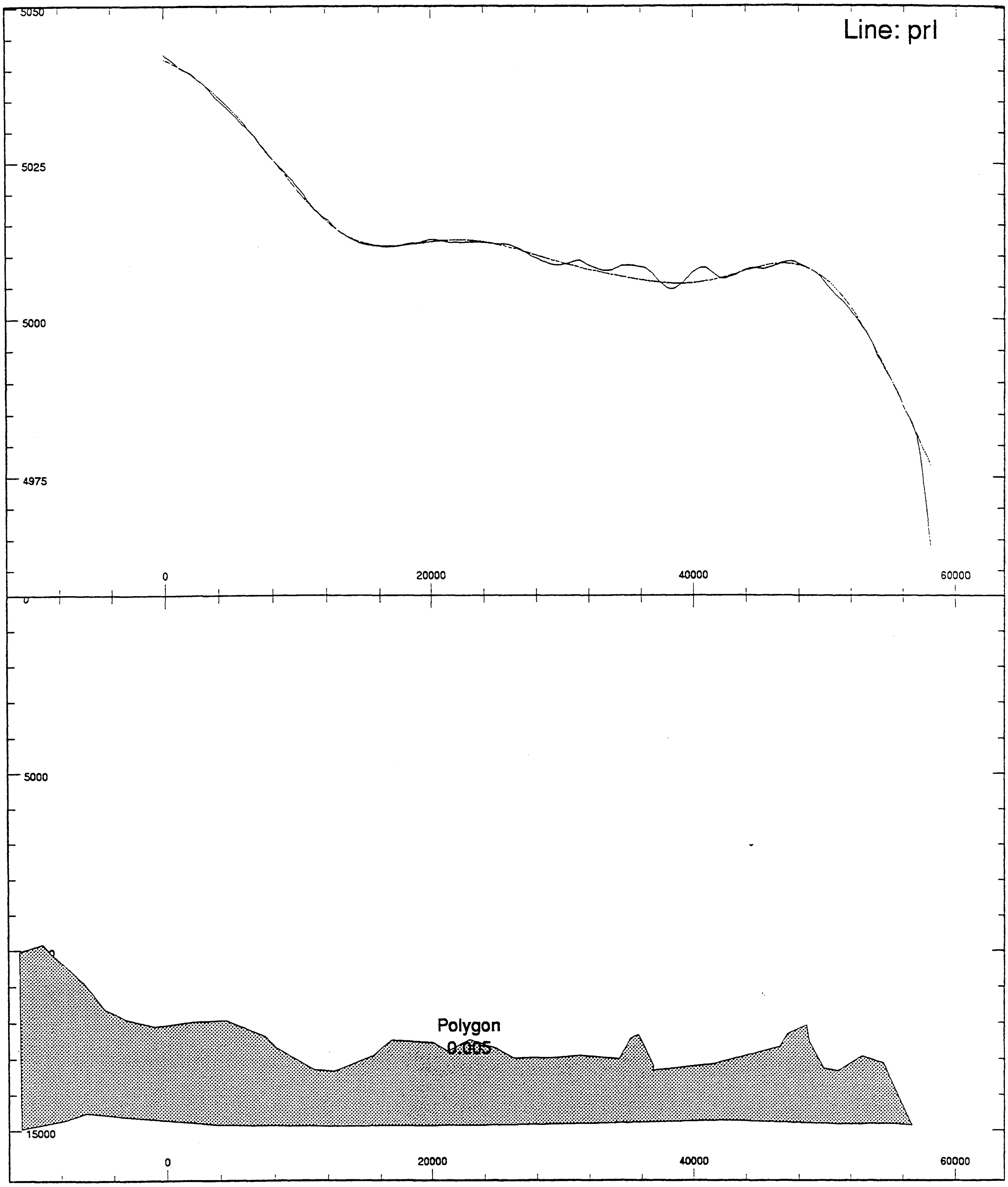
30000
40000
50000



Line: prl
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20000
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60000
0
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Polygon
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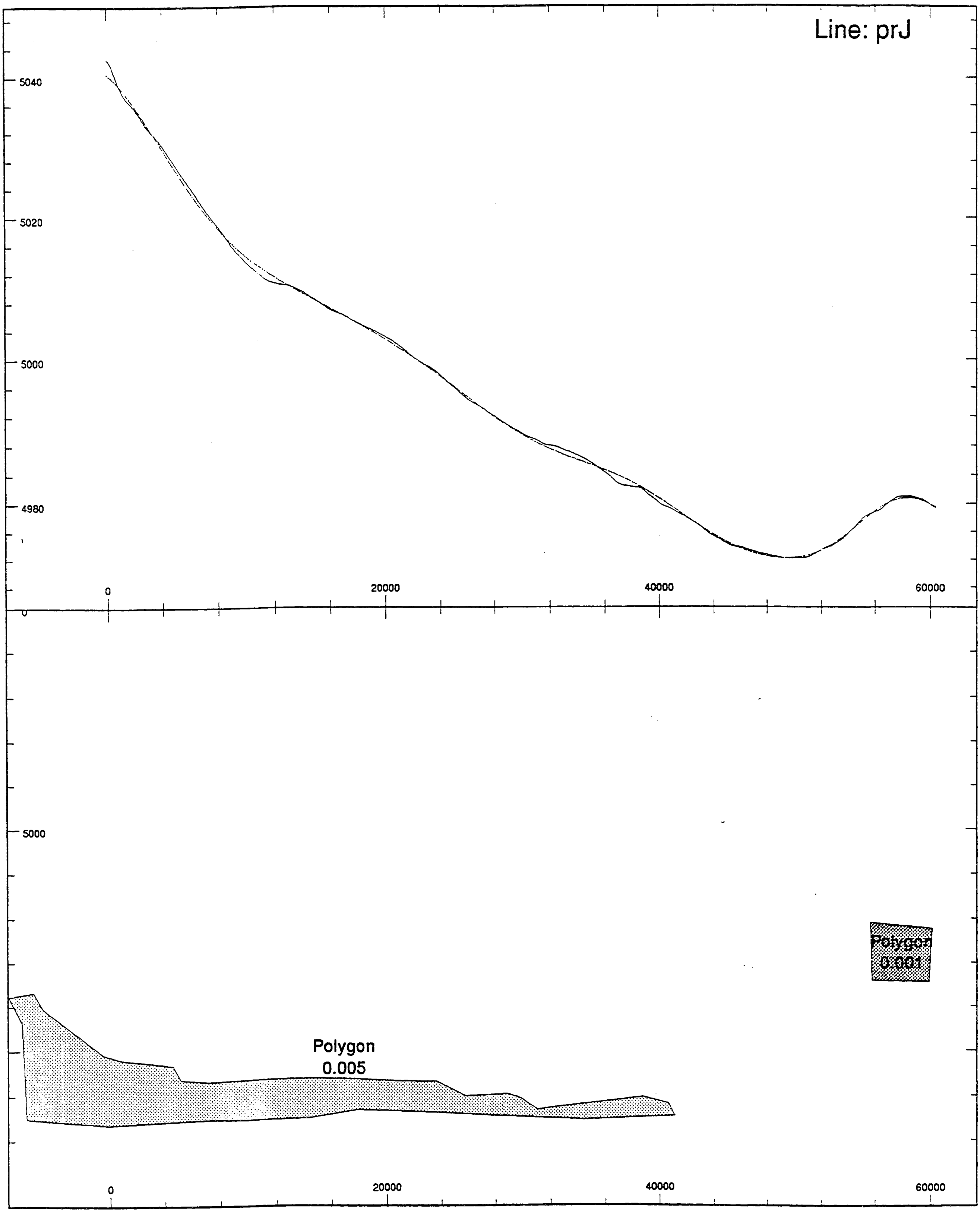
0
20000
40000
60000



Line: prJ
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5000
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Polygon
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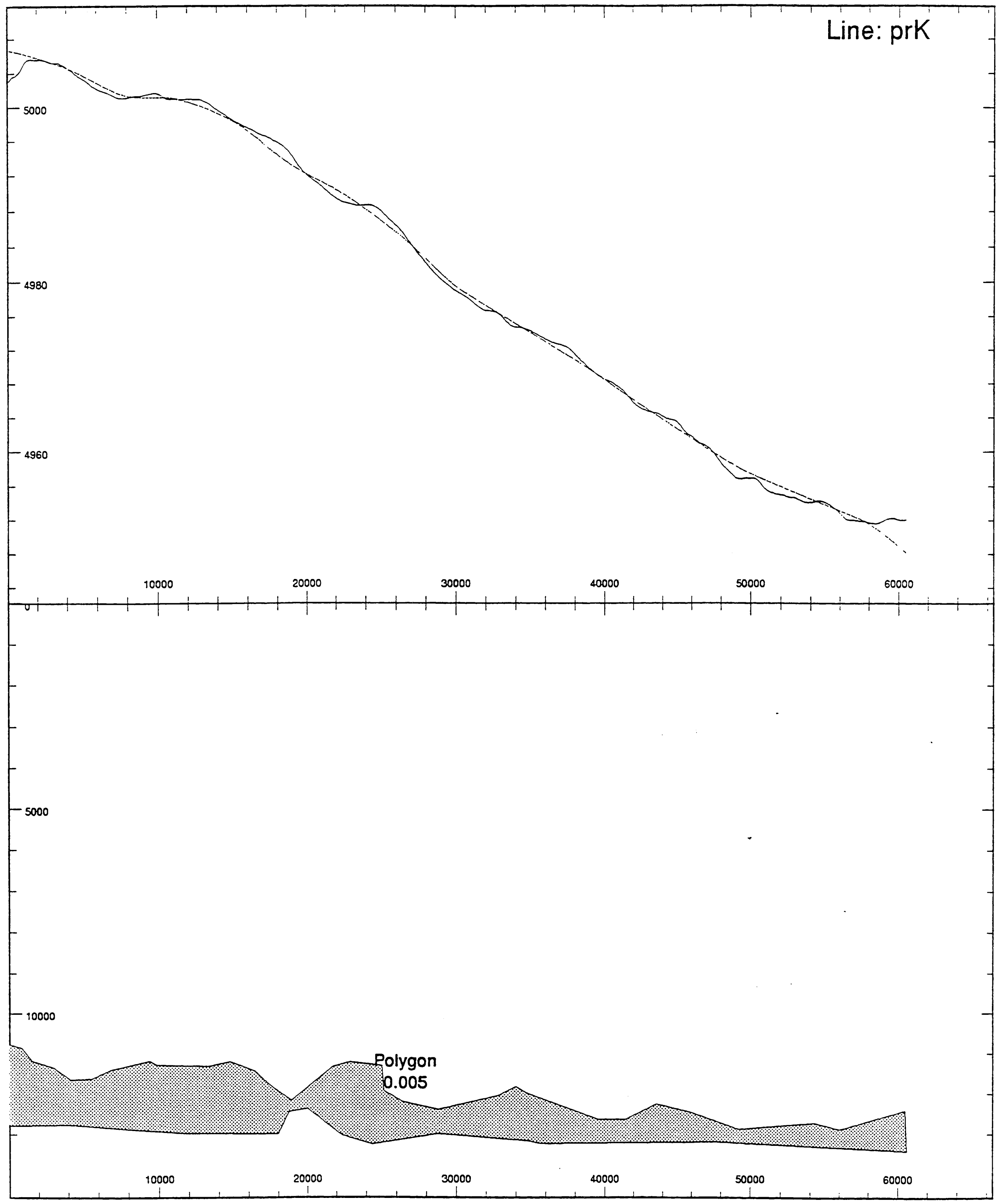
40000
60000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4960
10000
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Polygon
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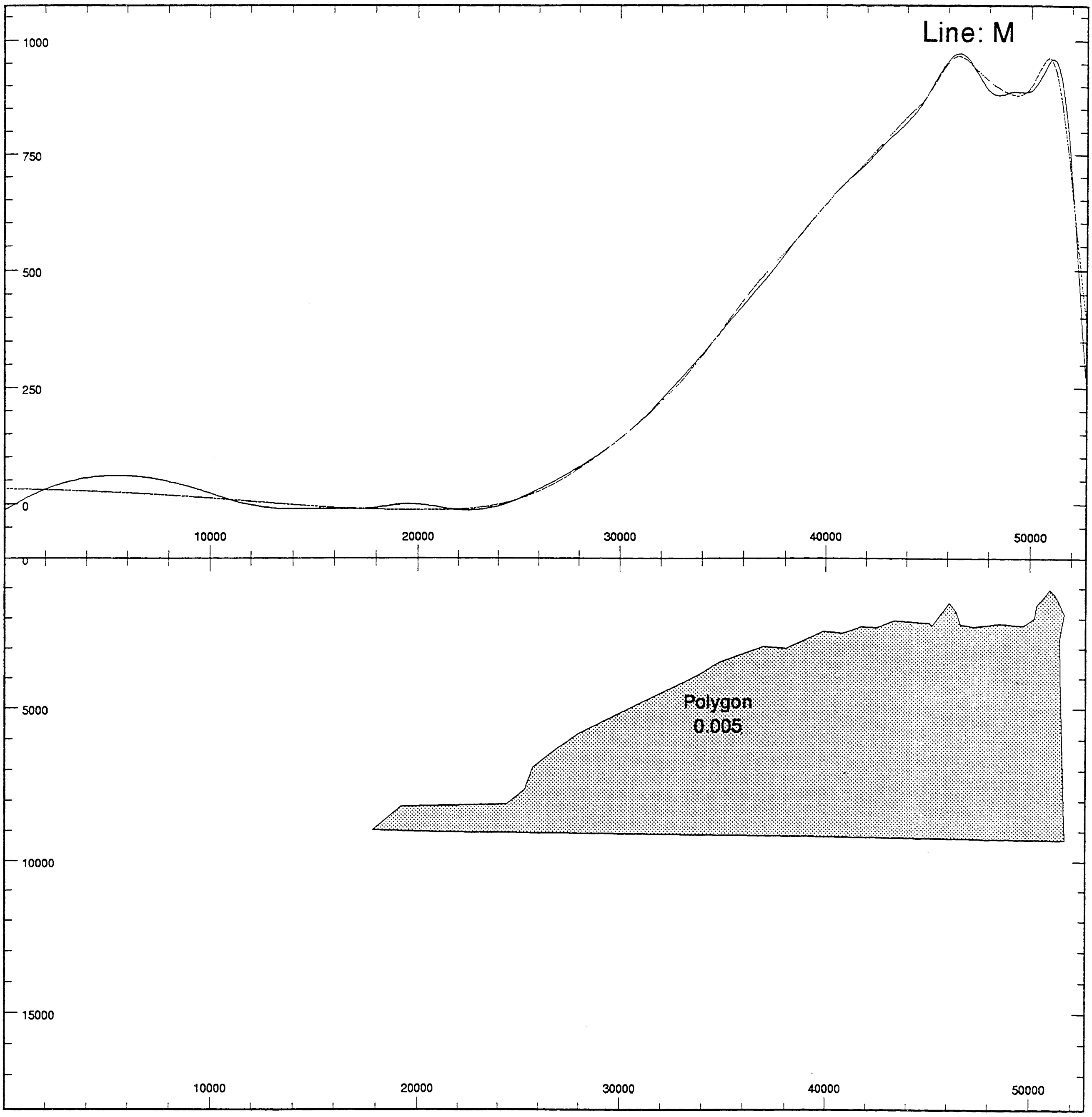
30000
40000
50000
60000



Line: M
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750
500
250
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10000
20000
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50000
0
5000
10000
15000
Polygon
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20000
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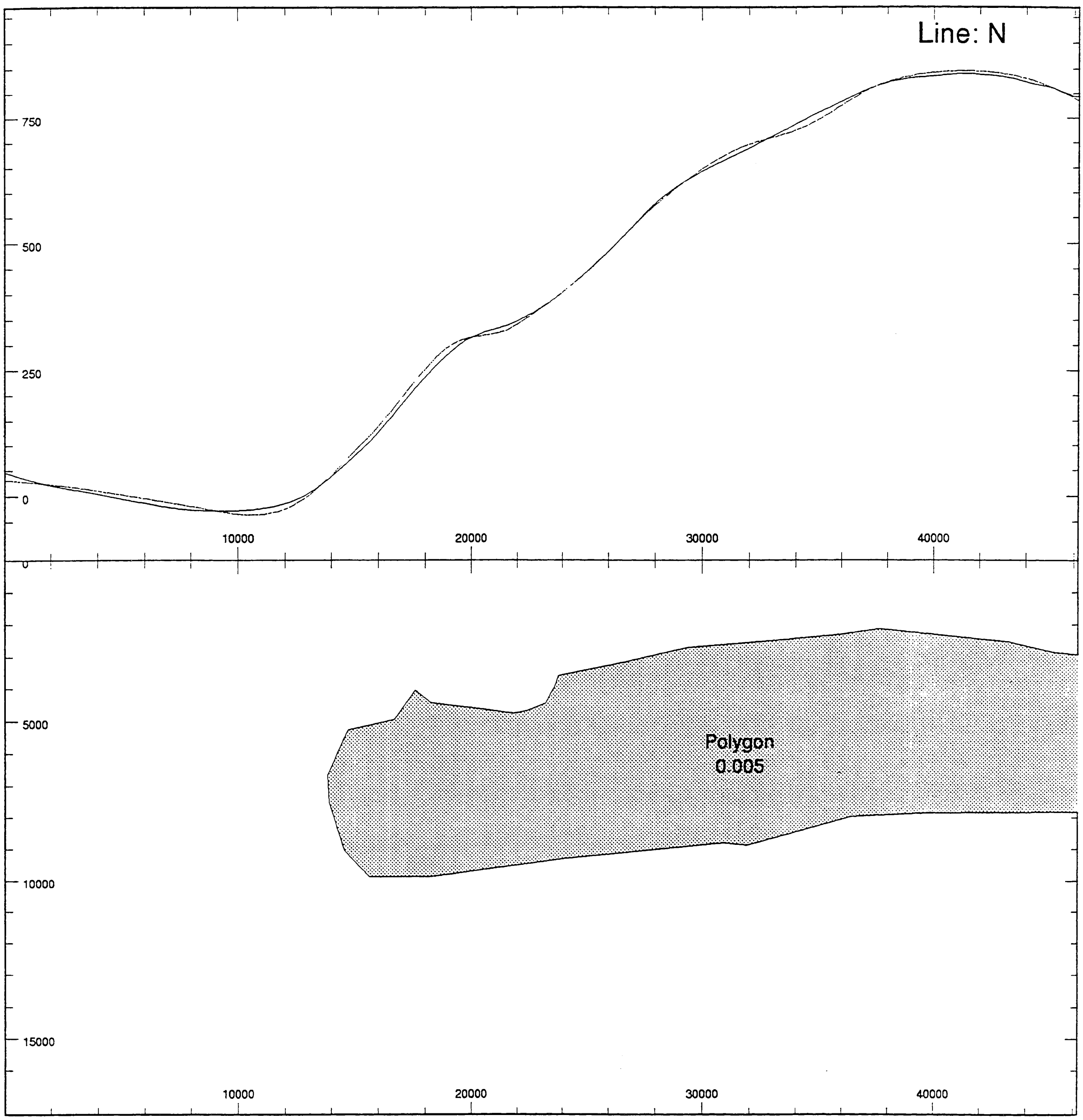
40000
50000



Line: N
750
500
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30000
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0
5000
Polygon
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10000
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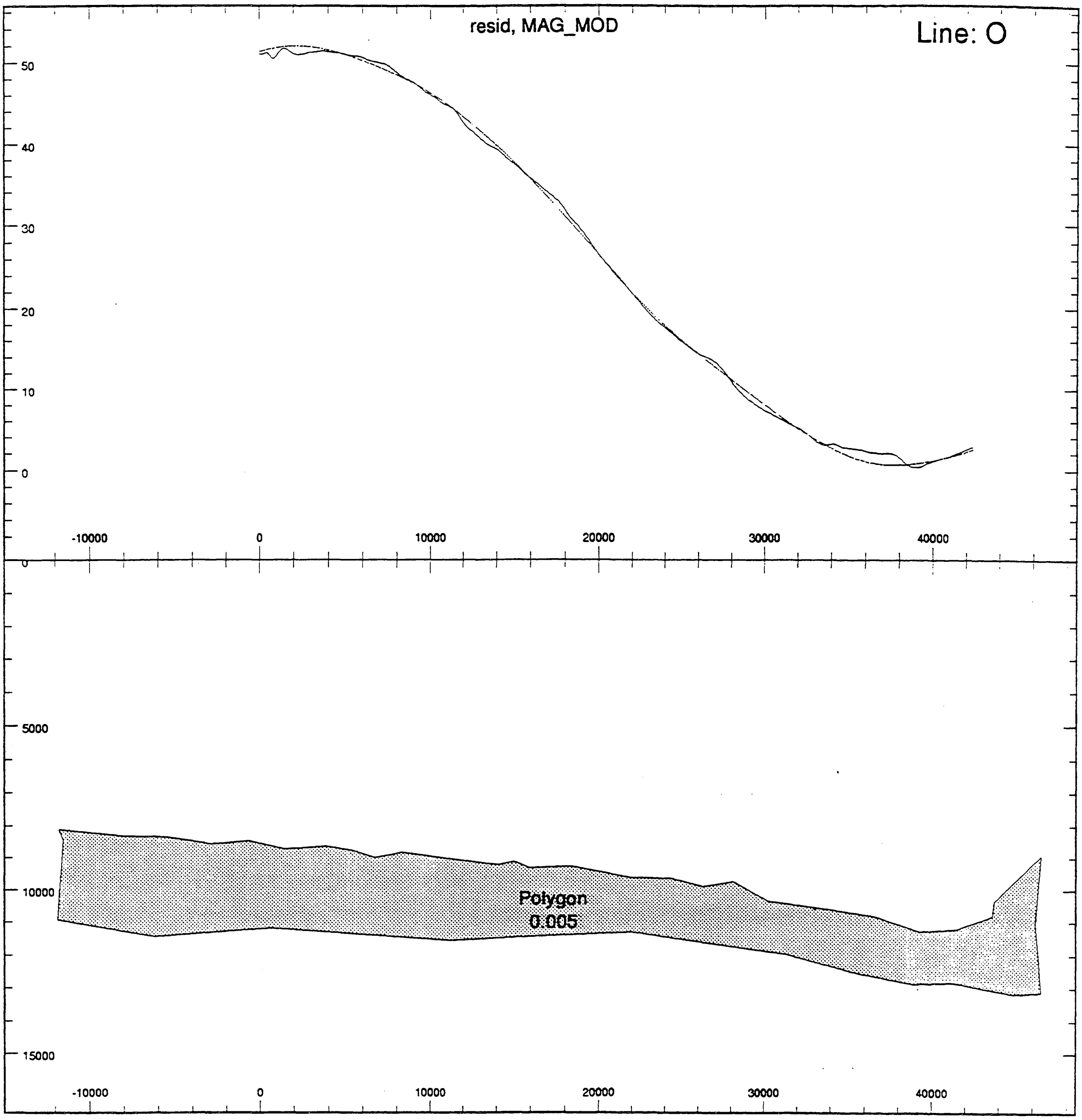
30000
40000


resid, MAG_MOD
Line: O
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10
0
-10000
0
10000
20000
30000
40000
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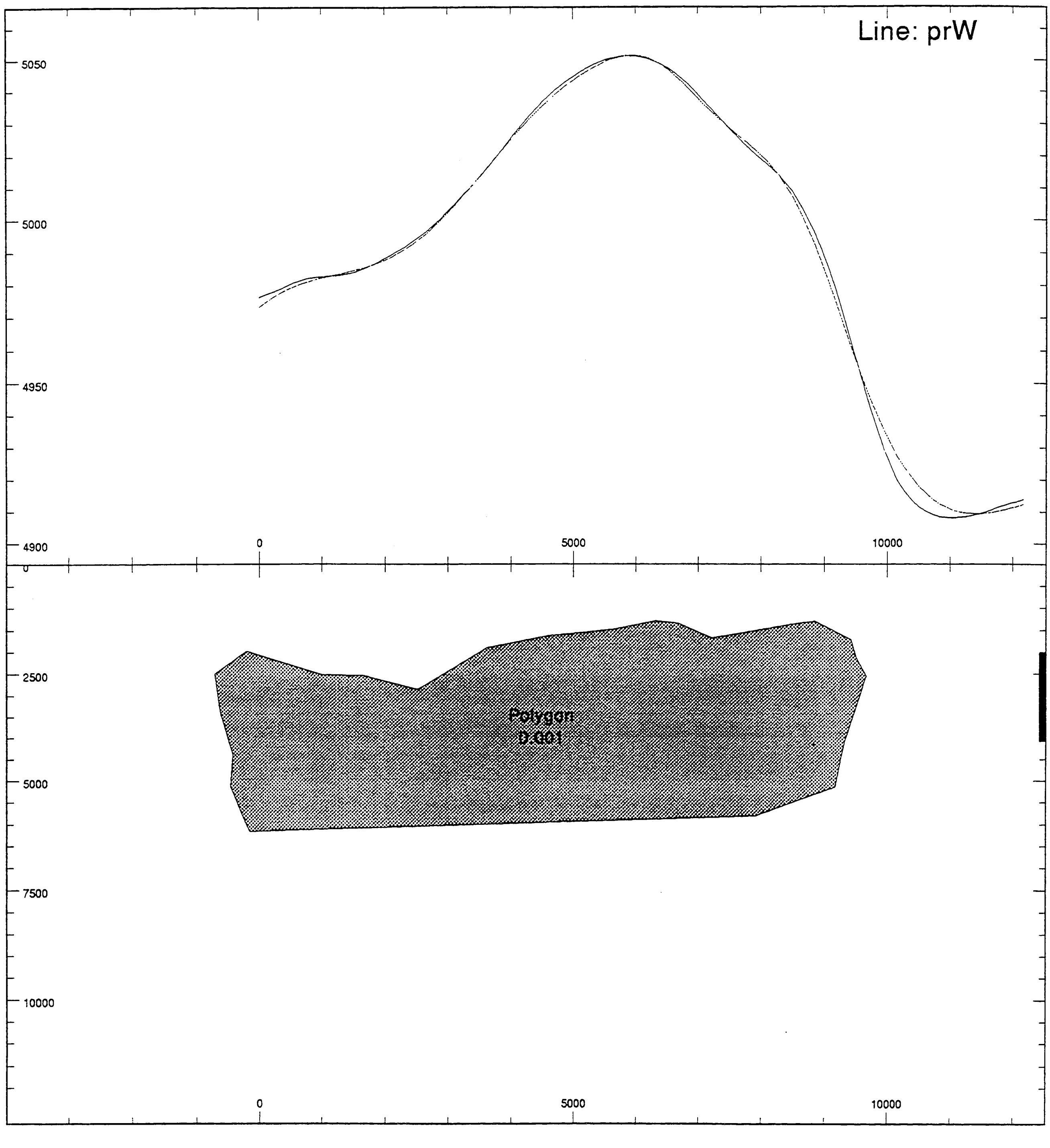
10000
15000
Polygon
0.005
-10000
0
10000
20000
30000
40000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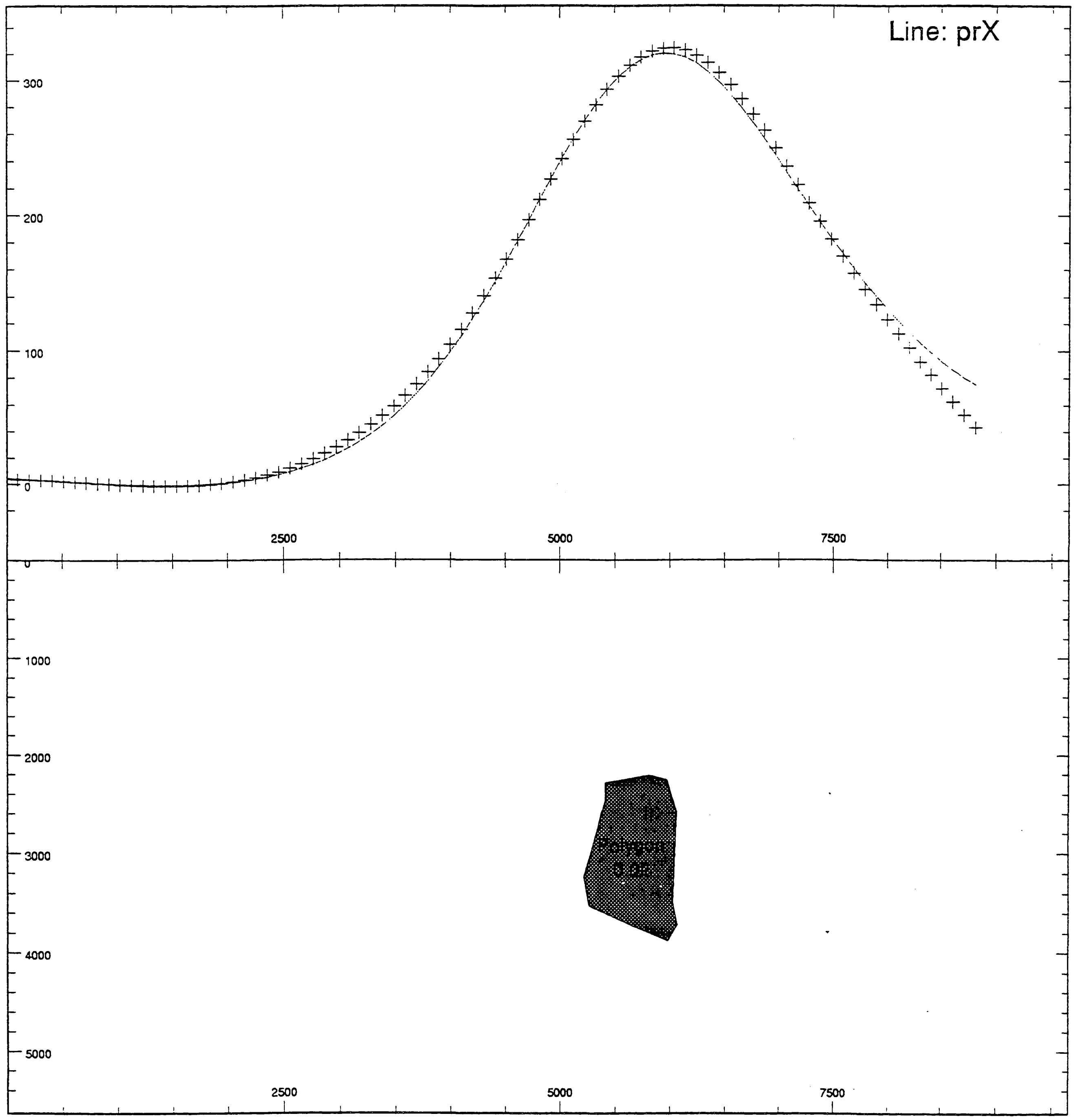
4950
4900
0
5000
10000
0
2500
5000
7500
10000
Polygon
D.001
0
5000
10000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2500
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7500
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1000
2000
3000
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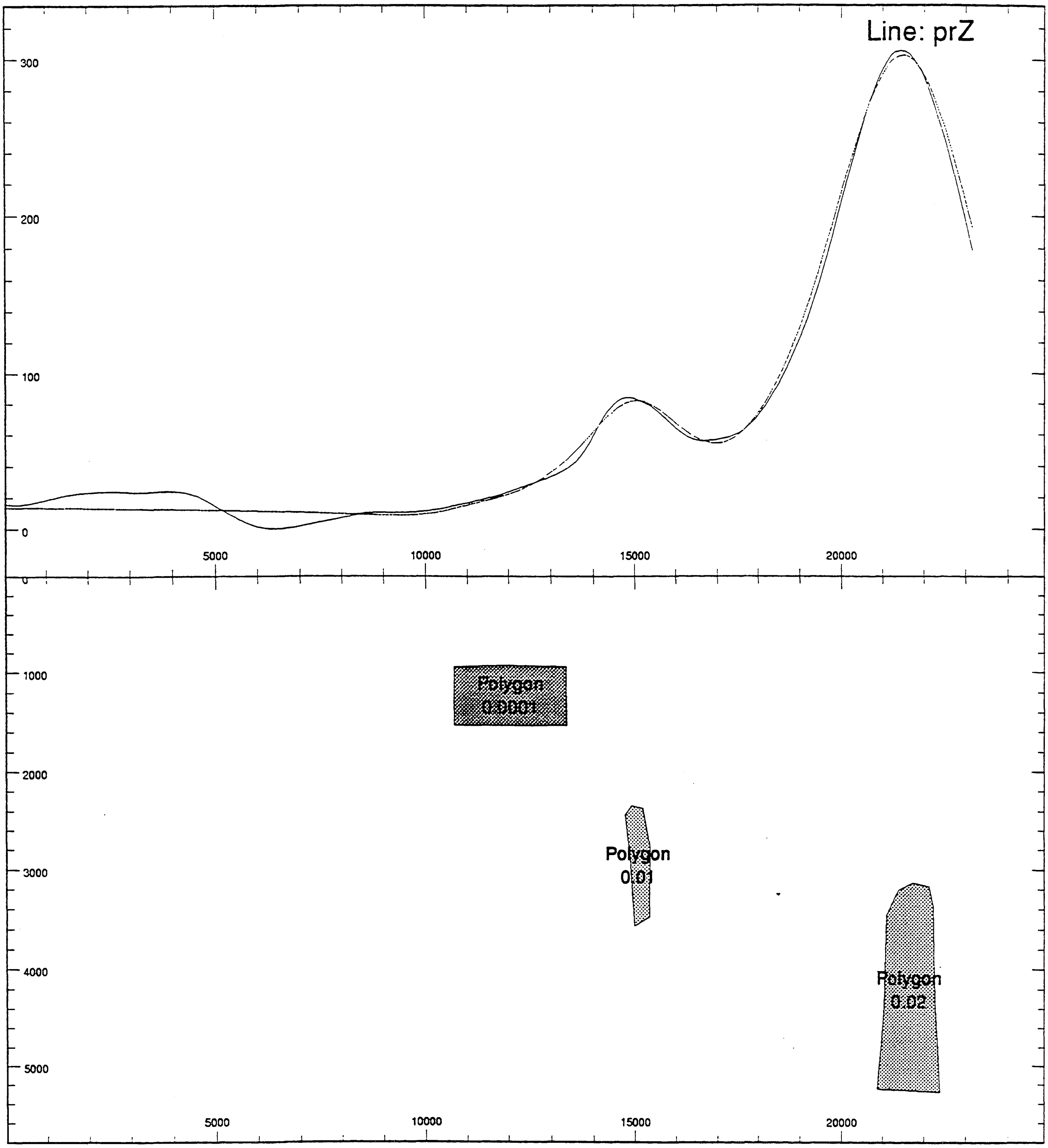
5000
2500
5000
7500



Line: prZ
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100
0
5000
10000
15000
20000
1000
2000
3000
4000
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Polygon
0.0001
Polygon
0.01
Polygon
0.02

FIGURES

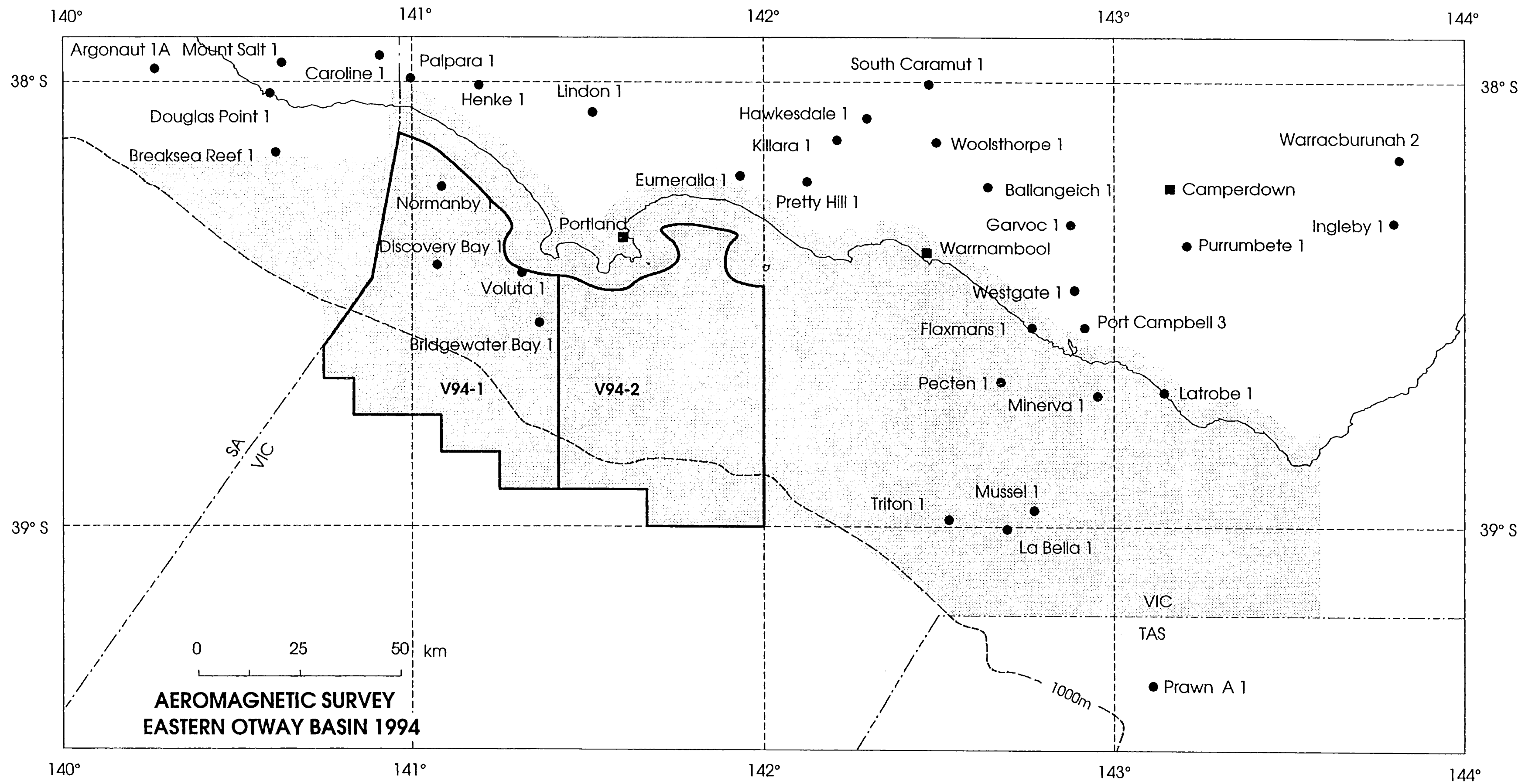


Figure 1. Survey Location

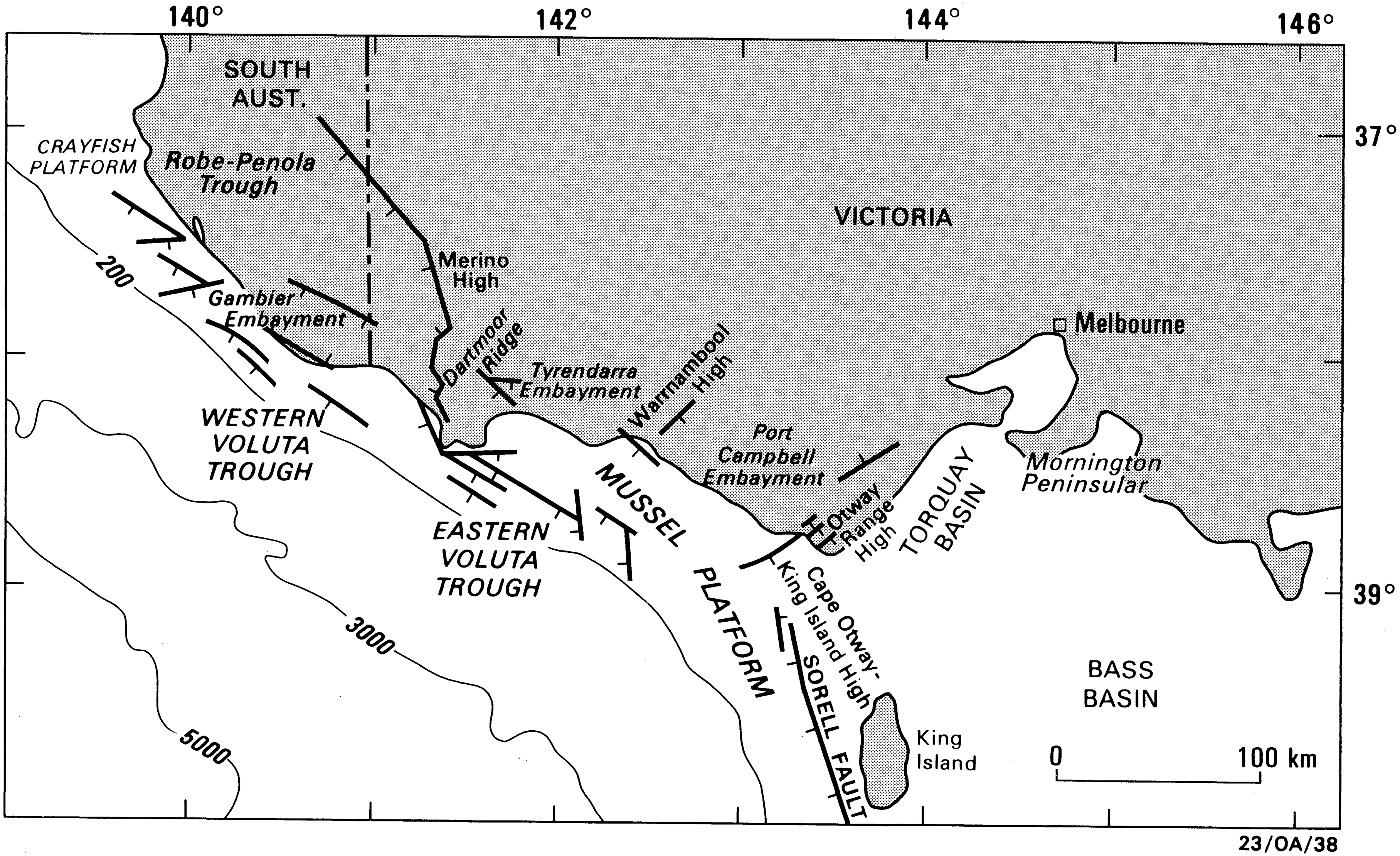


Figure 2 Otway Basin structural elements

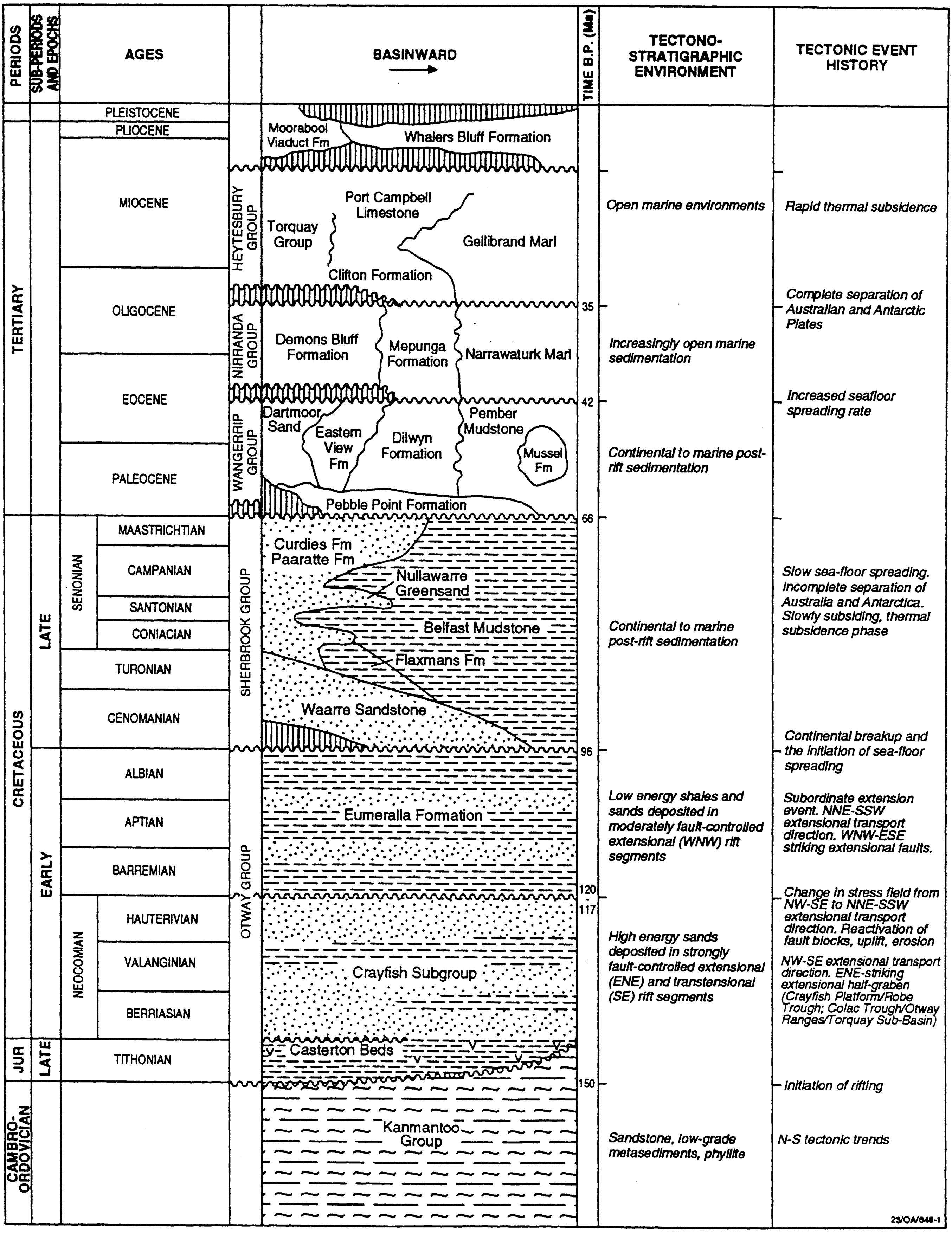
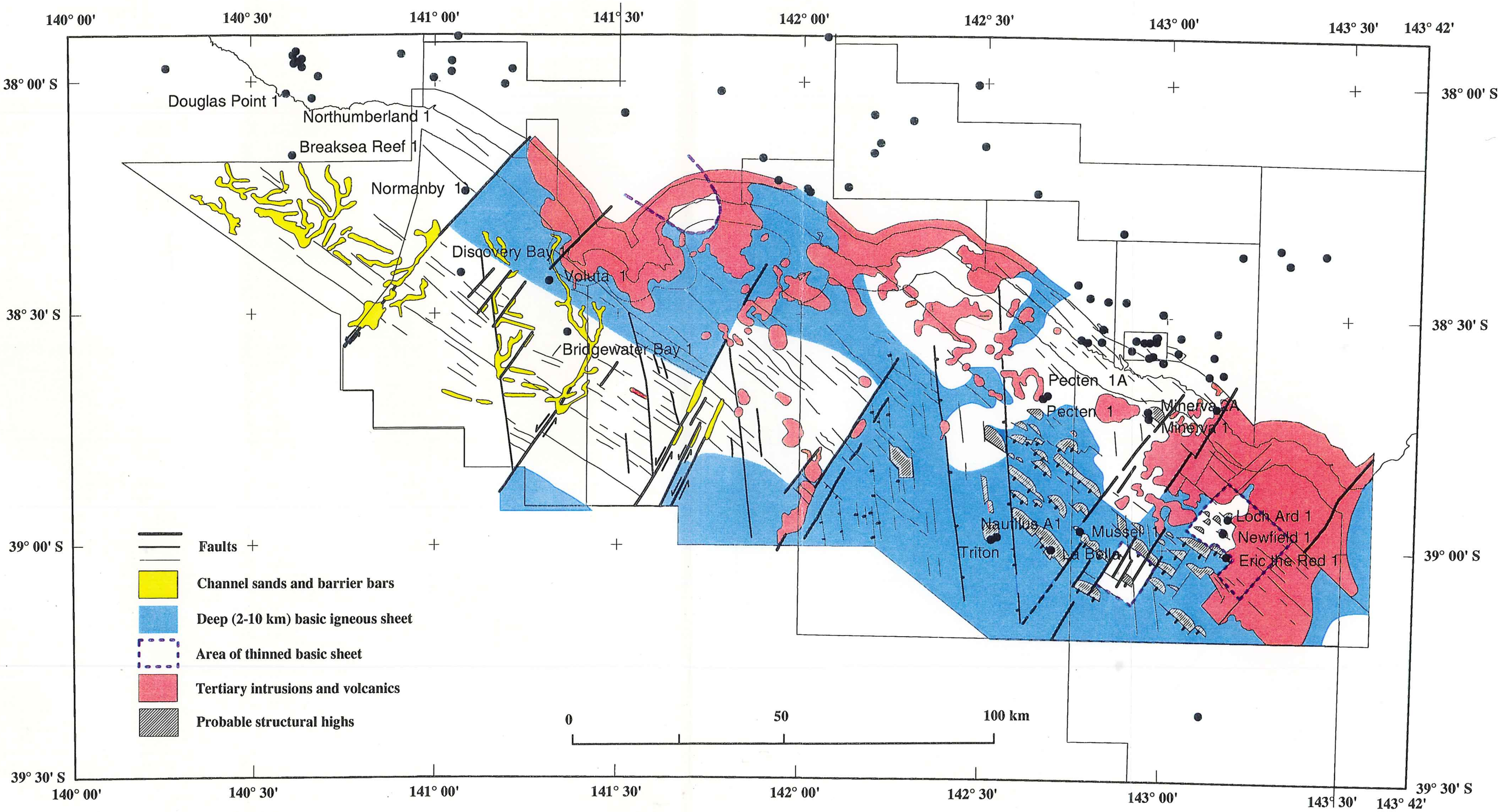


Figure 3 Stratigraphic column

Figure 4 **Interpretation map**

1:1 000 000 scale

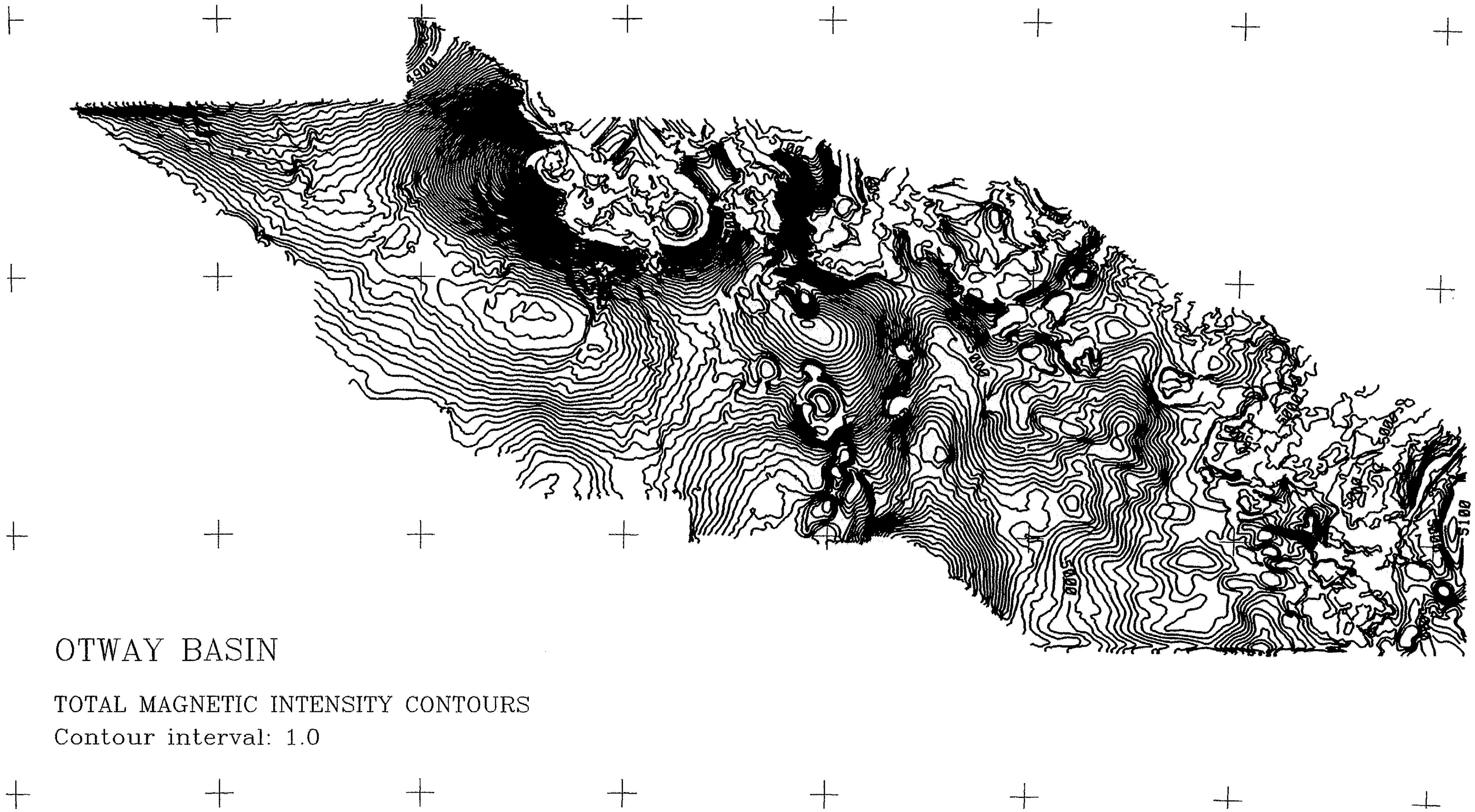


140° 00'
140° 30'
141° 00'
141° 30'
142° 00'
142° 30'
143° 00'
143° 30'
143° 42'
38° 00' S
38° 30' S
39° 00' S
39° 30' S
Douglas Point 1
Northumberland 1
Breaksea Reef 1
Normanby 1
Discovery Bay 1
Voluta 1
Bridgewater Bay 1
Pecten 1A
Pecten 1
Minerva 2A
Minerva 1
Loch Ard 1
Newfield 1
Eric the Red 1
Nautilus A1
Triton
Mussel 1
La Bella
Faults
Channel sands and barrier bars
Deep (2-10 km) basic igneous sheet
Area of thinned basic sheet
Tertiary intrusions and volcanics
Probable structural highs
0
50
100 km

Figure 5 **Total magnetic intensity contours**

1:1 000 000 scale

R9702403



OTWAY BASIN

TOTAL MAGNETIC INTENSITY CONTOURS
Contour interval: 1.0

R9702404

Figure 6 **Total magnetic intensity colour image**

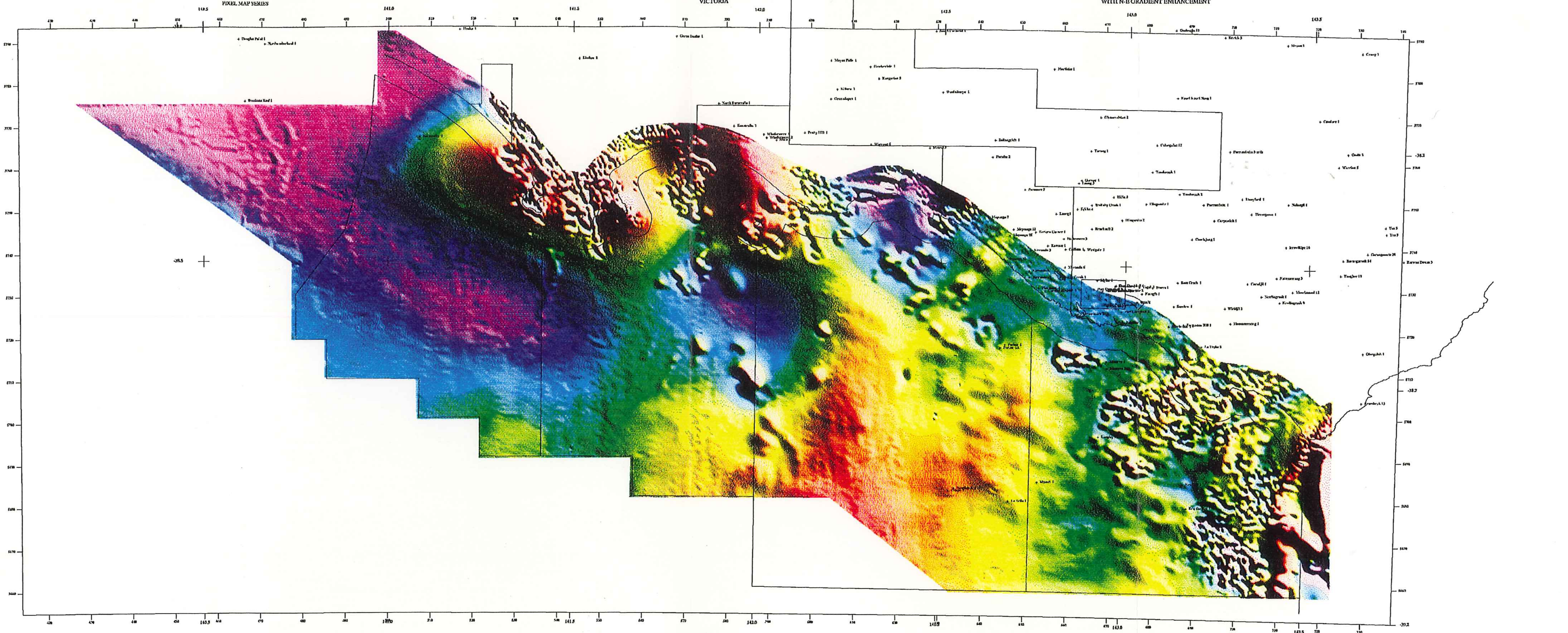
1:1 000 000 scale

R9702405

AUSTRALIA 1:1 000 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

OTWAY BASIN SURVEY
VICTORIA

TOTAL MAGNETIC INTENSITY
WITH N-E GRADIENT ENHANCEMENT



AGSO
Australian Geological Survey Organisation

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

[illegible]

TOTAL MAGNETIC INTENSITY WITH N-E GRADIENT ENHANCEMENT

SCALE 1:1 000 000

Kilometres

0 5 10 15 20 25 30

[illegible]

INDEX TO
1:250 000 MAP AREAS

PENOLA	HAMILTON	BALLARAT
[illegible]	PORTLAND	COLAC
[illegible]	[illegible]	[illegible]

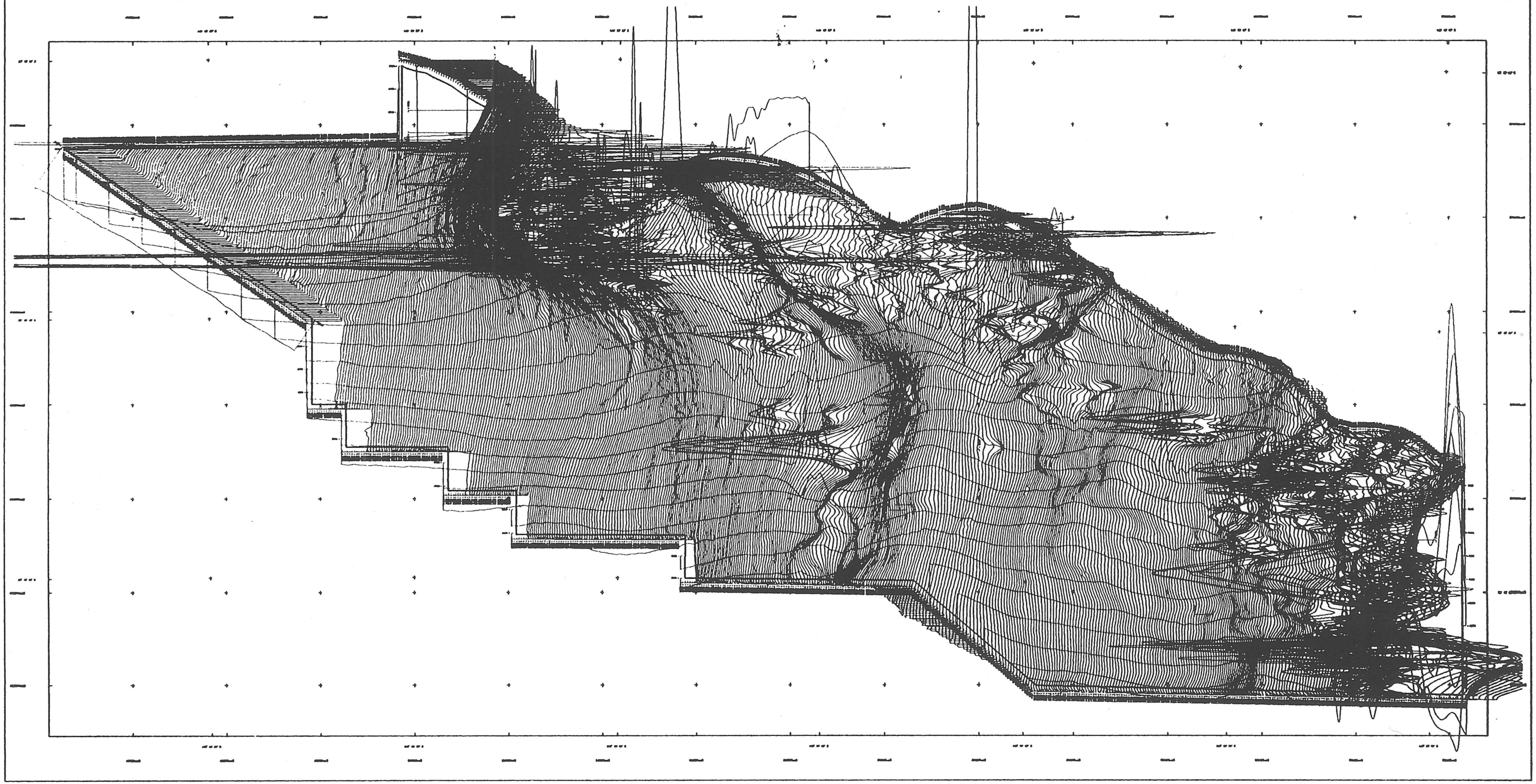
OTWAY BASIN SURVEY, VIC

AGSO 22-1/SPECIAL/XX

Figure 7 Stacked profiles of the magnetic data

1:1 000 000 scale

R9702407



AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

OTWAY BASIN

AIRBORNE GEOPHYSICAL SURVEY

STACKED TMI PROFILES

Figure 8 **Reduction to the pole of the total magnetic intensity**

1:1 000 000 scale

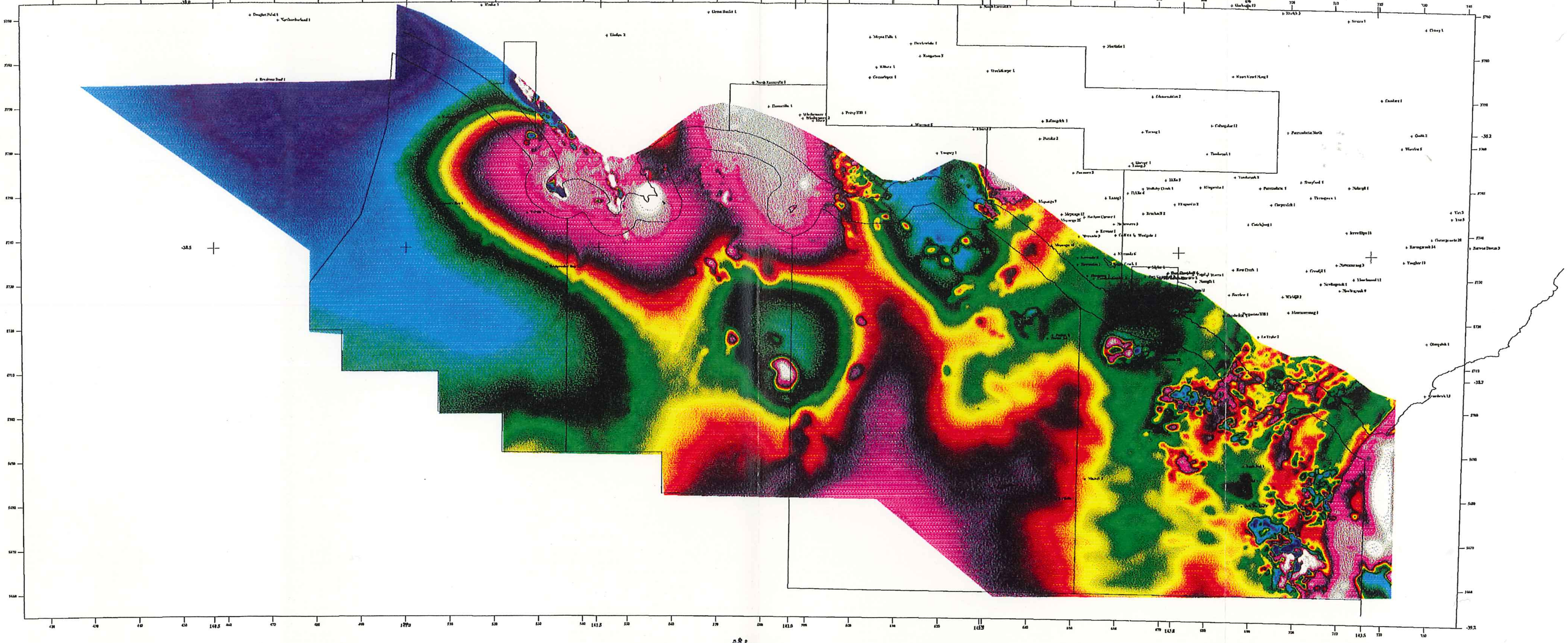
AUSTRALIA 1:1 000 000 AEROMAGNETIC ANOMALY

PIXEL MAP SERIES

OTWAY BASIN SURVEY

VICTORIA

TOTAL MAGNETIC INTENSITY
REDUCED TO THE POLE



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Australian Geological Survey Organisation

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

TOTAL MAGNETIC INTENSITY
REDUCED TO THE POLE

SCALE 1:1 000 000

Kilometres

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1:250 000 MAP AREAS

PENOLA	HAMILTON	BALLARAT
	PORTLAND	COLAC

OTWAY BASIN SURVEY, VIC

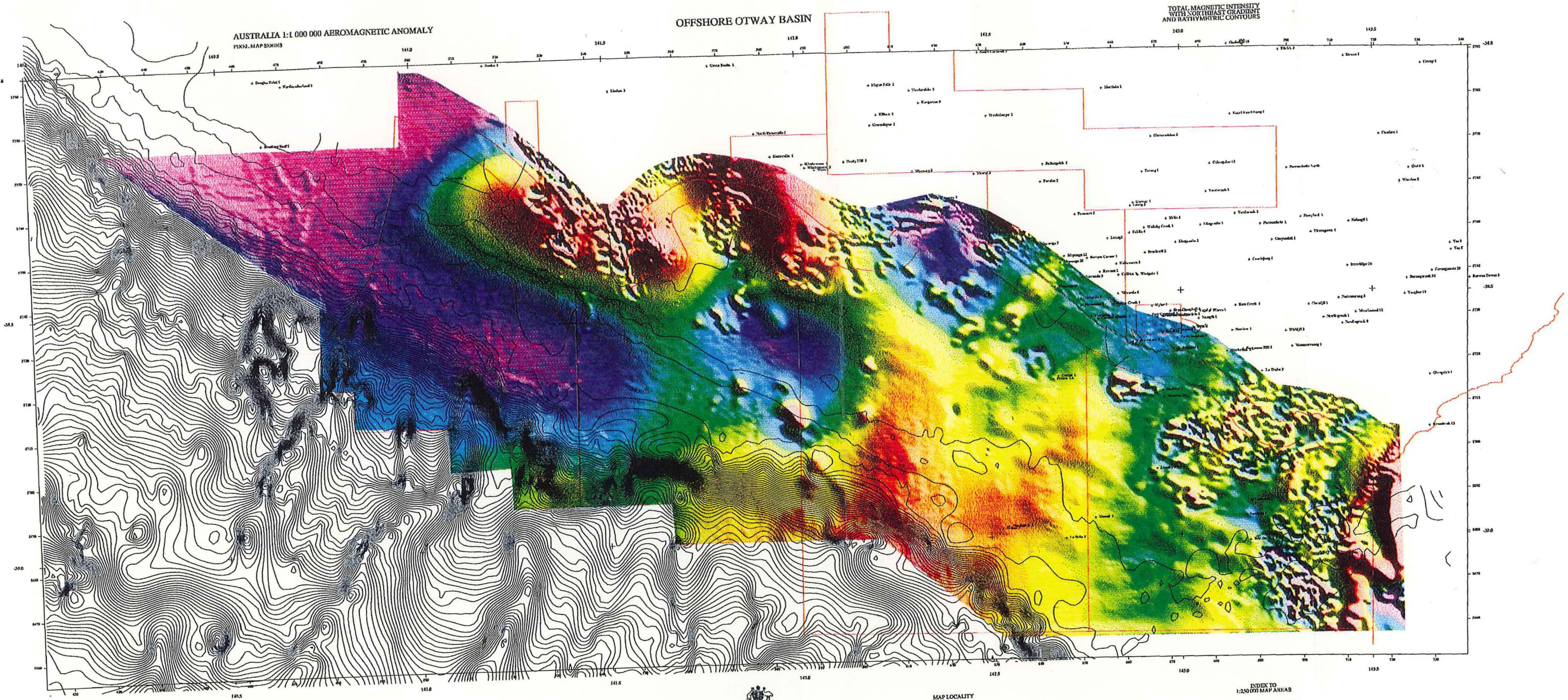
AGSO 22-1/SPECIAL/XX

Figure 9 Bathymetric contours superimposed on total magnetic intensity

1:1 000 000 scale

Contour interval 40 m. Shallowest contour is 40 m.

R9702409



AGSO

GEOPHYSICAL MAPPING
AIRBORNE GROUP

Data Specifications

We recommend that this publication be referred to as:

References

TOTAL MAGNETIC INTENSITY WITH NORTHEAST GRADIENT AND BATHYMETRIC CONTOURS

SCALE 1:1 000 000

Kilometres

0 5 10 15 20 25 30

Grid ticks indicate 10 000 metre intervals on the Universal Transverse Mercator Grid, Zone 54. Australian National Spheroid

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MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

	HAMILTON	BALLARAT
SJ 54-10	PORTLAND	COLAC

OFFSHORE OTWAY BASIN

Figure 10 **Computed vertical gradient contours**

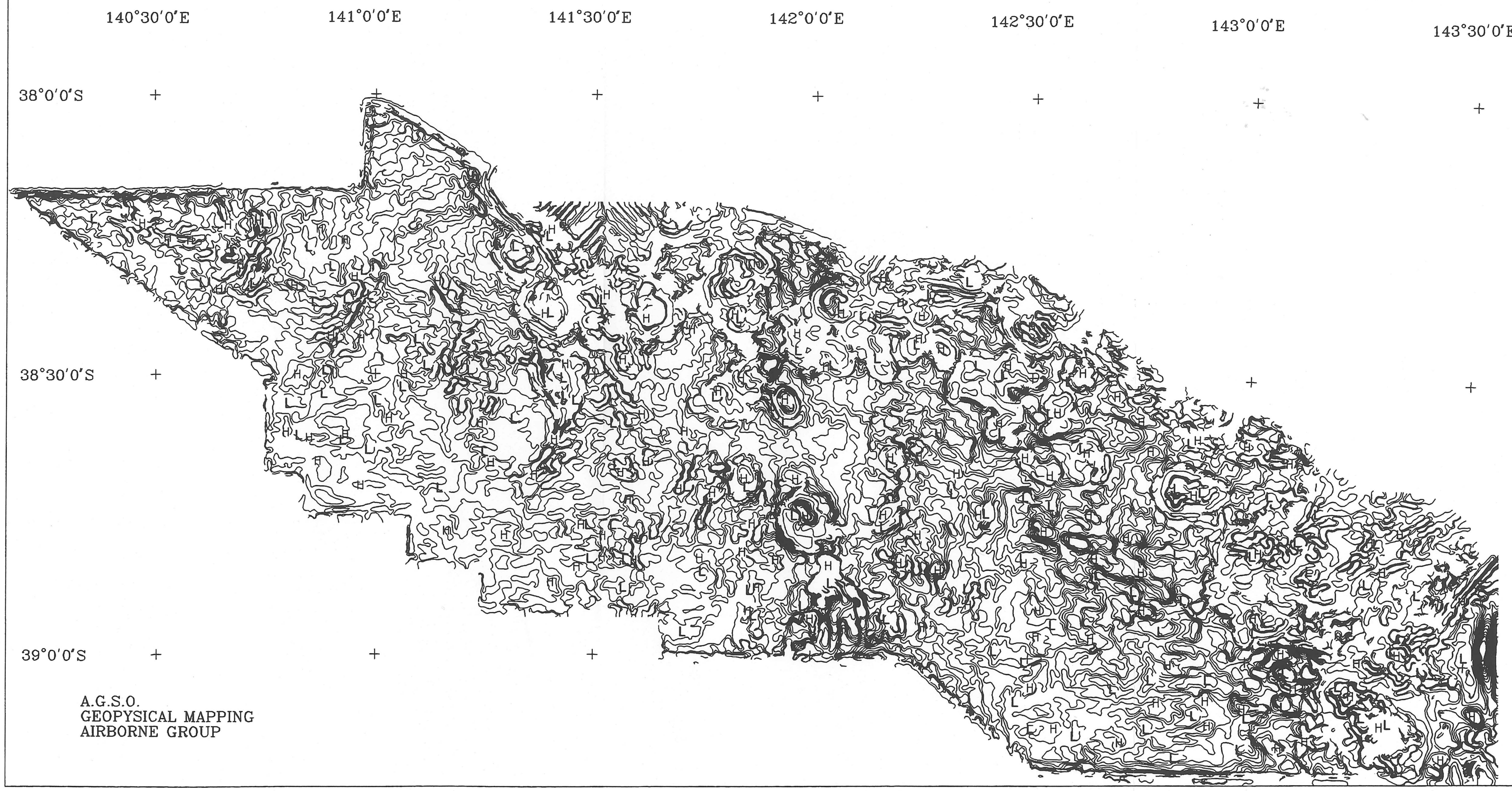
1:1 000 000 scale

R9702411

OFFSHORE OTWAY BASIN

FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY

contour interval: 0.0005 nT / m
scale 1:1 000 000



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GEOPYSICAL MAPPING
AIRBORNE GROUP

Figure 11 **Colour image of computed vertical gradient with northeast illumination**

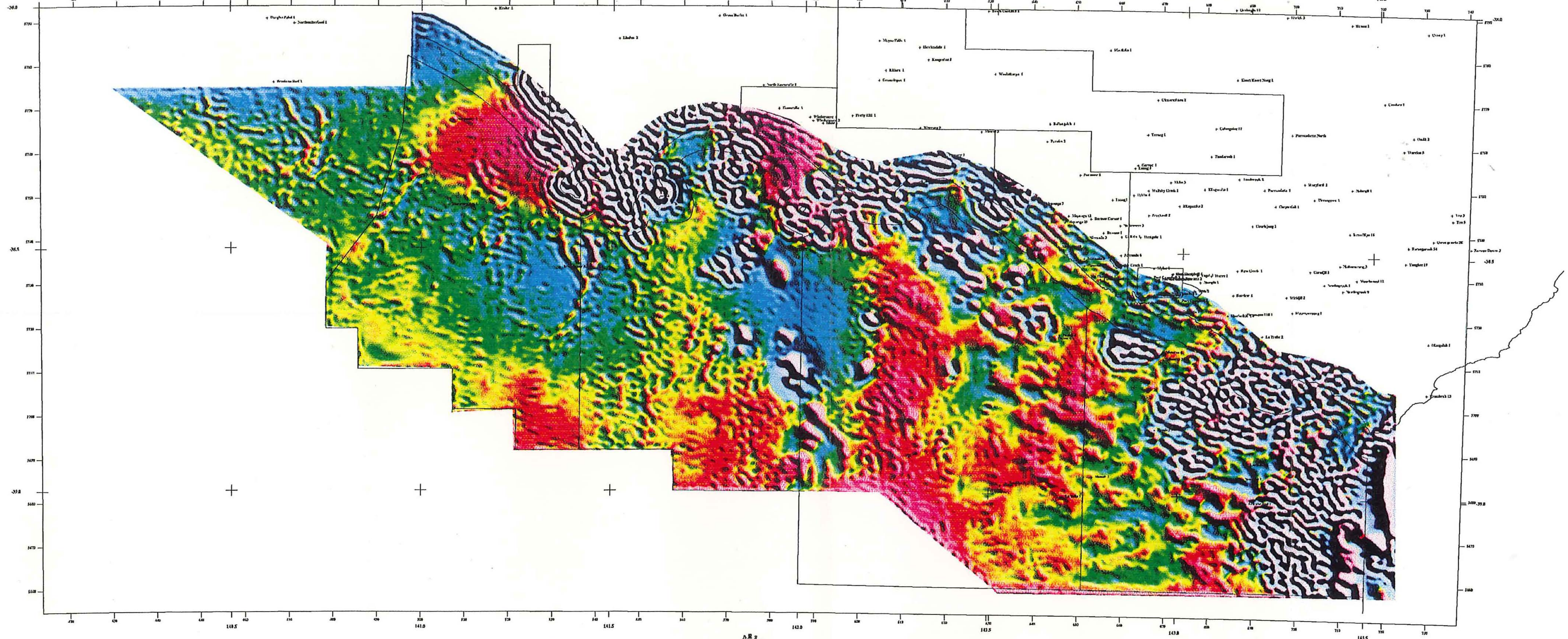
1:1 000 000 scale

R9702413

AUSTRALIA 1:1 000 000 AEROMAGNETIC ANOMALY
PIXEL MAP SERIES

OFFSHORE OTWAY BASIN

FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY WITH NORTHEAST GRADIENT



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FIRST VERTICAL DERIVATIVE OF TOTAL MAGNETIC INTENSITY WITH NORTHEAST GRADIENT

SCALE 1:1 000 000

Kilometres

0 5 10 15 20 25 30

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MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

PENOLA	HAMILTON	BALLARAT
[illegible]	PORTLAND	COLAC
[illegible]	[illegible]	[illegible]

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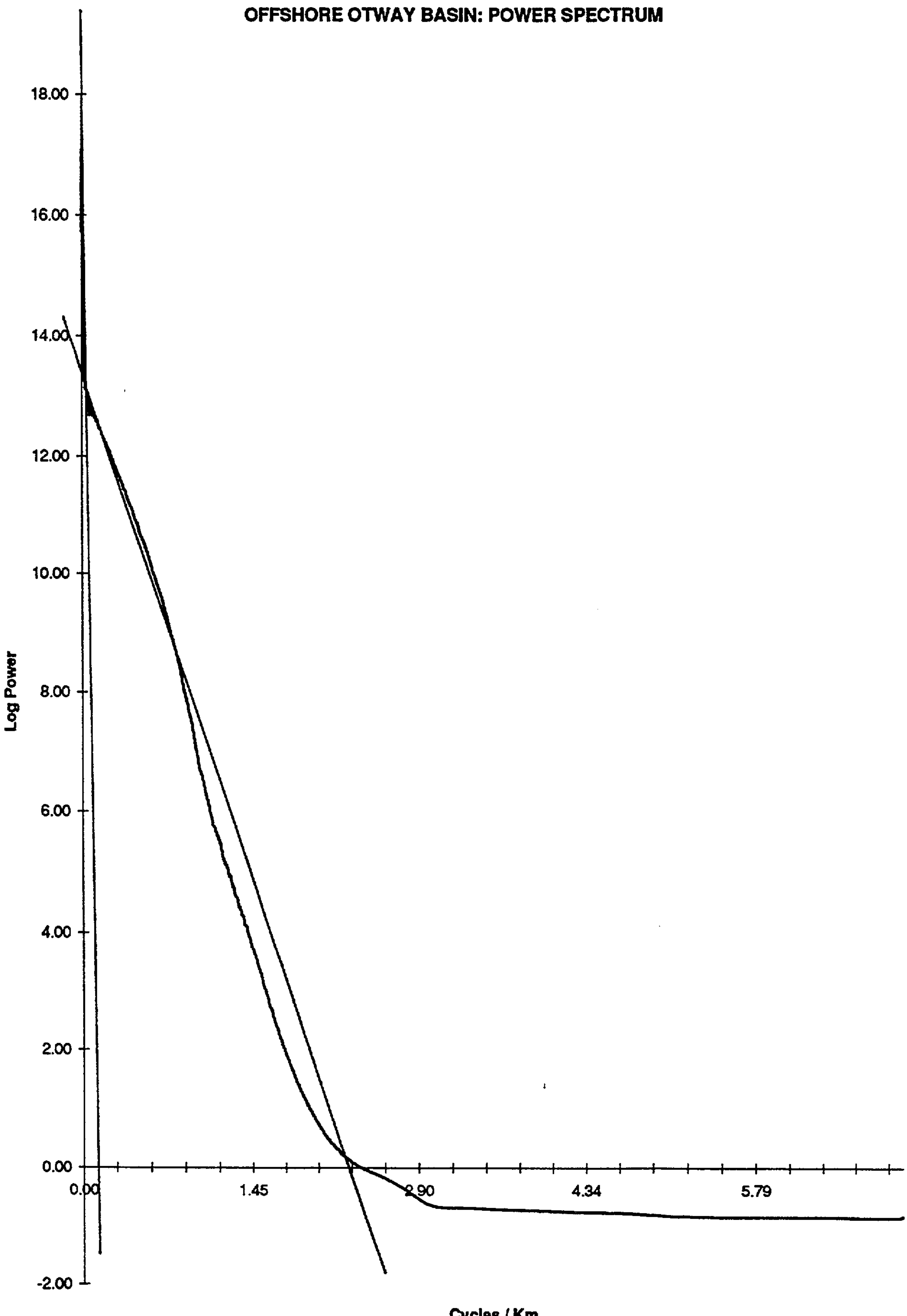

R97024I5

Figure 12 Logarithmic radial energy spectrum of the total magnetic intensity

Figure 13 Highpass matched filter image

1:1 000 000 scale

AUSTRALIA 1:1 000 000 AEROMAGNETIC ANOMALY

PIXEL MAP SERIES

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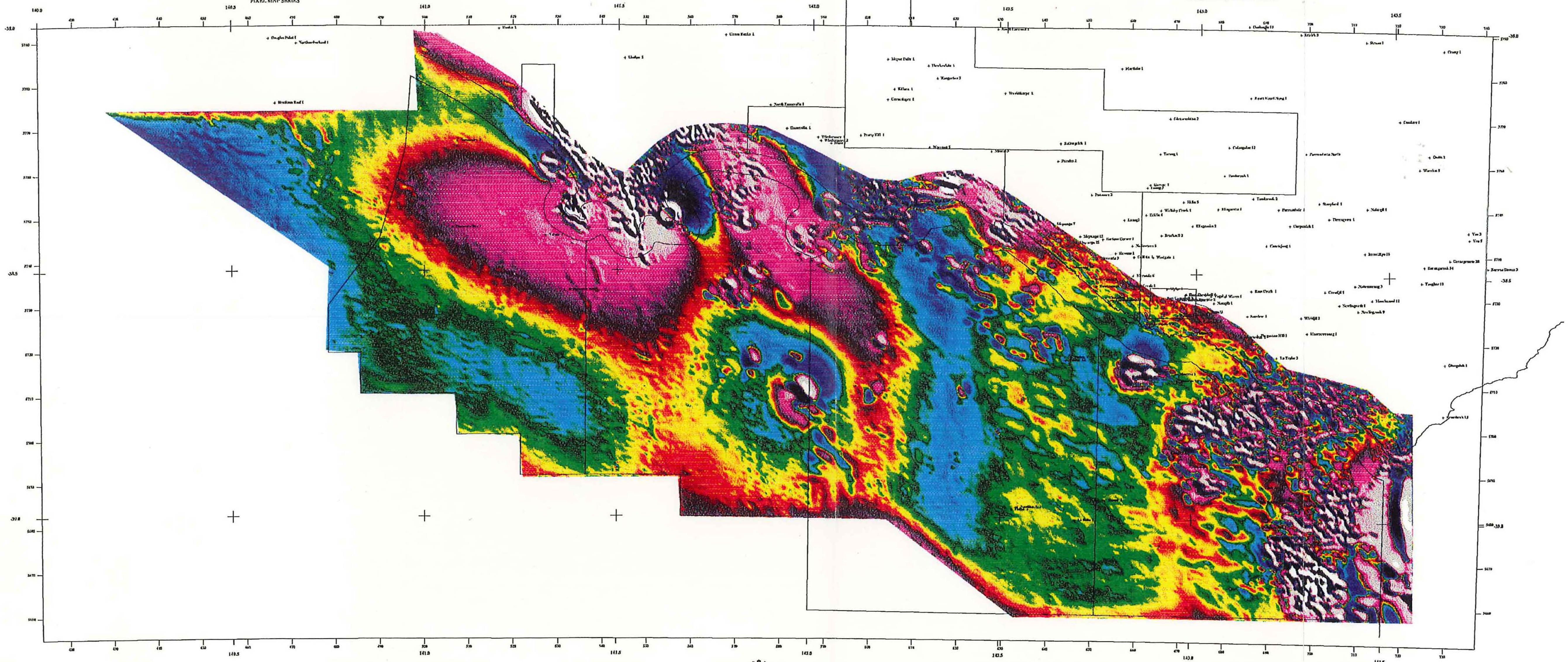
'MATCHED FILTER' RESIDUAL
WITH NORTHEAST GRADIENT



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AIRBORNE GROUP

Data Specifications

Data acquisition and reduction: Kevron Geophysics.
Image processing and filtering (Interpid) at ER Mapper: T. Mackey, AGSO.

References

'MATCHED FILTER' RESIDUAL
WITH NORTHEAST GRADIENT

SCALE 1:1 000 000

Kilometres

0 5 10 15 20 25 30

Grid ticks indicate 10 000 metre intervals on the Universal Transverse Mercator Grid, Zone 54, Australian National Spheroid

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MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

PENOLA	HAMILTON	BALLARAT
[illegible]	PORTLAND	COLAC
[illegible]	[illegible]	[illegible]

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Figure 14 **Lowpass matched filter image**

1:1 000 000 scale

R9702417

AUSTRALIA 1:1 000 000 AEROMAGNETIC ANOMALY

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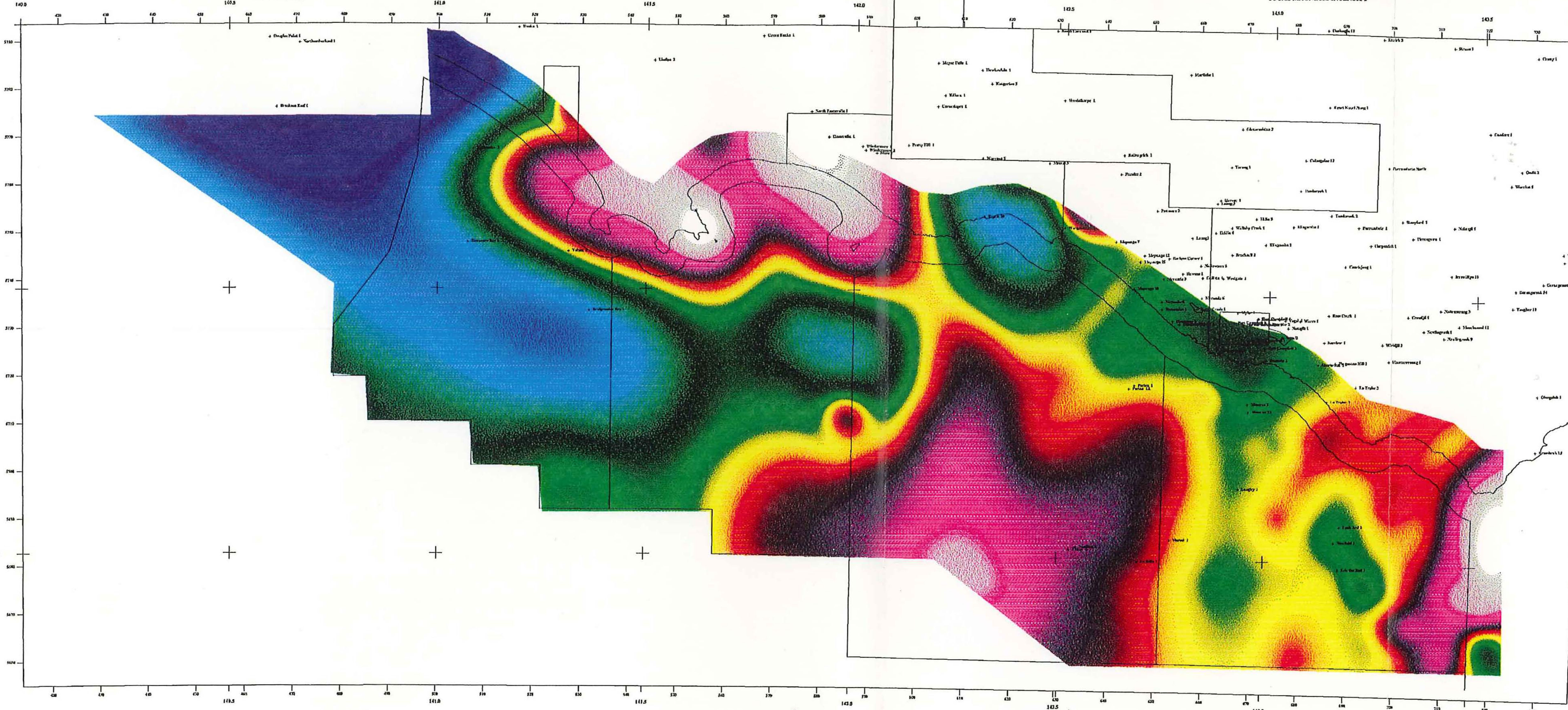
'MATCHED FILTER'
TOTAL MAGNETIC INTENSITY



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Data Specifications

'MATCHED FILTER'
TOTAL MAGNETIC INTENSITY

SCALE 1:1 000 000

Kilometres

0 5 10 15 20 25 30

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MAP LOCALITY

INDEX TO
1:250 000 MAP AREAS

		BALLARAT
SJ54-10	PORTLAND	COLAC
SJ54-14	SJ54-15	SJ54-16

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Figure 15 Regional gravity image

R9702419

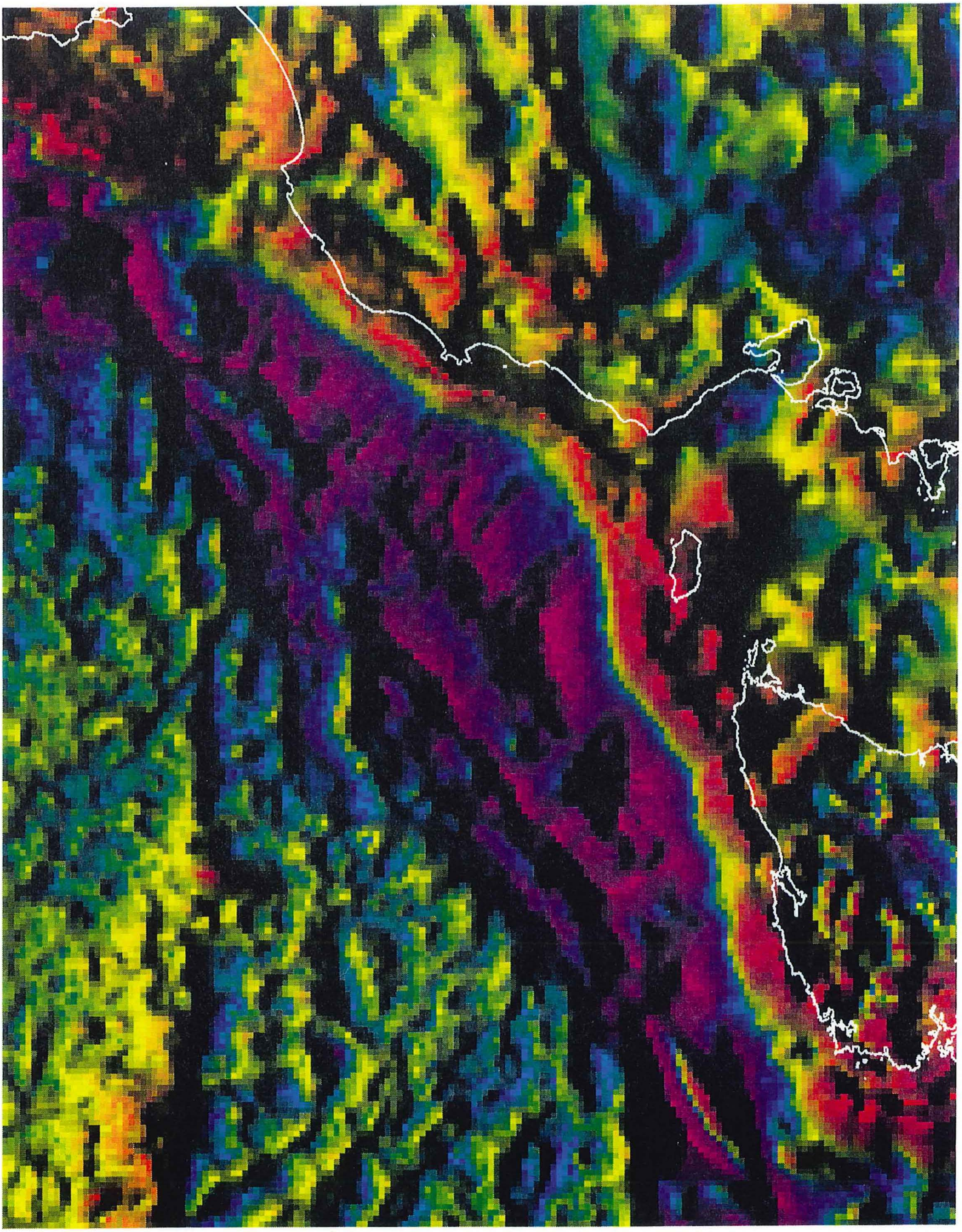
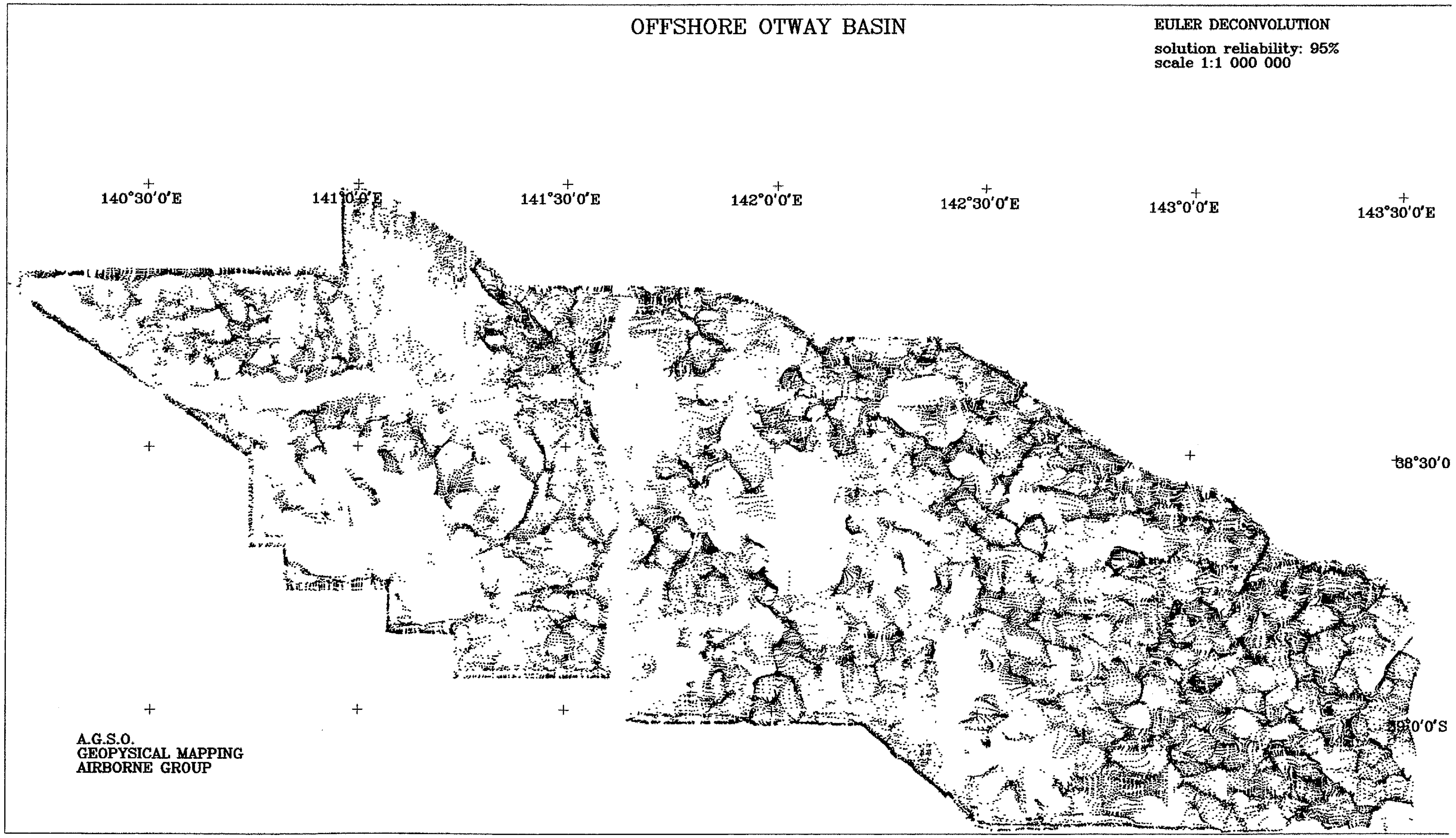


Figure 16 **Euler deconvolution used to map magnetic source outlines**

1:1 000 000 scale

R9702421


OFFSHORE OTWAY BASIN
EULER DECONVOLUTION
solution reliability: 95%
scale 1:1 000 000
140°30'0'E
141°0'0'E
141°30'0'E
142°0'0'E
142°30'0'E
143°0'0'E
143°30'0'E
38°30'0
39°0'0'S
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R9702422

Figure 17 **Locations of modelled profiles**

1:1 000 000 scale

R9702423

AUSTRALIA 1:1 000 000 AEROMAGNETIC ANOMALY
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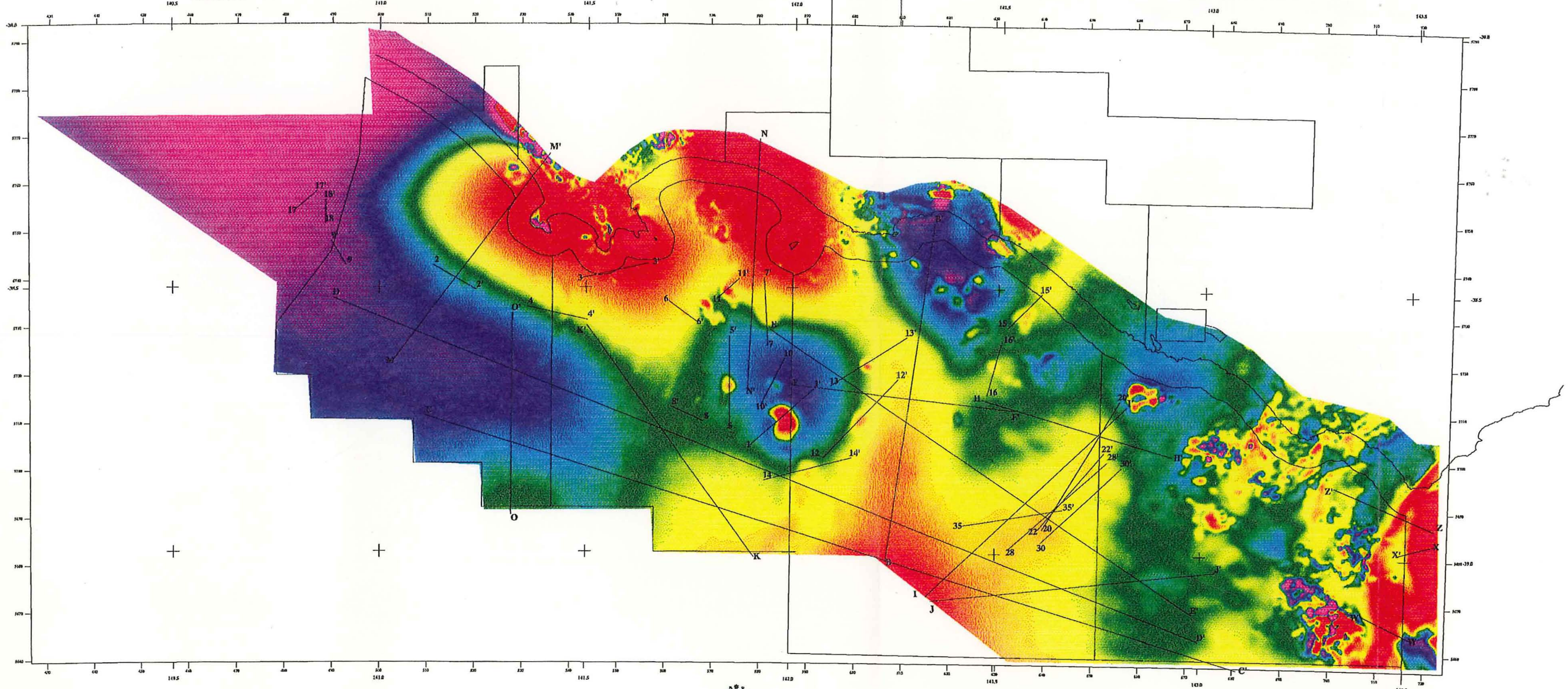
TOTAL MAGNETIC INTENSITY (RTP)
WITH MODEL PROFILE LOCATIONS



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Data Specifications

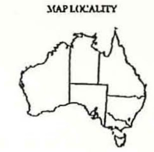
TOTAL MAGNETIC INTENSITY (RTP)
WITH MODEL PROFILE LOCATIONS

SCALE 1:1 000 000

Kilometres

0 5 10 15 20 25 30

MAP LOCALITY



INDEX TO
1:250 000 MAP AREAS

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[illegible]	PORTLAND	COLAC
[illegible]	[illegible]	[illegible]

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