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BATHYMETRIC MAPPING OF THE AUSTRALIAN CONTINENTAL MARGIN : A POSSIBLE MODEL FOR THE IOC WESTPAC REGION ?

C.R. Johnston, D. Jongsma, D.A. Falvey & P. Jernakoff

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C.R. Johnston
Division of Marine Geosciences and Petroleum Geology
Bureau of Mineral Resources, Canberra, Australia

D. Jongsma
Division of Marine Geosciences and Petroleum Geology
Bureau of Mineral Resources, Canberra, Australia

D.A. Falvey
Petroleum and Marine Geoscience Group
Bureau of Mineral Resources, Canberra, Australia

P. Jernakoff
Bureau of Rural Resources, Canberra, Australia

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INTRODUCTION

The Bureau of Mineral Resources *Geology and Geophysics* (BMR) in conjunction with the Bureau of Rural Resources and the Australian Hydrographic Service, is producing a series of 32 contoured bathymetric maps at 1:1m scale covering the Australian continental margin. This extensive project known as the Offshore Resource Map Series (ORMS) began in 1989 and has involved considerable development and evaluation to achieve publication of the first map in September 1990. The Sheet areas that make up this series are shown on Figure 1. The objective is to complete the series by December 1992.

In order to outline some interesting aspects of this development a small portion of the Hartog sheet (Fig. 1) will be used to illustrate a variety of matters dealt with in regard to the production of this map and the series as a whole.

It should be noted that prior to the present effort there has never been a single systematic assemblage of digital bathymetric data depicting contours for the entire Australian continental margin.

EARLIER MAPS

A number of contoured bathymetric maps covering portions of the Australian margin have been published during the last couple of decades, both as inclusions within scientific papers and as stand-alone special purpose maps. On the west coast there have been at least three maps which should be looked at in the context of the Hartog 'analysis area' :

1. Falvey and Veevers (1974) (Fig. 2) - This map was manually contoured using data from Australian Hydrographic Office sources. A number of canyon-like features were interpreted from digital data and continuous depth profiles. These features were then mapped on the continental slope. Regional bathymetric trends were established as a consequence of this mapping.

2. Veevers and others (1985) (Fig. 3) - Once again this map has been manually contoured and shows the simple NW-SE regional trend plus the inclusion of local features which were not evident on the earlier Falvey and Veevers map. The canyons, however, have not been shown on this map.

3. Wellman and others (1988) (Fig. 4) - These contours have been computer drawn using the SYNBAP-II global, 5 minute data-grid. The regional trend is consistent with the other maps. However, the data appears to have been filtered to remove local irregularities. The 6000 m contour at the bottom centre of the 'analysis area' is in error by -300 m.

None of the above earlier maps portray the bathymetry with the same degree of detail as the current series. In order to produce a map based on all the available, reliable bathymetry it is necessary to firstly assemble individual soundings in digital form.

PRIMARY REQUIREMENTS OF ORMS

When the project was initiated some basic requirements were established including the following:

- The maps had to be easily updated. It is anticipated that sufficient new data will be gathered to warrant production of a new edition on about a 5-10 year cycle. It is important that new data be easily added to existing data in order to produce new maps. The only way to achieve this requirement efficiently is by saving depth soundings and positions in a digital database. Digitised contours, based on irregular and sparse data, of variable quality, cannot be effectively and accurately updated. With modern computers the amount of data that can be stored in a depth sounding database is essentially limitless. The only problem for the project was that a large percentage of the data was only available in analogue form as posting, or 'collector' sheets.

- The maps had to match at their common boundaries. This made it necessary to choose a single, fixed map projection for the entire area. It was agreed that Mercator projection with true scale at latitude 33^{o} N and S would be the best alternative for this purpose. This would mean that scale distortion over the area covered by the series would be no greater than 20% and the actual scale at any point on the maps could be easily computed. In fact this condition holds true for the entire region between parallels 48^{o}N and 48^{o} S, i.e. almost the entire WESTPAC region.

- Desirable that all data should be regarded with equal reliance on accuracy. However, discontinuities in the data can arise from inaccuracies in either depth or position or both. It is sometimes possible to discriminate between data sets on the basis of navigational systems and their associated accuracy (e.g. GPS versus Transit Satellite versus Sextant).

SOURCES OF DATA

Regional marine geophysical and geological surveys carried out by the Bureau of Mineral Resources over 20 years proved to be a detailed and accurate source of digital data providing approximately 50% of the deep-water data required to carry out the project. Other data sources included GEBCO data as analogue posting or 'collector' sheets, and detailed shelf data acquired as part of the National Bathymetric Map Series (NBMS) (1976-90). Survey lines were run from near shore out to the 300 m isobath and were spaced at approximately 3 km intervals over most of the shelf. About one third of these data are still in analogue form.

Given that the continental shelf area has been so consistently well covered, especially relative to the deeper water areas, it was decided to digitise the shelf contours in the interest of expediency. In this way all of the shelf data were handled consistently. Depth values from the shelf will be incorporated into the database at a later date.

THE DATABASE

The database on the continental shelf (<300 m) consists of digitised contours derived from published contour charts (NBMS, 1976-90). Initially these data were digitised on a digitising table and the contours were sampled at discrete intervals. Later, with the development of optical scanning techniques, the analogue contours were converted to digital form automatically without the need for manual digitisation. It is not expected that the shelf data can be significantly improved until detailed swathe mapping techniques are employed and when this does occur whole areas of shelf data can be replaced by the digital swathe data.

In areas off the continental shelf in deeper water the database comprises BMR marine data with depths along track at approximately 5 km intervals. Supplementary data from the GEBCO posting sheets were manually digitised to provide additional control in areas where the line spacing of the digital data was greater than about 35 km. The project team is investigating the possibility of optical scanning of the GEBCO sheets as a means of overcoming the manual effort involved in the digitising and subsequent data checking operations.

A small amount of data from 'special' surveys, which are neither included in the BMR data set nor recorded on the GEBCO sheets, have also been digitised and added to the database.

A plot of the digital database from the Hartog analysis area can be seen on Figure 5. The mean data line spacing is approximately 25 km.

GRIDDING AND CONTOURING

The next step in producing a contoured bathymetric map is to decide on a suitable algorithm for automatic computer gridding and contouring. A number of algorithms were tested by the ORMS project and these are discussed below. All of the algorithms assume that data are collected using a regularly spaced grid as is usually the case in terrestrial examples. Ocean soundings, however, are often collected opportunistically as vessels steam to their respective destinations. Ship tracks are often irregularly spaced and soundings over many areas are therefore incomplete. This irregular data makes automatic machine contouring very difficult and contour distortions are produced by all algorithms. The effect, however, is minimal in the 'Preferred Machine Contouring' algorithm (see below). Each of the following examples has been computed using a 5 km square grid.

Line Focussed Contouring (Fig. 6) - With this algorithm sea-bed features that extend across adjacent tracks of bathymetric data have not been well contoured. Trends of linear features cutting obliquely across data tracks are depicted by wavy rather than straight contours. The contours are forced by the algorithm to intersect data tracks almost at right angles and then abruptly change direction between tracks. This effect is very apparent with respect to the NW-SE trending gradient between the 4600 m and 5600 m contours. This feature is believed to be a linear, or nearly linear, fracture zone and thus these contours do not appear to define the feature in a satisfactory way.

Overshoot Contouring or Minimum Curvature Contouring (Fig. 7) - Bathymetric data does not lend itself to minimum curvature contouring. Bathymetry, unlike other data sets such as gravity or magnetic data, often exhibits very sharp changes in gradient, or discontinuities, similar to topographic data. The effect of this contouring technique is to build erroneous highs and lows in areas where there is poor data control. A prime example is the 3500 m high and the 6200 m low either side of the steep gradient at the top left corner of the 'analysis area'. The available digital control limits the range of this gradient to a high of 3800 m and a low of 5600 m. Thus the algorithm has exaggerated the depth range of this feature by nearly 1000 m. This effect occurs in many other places.

Smoothed Grid Contouring (Fig. 8) - The grid has been computed using the same algorithm as for Fig. 10. However, before contouring occurred the grid was filtered to remove local, high frequency features. The result is remarkably similar to the Wellman and others (1988) map (Fig. 4). It would not be surprising to find out that the SYNBAP-II grid was produced using a minimum curvature algorithm and some post grid smoothing. The retention of high frequency features in the contoured presentation is important. Such features are likely to be targets for deep-sea fishing and provide key indicators for understanding sea-bed geology and continental margin development.

Preliminary Release Contouring (Fig. 9) - The contouring for this map, released in April 1990, is a combination of machine minimum curvature contouring and contour manipulation or editing by an experienced marine geologist with the skill to ensure that the contours are not misrepresenting features in regions where there is little or no data. One of the problems with the technique is the apparent tendency to miss some high frequency features. This can be seen by comparing the 3500 m isobath on Figures 9 and 10 in the vicinity of latitude 26^{o}S.

Preferred Machine Contouring (Fig. 10) - This method uses a distance weighted average algorithm to determine grid values. The weighting used is inversely proportional to the square of the distance between the grid point and the data point. The search radius about each grid point is 50 km so that cross track trends are retained to some extent. Admittedly this map still exhibits some of the less desirable features seen in other examples. However, recognising that gridding and contouring of widely spaced, irregularly distributed bathymetric data will always be a compromise, and that a completely satisfactory automatic method does not exist, then this map exhibits more of the desirable features and less of the undesirable features than any of the other examples.

Prior to producing this map a decision was made to delete one data track. This was the track along the southern side of the steep gradient feature at the top left corner of the map (Fig. 9). The reason for removing this track was that the data was acquired in 1962 without the aid of satellite navigation whereas the track along the northern side of the feature was recorded in 1972 using both transit satellite navigation and linked dead-reckoning between satellite fixes giving a position error of <1-2 km. The southern track would have been positioned using sun and star shots and thus the position error could easily be as large as 10 km. Removal of this track of data has removed the need for the extraordinary gradient between the two tracks.

Final Release Contouring (Fig. 11) - The contours shown on Figure 10 were manipulated and edited by an expert geologist, as previously discussed, to produce a final map. This sometimes tedious, but essential stage of bathymetric contouring is achieved interactively at a computer terminal using deletion, insertion, and 'elastic band' contour manipulation techniques to produce features which are consistent with the data but are more geologically acceptable than pure machine drawn contours.

FUTURE DEVELOPMENT OF AN INTEGRATED SYSTEM

BMR is considering the feasibility of developing a stand-alone system specifically for bathymetric mapping. If developed this system would be available for purchase by other organisations. The proposed system would be PC based and would incorporate the following features :

- a data manager for storage, retrieval and editing of data including position, depth, and acquisition details such as year, ship, navigation type, survey, etc;

- a data entry facility including digitising and optical scanning capabilities together with a facility for incorporating swathe data;

- gridding and contouring capability using an improved algorithm yet to be developed;

- interactive contour manipulation and map editing capability;

- ability to include other marine resource related information such as seismic lines, exploration wells, sea-bed sediment types and any national or international boundaries. Integration of different types of data sets is being researched in Australia;

- a facility to produce maps on stable base using a multi-coloured pen plotter;

BMR has gained a wealth of experience in bathymetric mapping from the ORMS project and is in a strong position to use this experience to produce an easy-to-use, cost effective system and thus allow other nations to gain from the experience. If the feasibility study is positive then it is hoped that development could commence within six months and that the system could be fully operational within two years.

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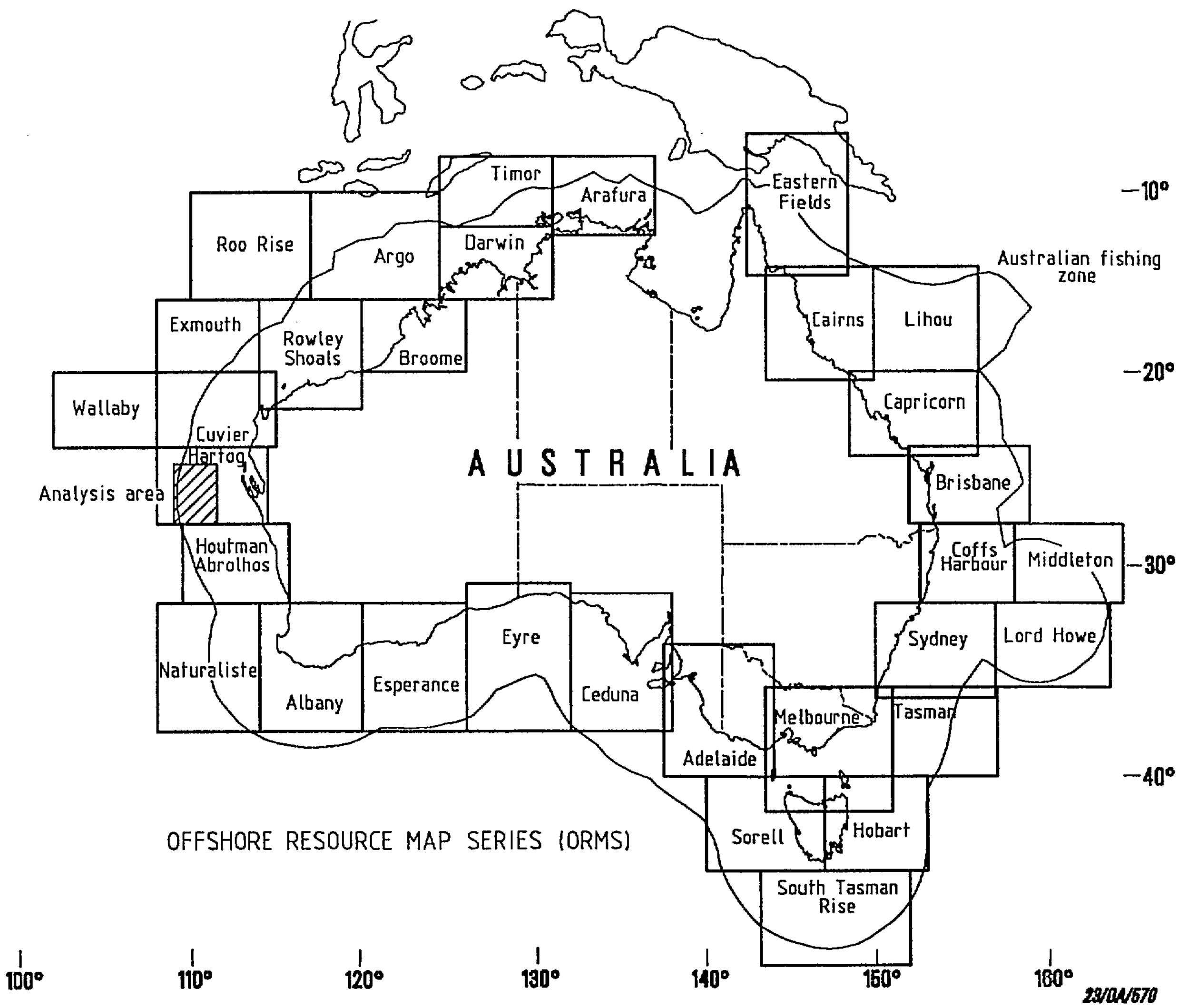

FIGURE 1

Proposed series of 1:1,000,000 scale Resource Maps for the Australian Margin. Analysis area within Hartog sheet is depicted in Figures 2 through 11.

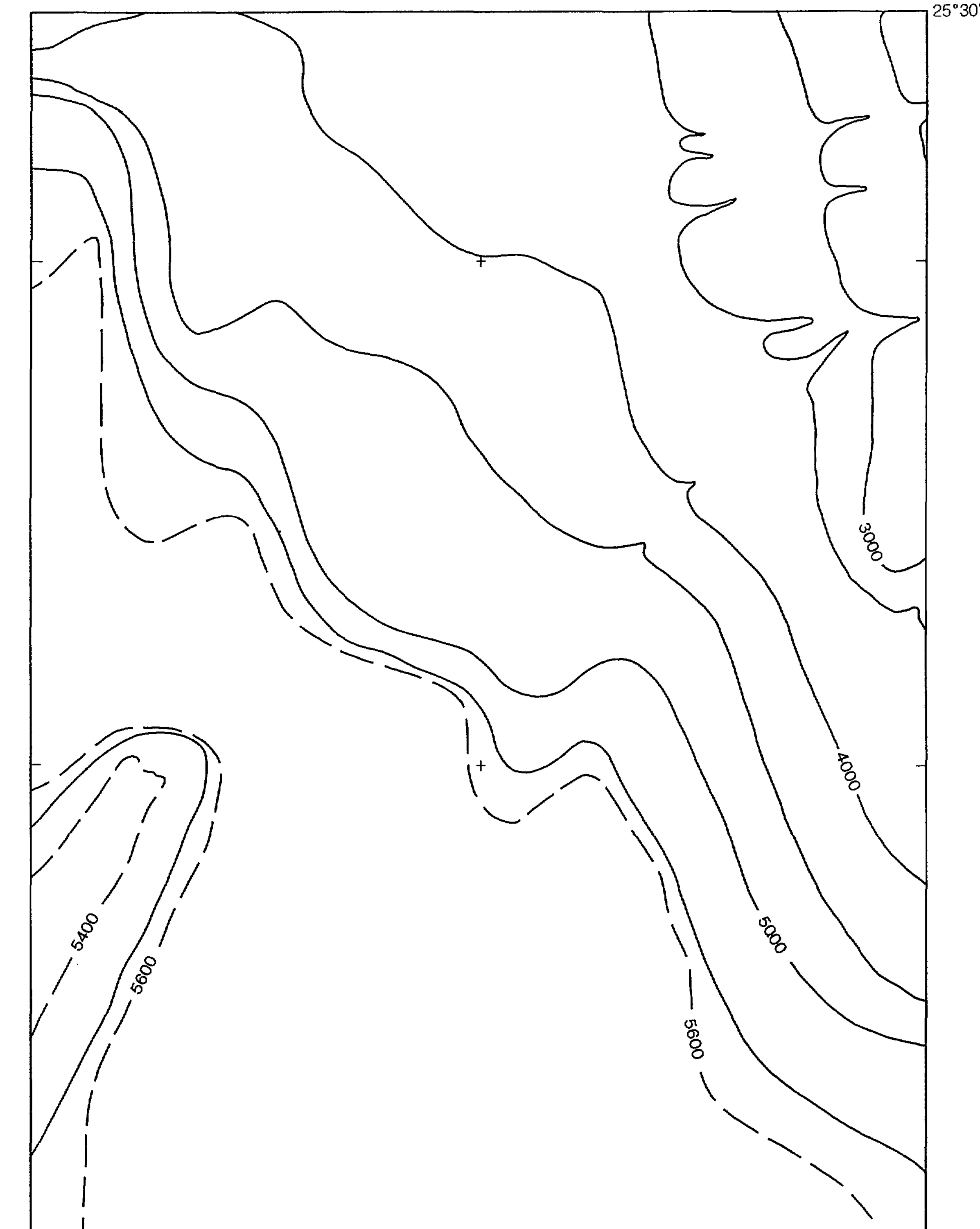

FIGURE 2

Analysis area within Hartog sheet (see Figure 1) showing bathymetry after Falvey and Veevers (1974). Contours are in metres.

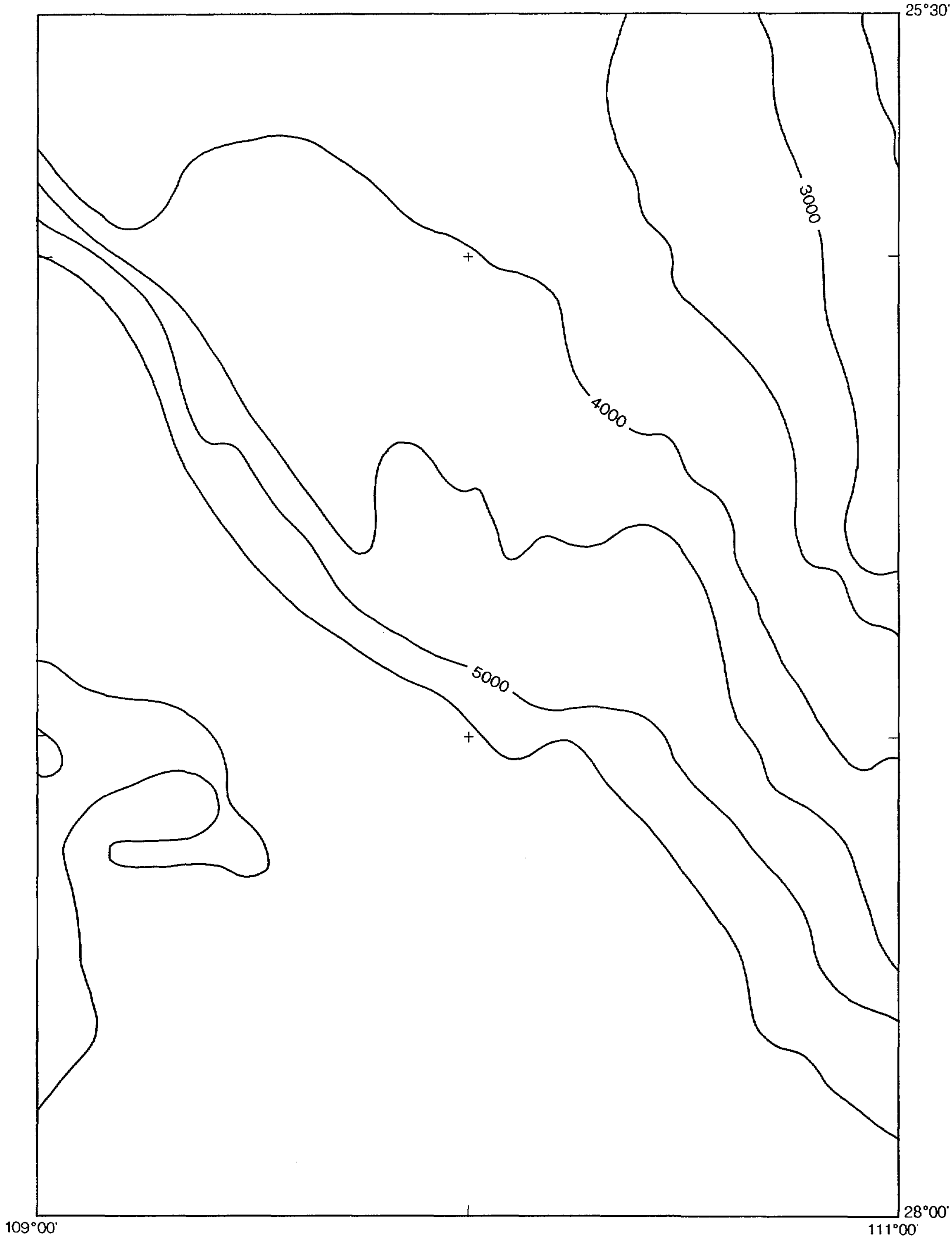

FIGURE 3

Analysis area within Hartog sheet (See Figure 1) showing bathymetry after Veevers and others (1985). Contours are in metres.

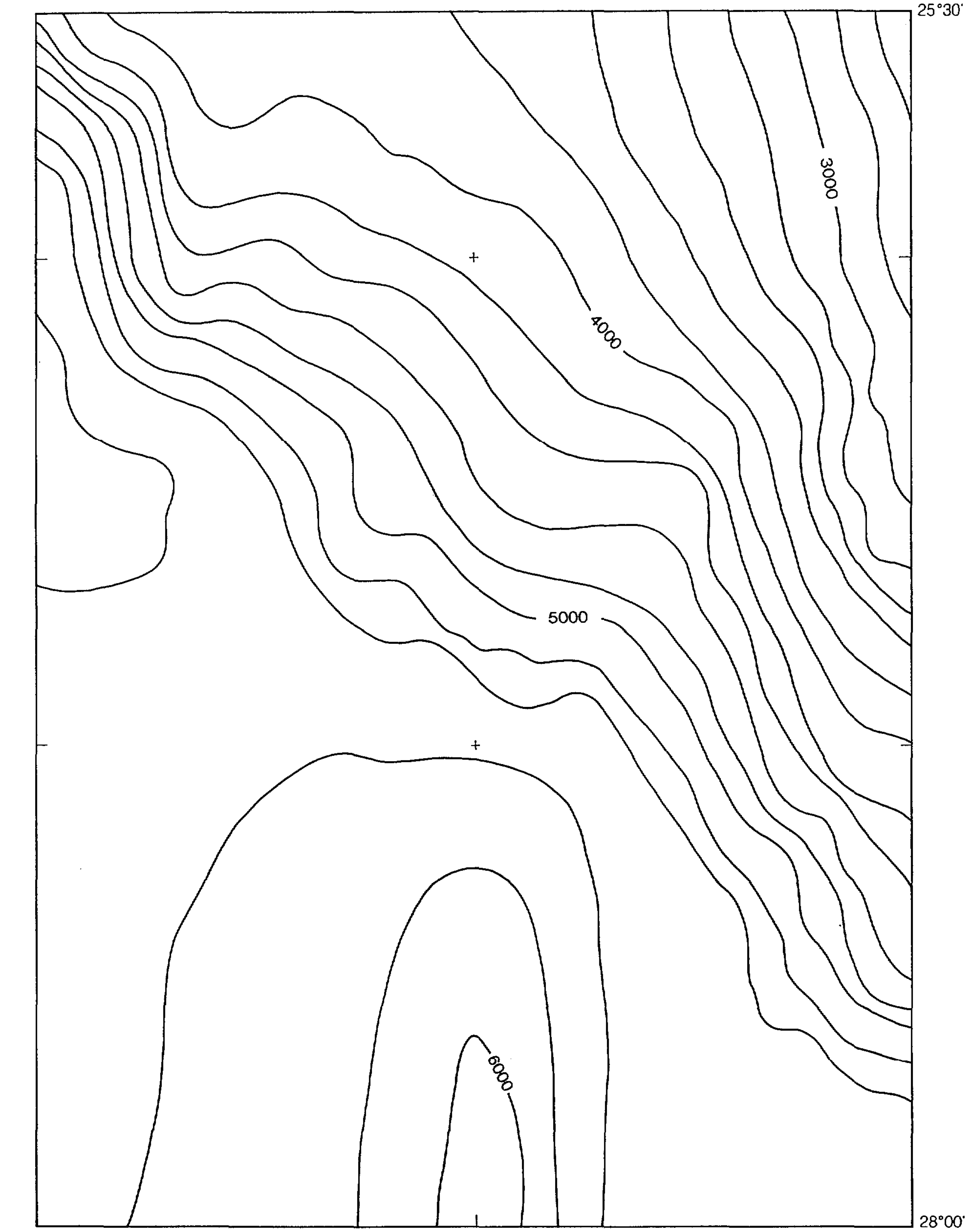

FIGURE 4

Analysis area within Hartog sheet (see Figure 1) showing bathymetry after Wellman and others (1988). Contours are in metres.

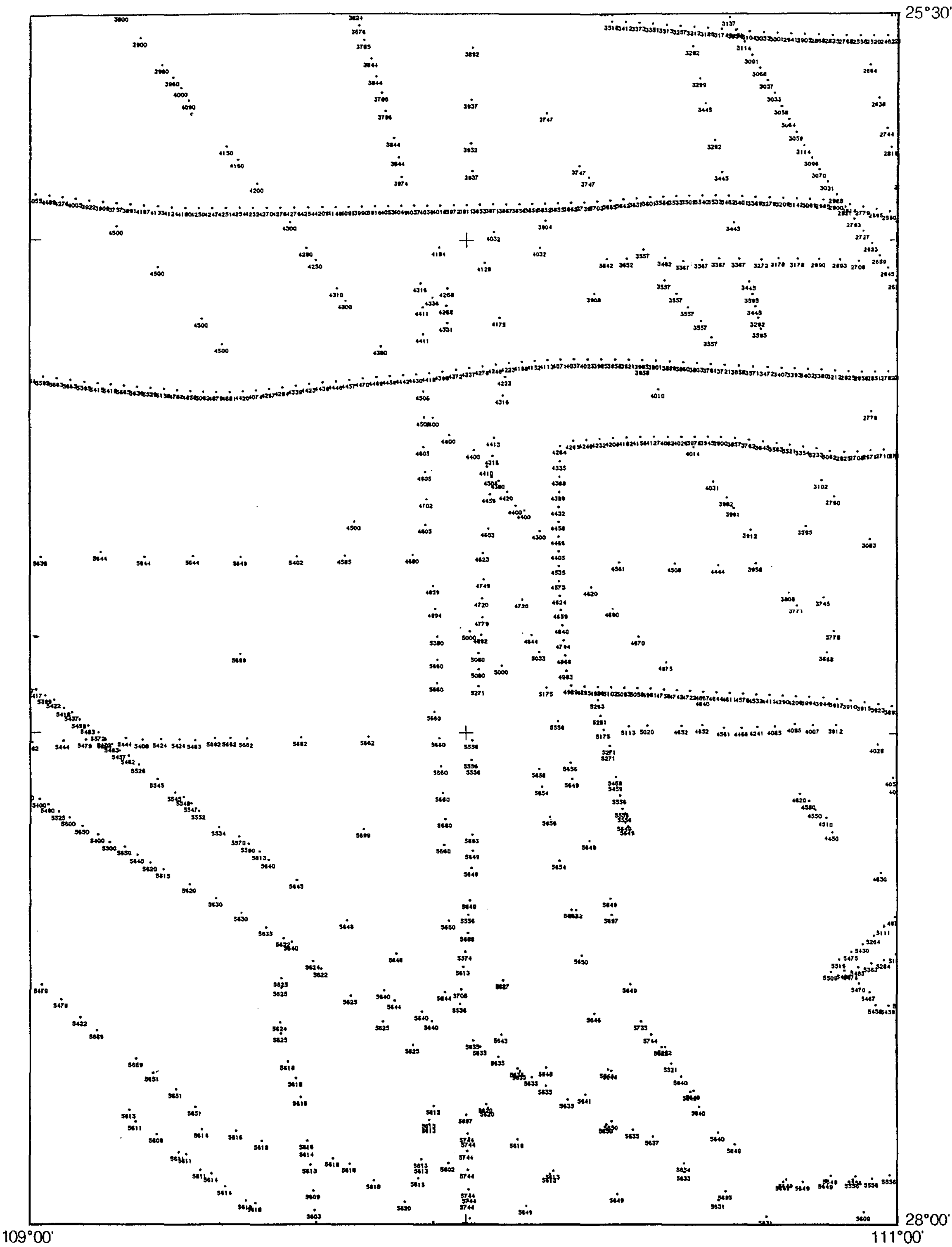

FIGURE 5

Analysis area within Hartog sheet (see Figure 1) showing distribution of digital data used in conjunction with computer gridding and contouring. Contours are in metres.

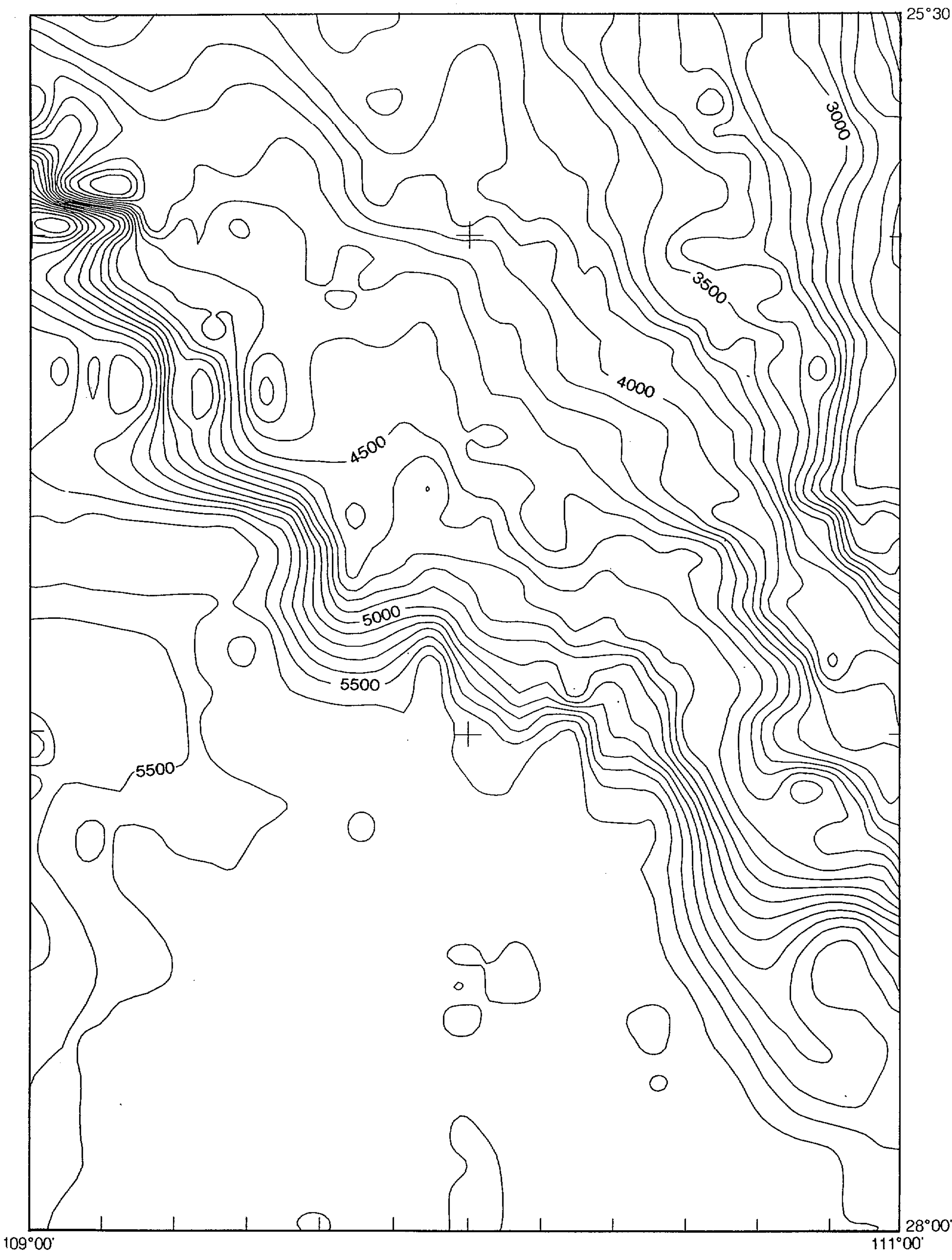

FIGURE 6

Analysis area within Hartog sheet (see Figure 1) showing example of computer generated line focussed gridding and contouring using the digital data shown on Figure 5. Contours are in metres.

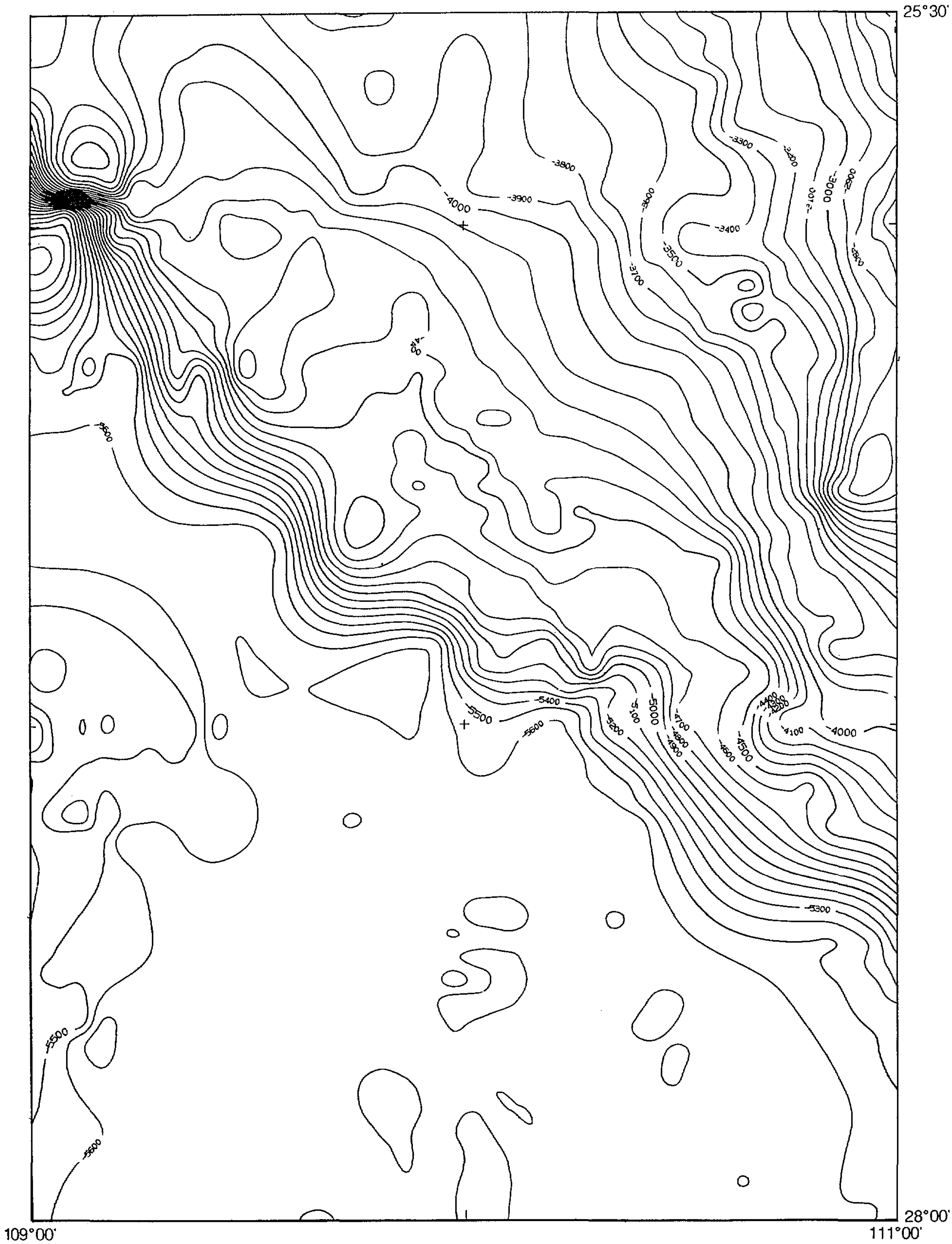

FIGURE 7

Analysis area within Hartog sheet (see Figure 1) showing example of computer generated minimum curvature gridding and contouring using the digital data shown on Figure 5. Contours are in metres.

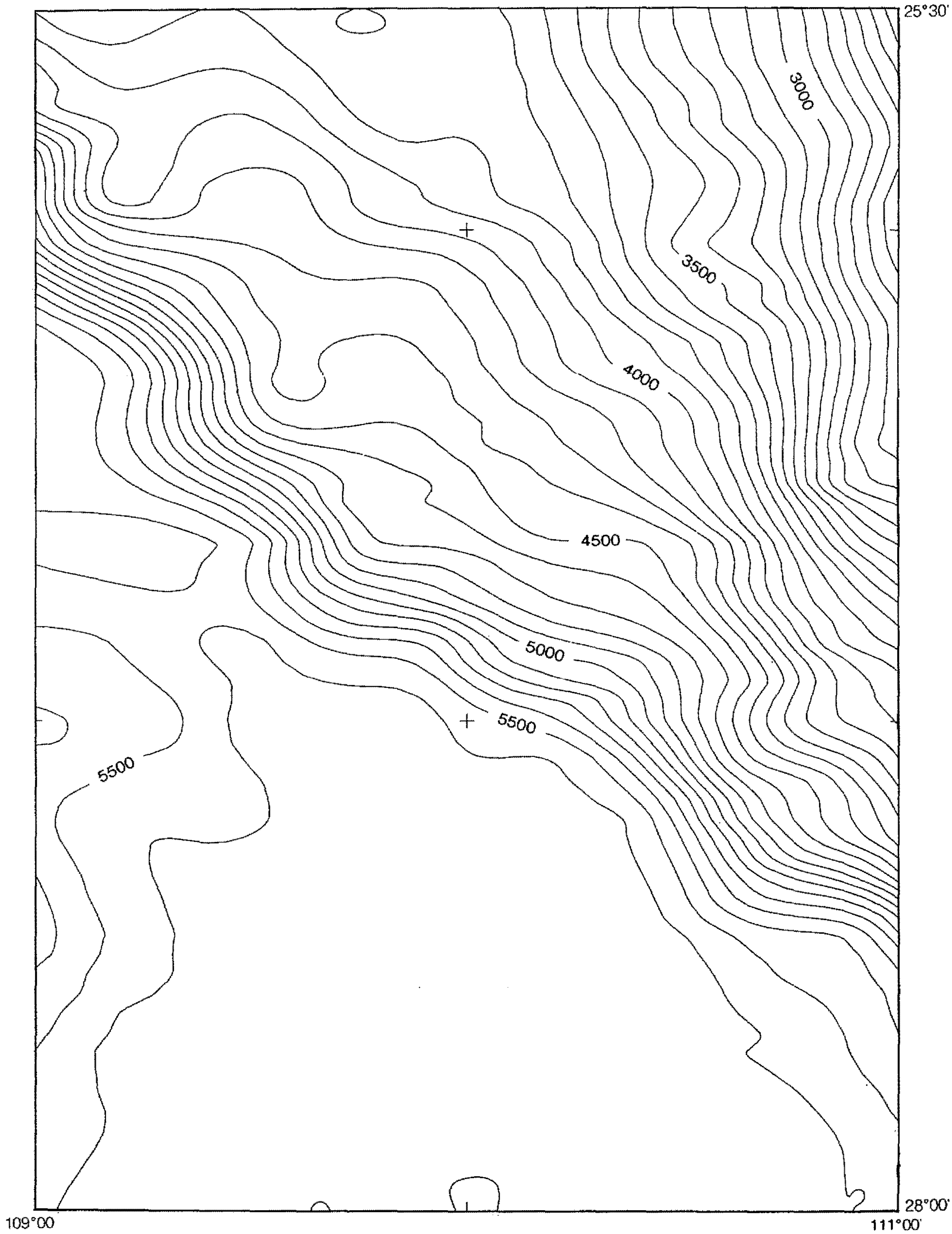

FIGURE 8

Analysis area within Hartog sheet (see Figure 1) showing example of computer generated smoothed grid contouring using the digital data shown on Figure 5. Contours are in metres.

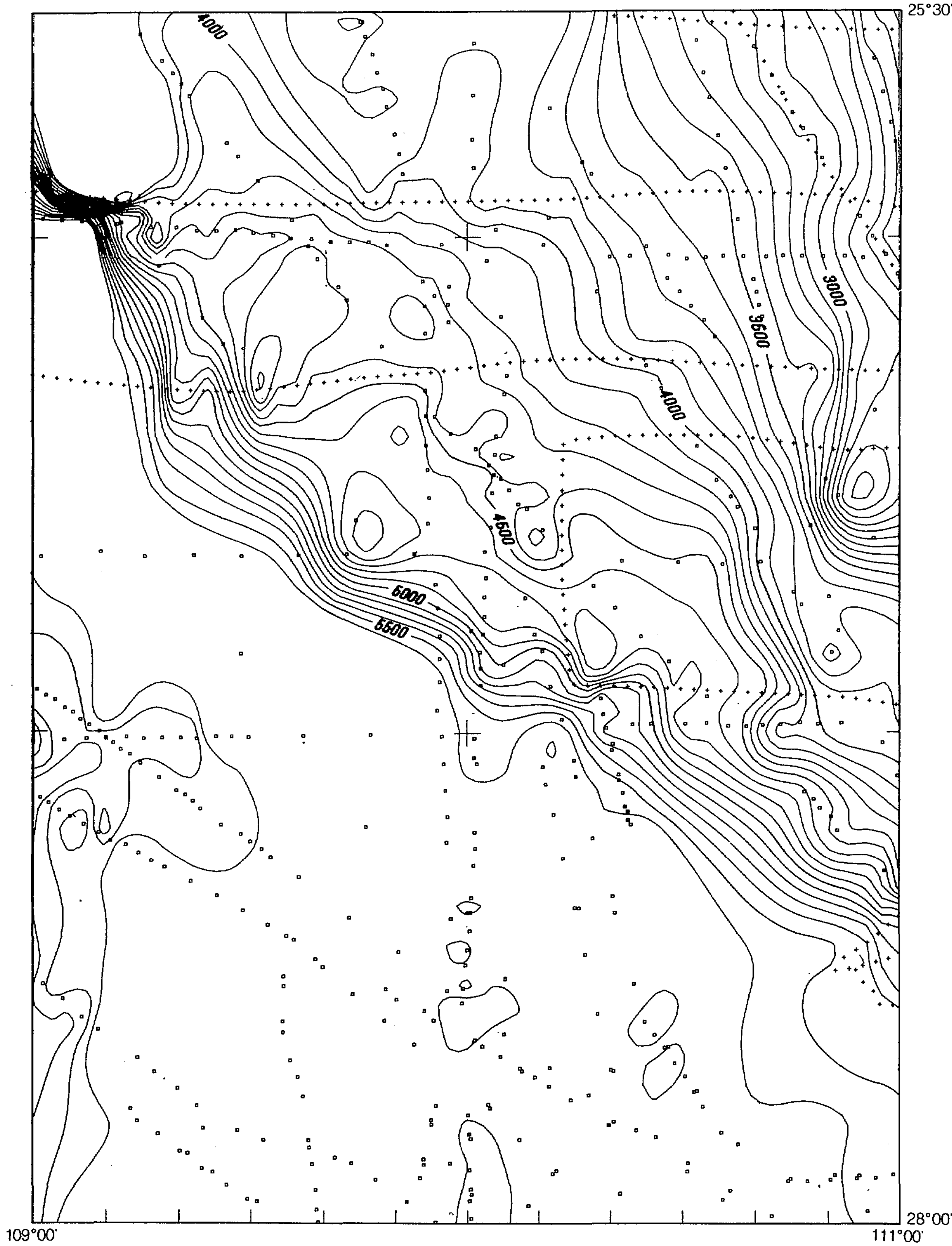

FIGURE 9

Analysis area within Hartog sheet (see Figure 1) showing computer generated minimum curvature gridding and contouring followed by contour string manipulation or editing using an Intergraph system. Contours are in metres.

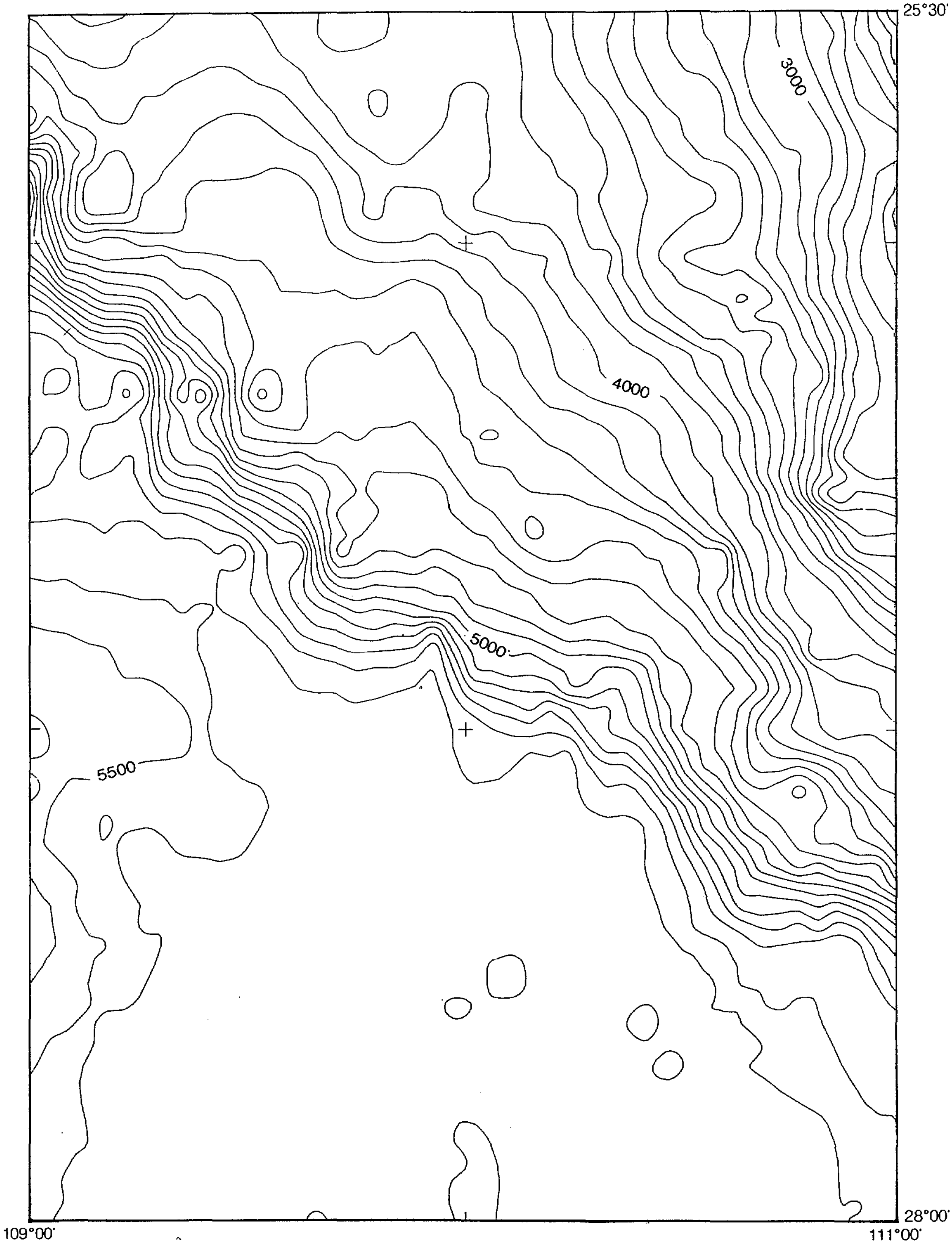

FIGURE 10

Analysis area within Hartog sheet (see Figure 1) showing computer generated distance weighted average gridding and contouring. Contours are in metres.

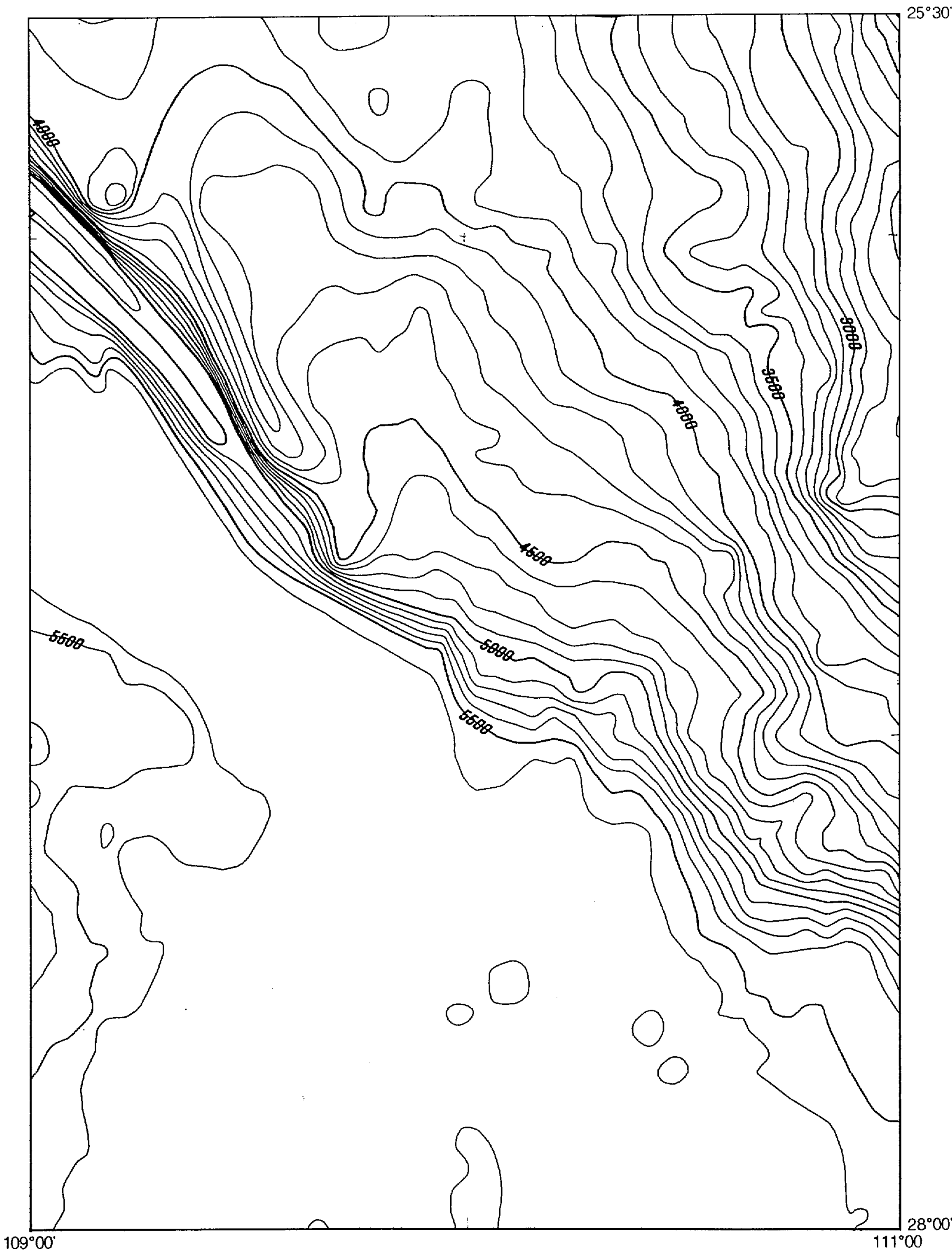

FIGURE 11

Analysis area within Hartog sheet (see Figure 1) showing final contours after manipulation and editing of contours generated by distance weighted average technique (Figure 10). Contours are in metres.