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CONTOUR PROCESSING AND 3-D IMAGE PROCESSING OF SEA BEAM BATHYMETRIC DATA

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Abstract

The Sea Beam system was installed aboard the survey vessel *Takuyo* (NAKANISHI, 1985), in September 1983. It is currently used for continental shelf surveys, bathymetric surveys for predicting earthquakes and other survey activities. Besides these activities, we have been engaged in the development of a computerized system for drawing precise bathymetric charts based on digital Sea Beam data logged on magnetic tapes. So far we have completed two programs — one for drawing bathymetric contour charts aboard a survey vessel and the other for drawing bathymetric contour charts on shore. By means of the former program one can gradually draw depth contours covering the swath width of Sea Beam along the track of the survey vessel. The latter program enables one to draw very precise bathymetric charts through batch processing of all Sea Beam data of the area surveyed. Incorporated in the latter program are data processing steps to delete defective data, reduce dispersion of data, make a mesh system and adjust the mesh size according to the depth of water. Furthermore, taking advantage of the precision and high density of Sea Beam data, the author developed a three-dimensional image processing program to represent clearly the topography of the seafloor. We have used these programs with the Sea Beam data obtained in bathymetric surveys, and as a result have confirmed their practicability and validity.

1. PROBLEMS INVOLVED IN PROCESSING SEA BEAM DATA

The Sea Beam system is a very sophisticated deep-sea swath survey system for conducting multi-beam soundings covering a width about 70% of the water depth. In this system, a total of sixteen beams are generated to form lines

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at intervals of 2°2/3 on both sides of the survey vessel to measure sixteen different depths of water at a time. Values for the water depth and for the cross track distance are then calculated by compensating for sound ray bending and beam rolling, and the values thus calculated are logged on magnetic tapes. Bathymetric contour charts with the swath surveyed widths are drawn on a real time basis. The problems likely to be faced in processing Sea Beam data are as shown below.

(1) Dispersion of the data

Figure 1 shows the water depth values on the basis of the Sea Beam data obtained and graphed during an actual survey on a flat seafloor about 9,000 meters deep. The depth values are arranged by grouping beams of the same oblique angle. This figure shows that depth values of vertical beam vary very little and that the greater the oblique angle of a beam, the wider is the dispersion of the values. Also, the data obtained from beams at both ends were shallower by dozens of meters than the actual depths.

(2) Sounding error

Although Sea Beam is capable of accurate digital bathymetric survey through analogue to digital conversion of the shapes of waves reflected from the seafloor, it sometimes happens that data obtained on the basis of this Sea Beam data differ widely from the real seafloor topography when Sea Beam is used under rough sea conditions or on a steep bottom slope.

(3) Positioning error

It sometimes happens that a bathymetric chart is distorted due to positioning errors. Figure 2 shows the case where a bathymetric chart is distorted due to errors of about 0.1 nautical mile in positioning.

2. ON-BOARD CONTOURING PROGRAM

We have developed a contouring program for use with an HP-1000 micro computer installed aboard the survey vessel *Takuyo*. This program is for drawing bathymetric charts along the track of the survey vessel, and makes it easier to detect lack of data, defective data and positioning errors. Figure 3 is produced by using this program. An outline of this program is as shown below.

(1) Link with positioning data and depth correction

This step adds position data to Sea Beam data and at the same time correct depth values by using the actual sound velocity profile. The NP139 Echo-

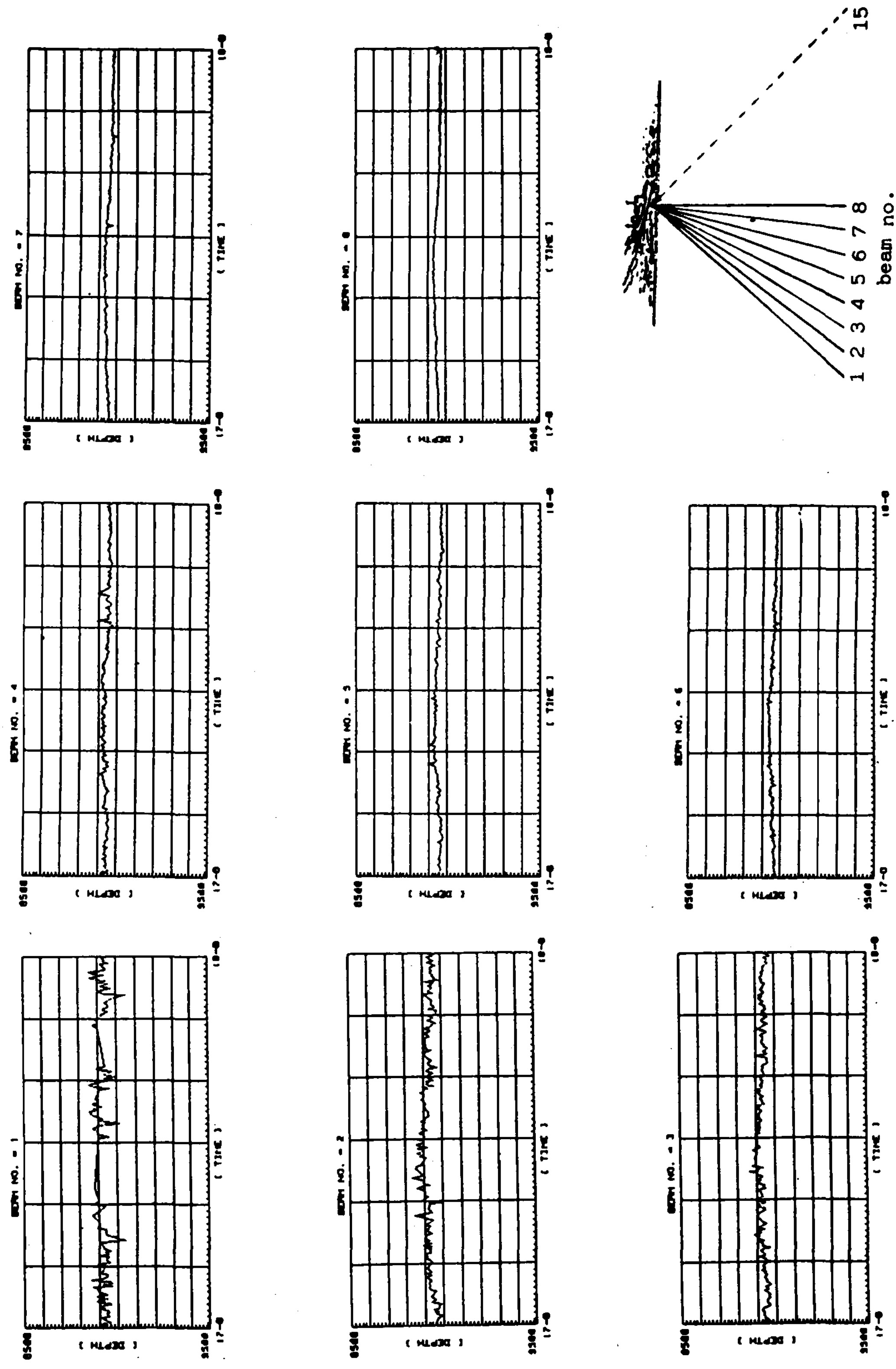


FIG. 1. — Dispersion in each beam data.

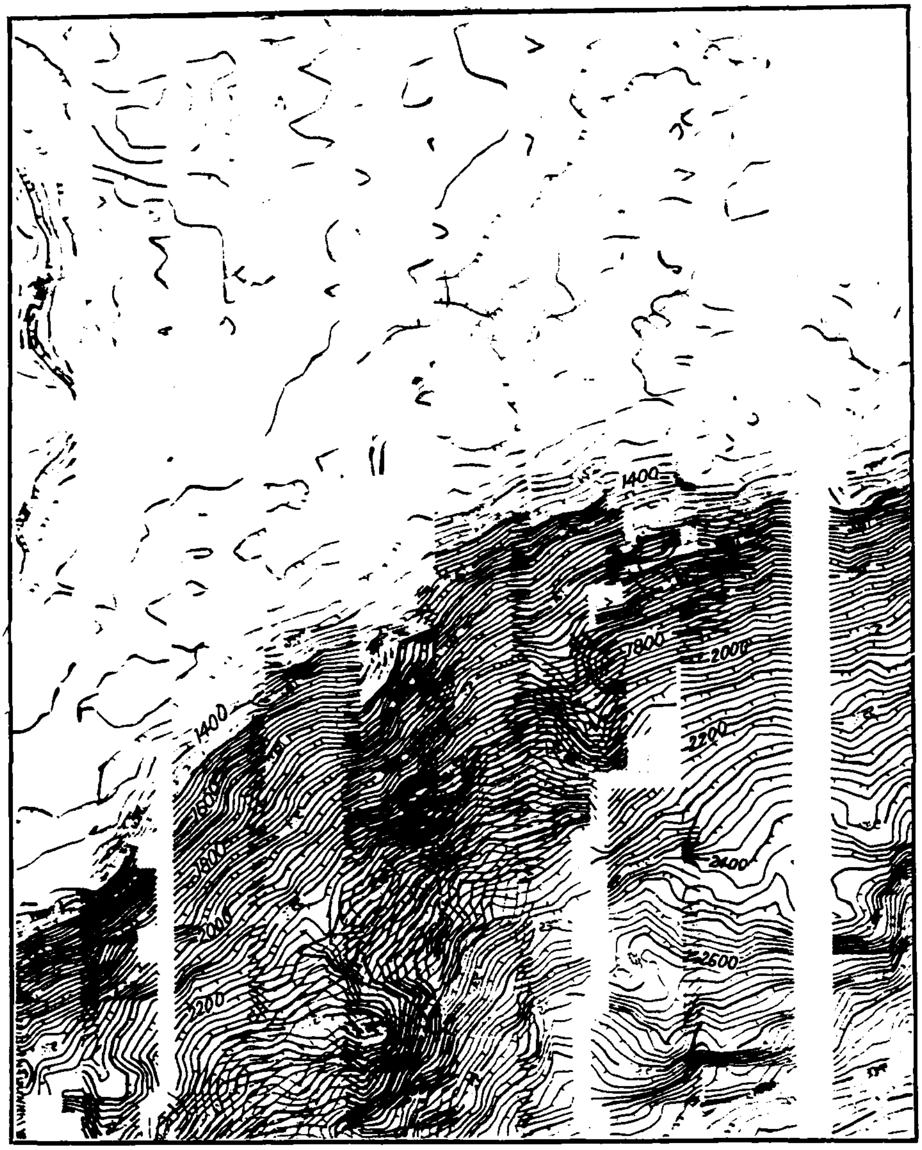


FIG. 2. — Positioning error judged by the contour chart.

sounding Correction Tables (CARTER, 1980) or a correction table prepared on the basis of the results obtained through measurement by means of CTD are used for the depth correction. Correction is done by entering several pairs of observed depth values and true depth values and by using Lagrange's function as an interpolation.

(2) Drawing depth contours

This step is to produce small depth contour charts in every 250 shots and to

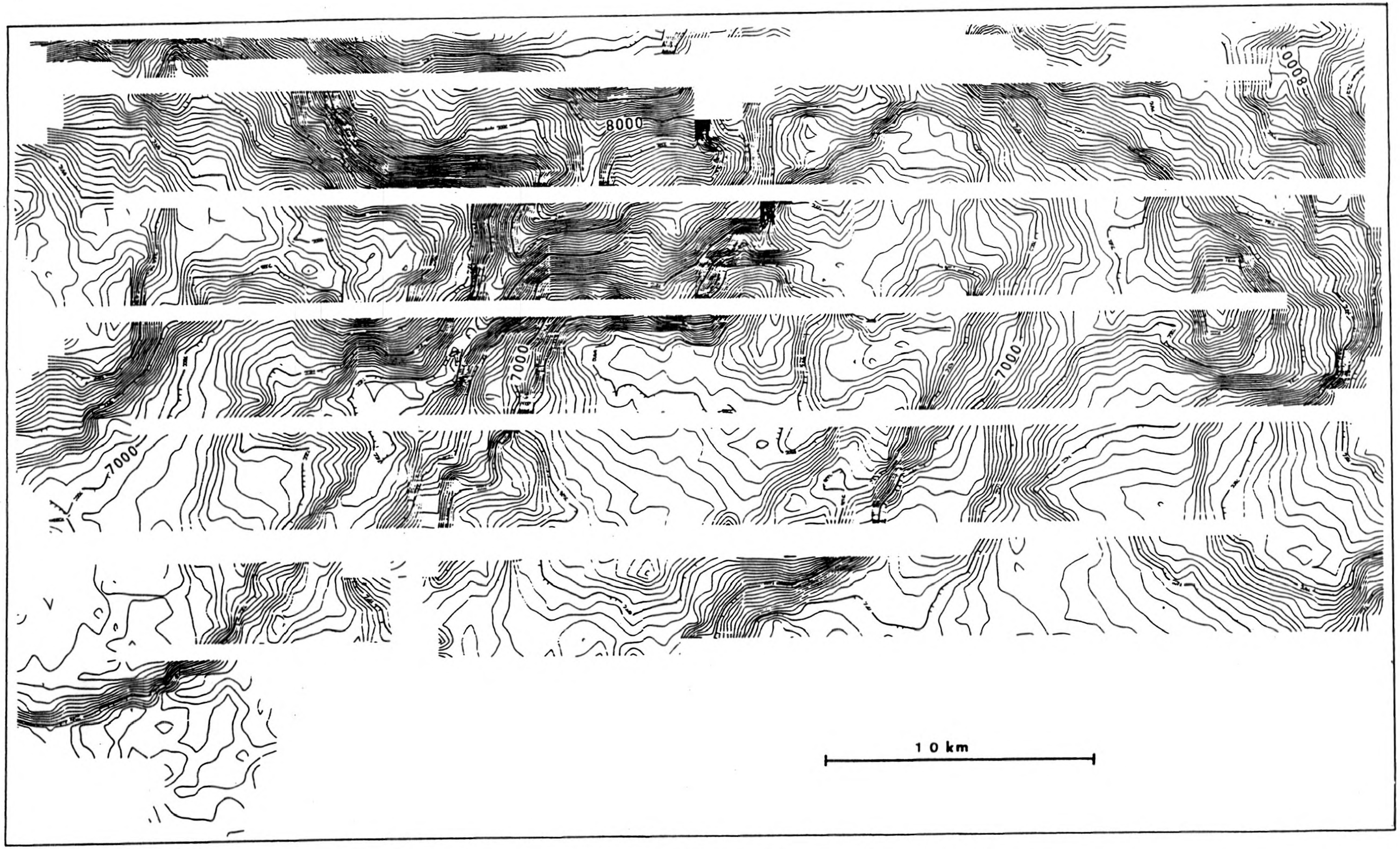


FIG. 3. — Contour chart produced by the on-board contouring program. Contour interval 20 m.

prepare a complete chart by mosaiking. First 250-shot data is read and then this data is distributed into a mesh system. In each mesh the mean value is the representative depth value. Furthermore, each mesh is divided into four (sub-mesh system) by obtaining an approximate equation of the quadratic surface. Based on these sub-mesh systems, depth contours are drawn in areas where data exist. Hachures are added to each depth contour showing the direction of declination. Great care is taken that contours may continue between adjoining 250-shot charts.

3. ON-SHORE CONTOURING PROGRAM

This program was developed for the purpose of preparing accurate and precise bathymetric contour charts. Figures 4(1), 4(2), 4(3) show examples of bathymetric charts prepared through this program. Figure 5 shows the areas drawn. The NEC ACOS 650, a general purpose computer, is used for the processing. An outline of this program is as shown below.

(1) Filtering

The greater the water depth, the wider becomes the variance of Sea Beam data. The data obtained from beams near both ends, with high oblique angles especially, seem to contain abnormal values. An approximate quadratic equation is obtained for a certain interval by arranging the data from the same beam and then the standard deviation value of this approximate quadratic equation is calculated to delete data with excessive variance or abnormal data.

(2) Calculating mesh data

As in the case of the contouring program aboard the survey vessel, the longitude and latitude of each data point of the sixteen beams are calculated, which are then distributed in the mesh system by utilizing disks. All the input data are processed at one time. Next, a weight value ranging from 1 to 8 is given to each data point in inverse proportion to the oblique angle of the beam, and then the center position of gravity of each mesh is calculated from the data distributed. At this position, it is possible to calculate the most reliable depth value. A weighted mean for the depth value is calculated through mean value calculation, plane approximation or quadratic curved surface approximation, depending upon the amount of data. On a shallow seafloor sounding beams are concentrated and data density is high. Therefore, more precise surveying is feasible in shallow depths than on a deep seafloor. Based on this fact, we have mesh data and sub-mesh data of more than two values in a single mesh. The number of sub-mesh data is approximately in proportion to the amount of the data distributed. Also the beam's weight serves to enhance the conformity of data between survey lines.

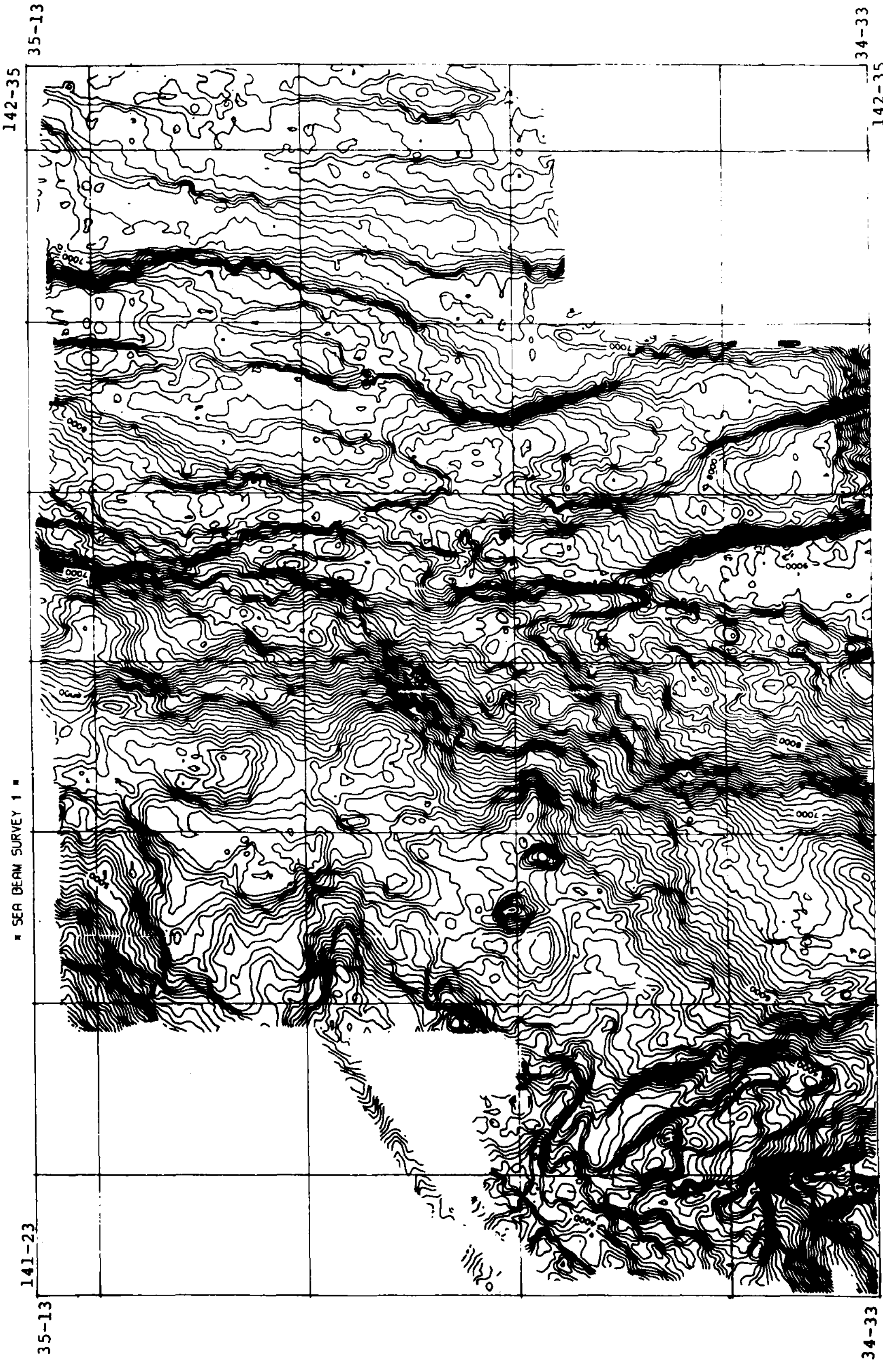


FIG. 4(1). — Contour chart produced by the on-shore contouring program.
Contour interval 50 m.

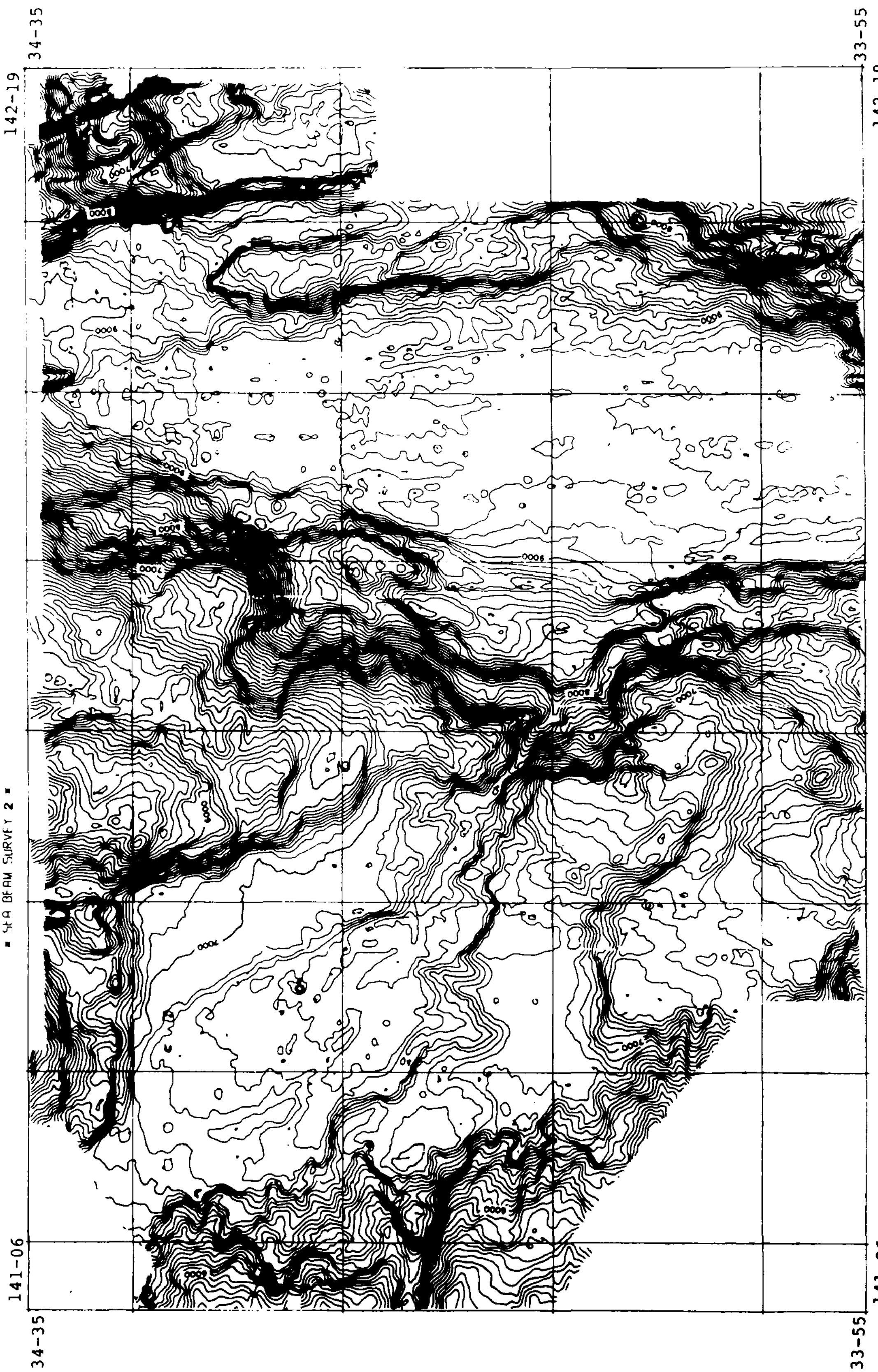


FIG. 4(2). — Contour chart produced by the on-shore contouring program.
Contour interval 50 m.

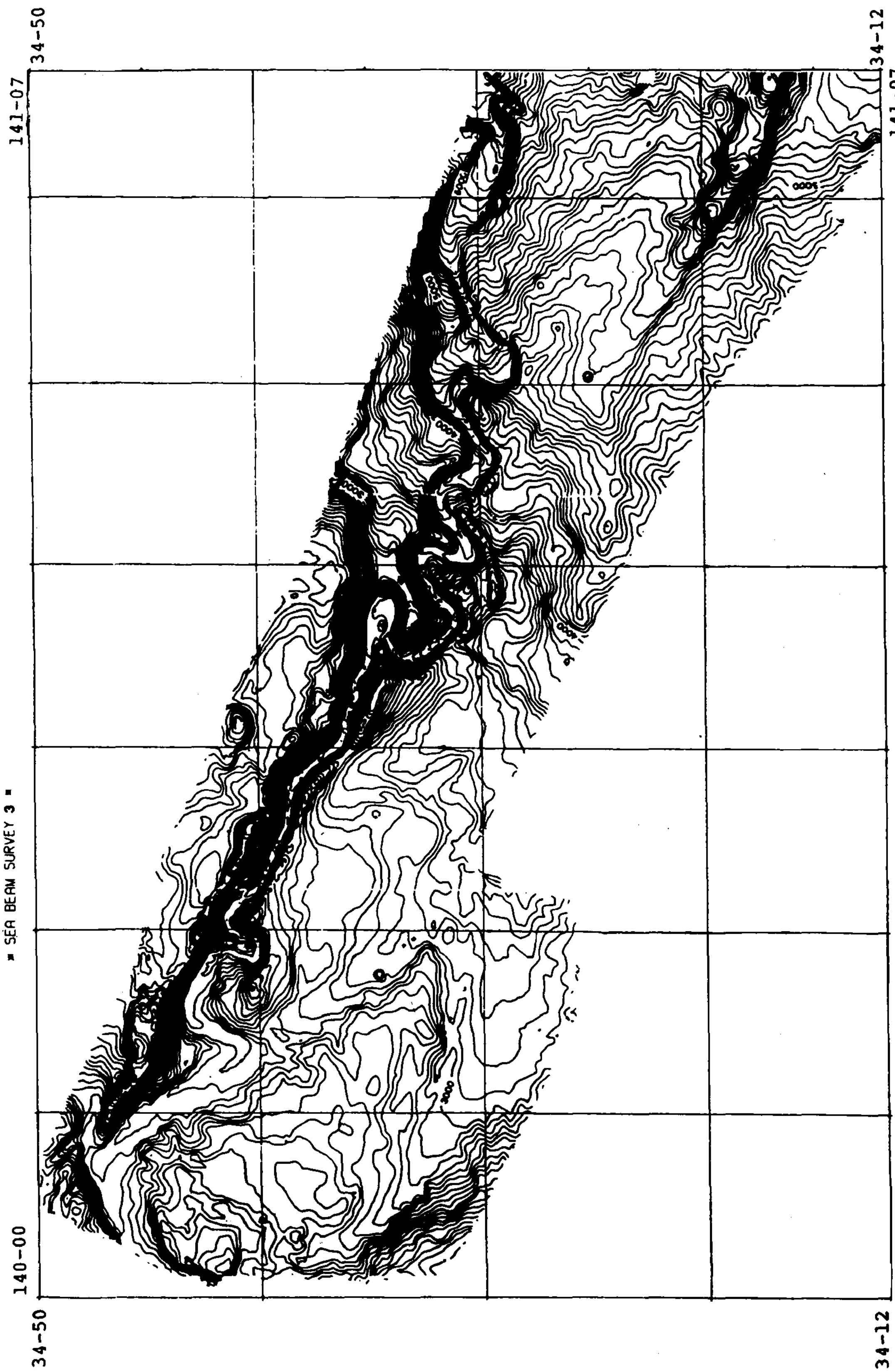


FIG. 4(3). — Contour chart produced by the on-shore contouring program. Contour interval 50 m.

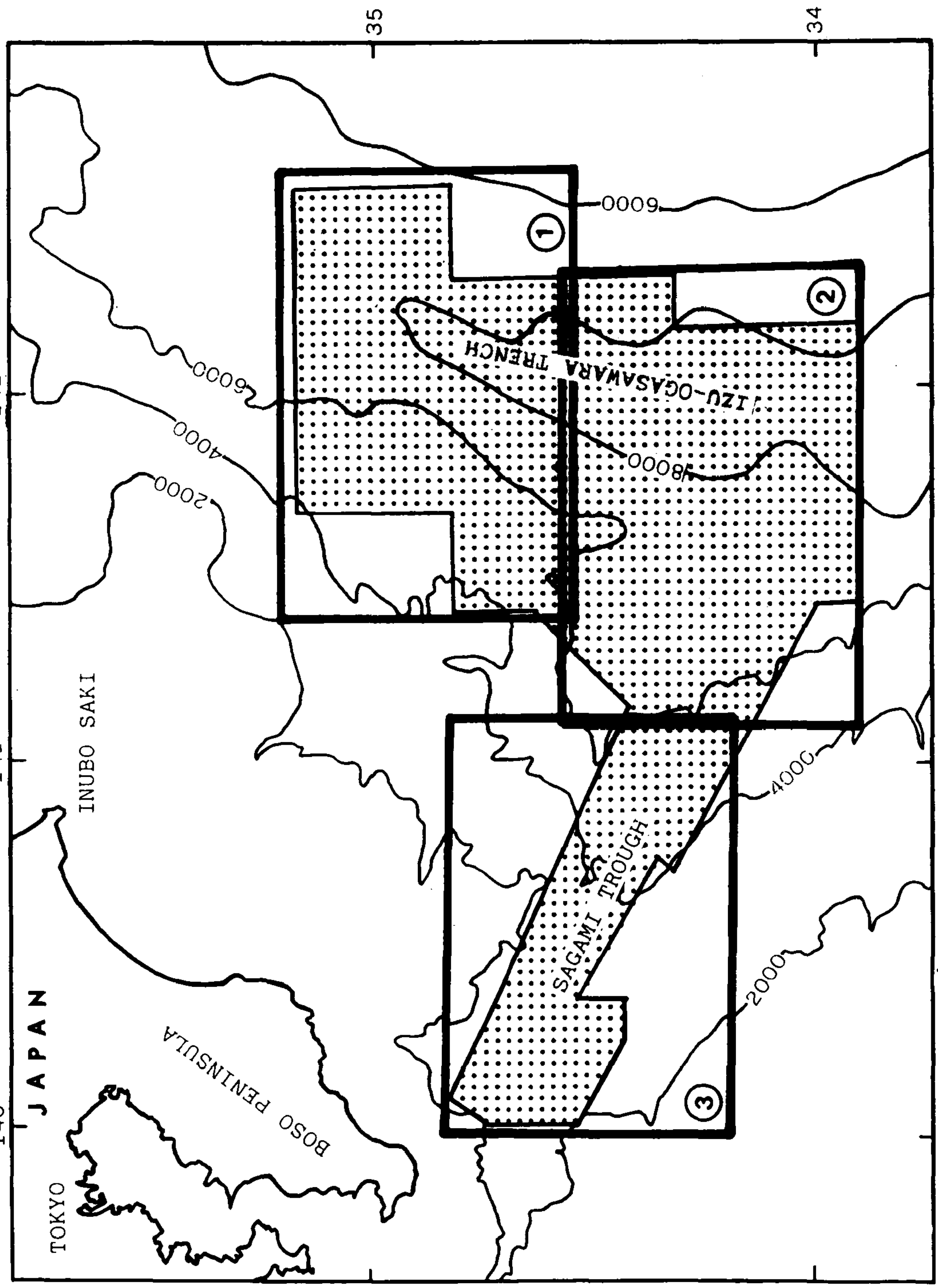


FIG. 5. — Index map of Sea Beam surveyed area (stippled) and drawing areas (boxes with heavy lines). (1), (2) and (3) correspond to figures 4(1), (2), (3) and figures 10(1), (2), (3), respectively.

(3) Drawing depth contours

The total number of meshes of a chart is unlimited. So, a bathymetric chart is divided into parts, each containing meshes of about 10,000 points. Great care should be taken so that depth contours may never overlap or slip when the chart is divided. Since a general purpose and multi-use computer is used for the computation, a divided drawing method is used so that the program may operate on a capacity of 100 kW. In this method, the number of divisions of a contour decreases, which makes the bathymetric charts drawn have high legibility.

First, the sub-mesh system values are calculated on the basis of the approximate equation of cubic curved surface, which is obtained from the mesh system. In the case of sub-meshes already calculated, the values calculated are used. Next, points on the depth contour are calculated from the sub-mesh system. A depth contour is drawn between these points in the form of a smooth curve. An arrow is added to the depth contour for the deepest point to show the direction of declination. Also numerals of a depth value written in a space of a depth contour are parallel to the contour curve. We see to it that a depth contour is never drawn for a depth value larger than the largest of the four depth values or smaller than the smallest of the four depth values in a quadrilateral, consisting of four meshes.

(4) Drawing sounding charts

A sounding chart is drawn by extracting only mesh data from the mesh file produced by step (2). The integral values of depths are written on a chart. The central point of the integral value is the sounding point. In the case of a three-digit number, the center of the second numeral is the sounding point.

(5) Editing mesh data

A number of mesh data editing programs were prepared for the purpose of effectively utilizing this program and enhancing its quality. The largest value of weights is added to each depth value in the mesh data. In the case of mesh data with weights of less than four, curved surface approximation is done for the surrounding mesh data. If the mesh data value varies from the approximation equation by more than a certain value, the mesh data is judged to be abnormal and is deleted.

It sometimes happens that blank spaces appear on a bathymetric chart due to omission of mesh data. In the case of a small blank space, an approximate equation of a cubic curved surface is formulated as an interpolation. It is essential to extract data so that they may surround the blank space. Satisfactory values can be found if constant parts of the approximate equations are determined, so that these equations may pass the extracted data and a weighted mean for each of the approximate values for the points is found by weighting in inverse proportion to the distance.

4. THREE-DIMENSIONAL IMAGE PROCESSING

Conventional three-dimensional view maps are mostly prepared by projecting a seafloor configuration formed by a meshy shadow on a plane. But these maps are not suitable for representing precise seafloor topography. They cannot clearly represent faults and other important sea bottom features. So, the author decided to develop an image view map to represent seafloor configuration by means of small shaded dots. A three-dimensional image processing program was developed. This program expresses the seafloor topography projected on a plane with precise shaded dots and color-coded depth contours. This method can only be put to practical use if it is supported by high-quality, precise Sea Beam data. Figure 9 is the image view map compiled by using Sea Beam data and Digital National Land Information prepared for national and regional land use planning by the Geographical Survey Institute, Ministry of Construction. An outline of this program is as shown below.

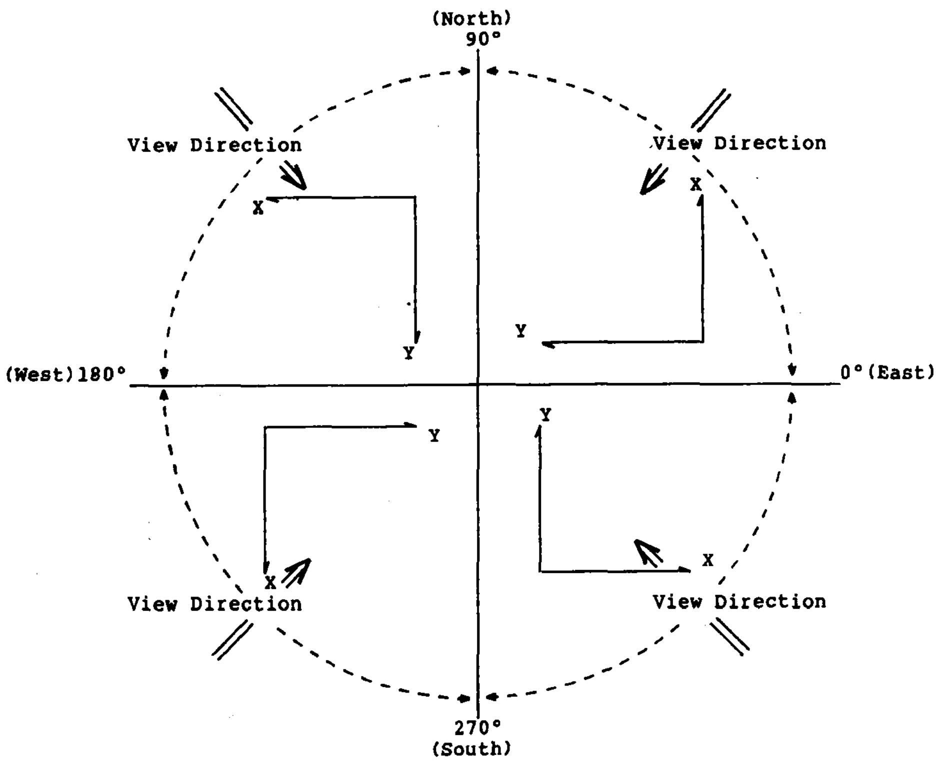


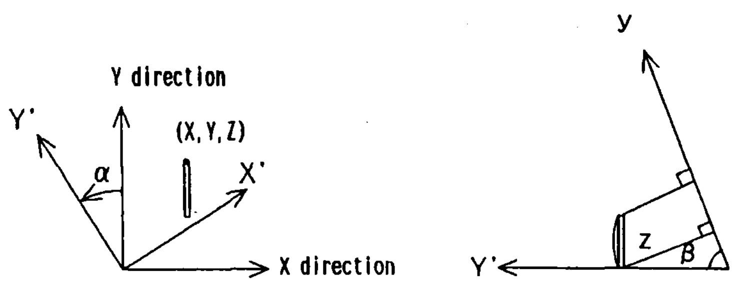
FIG. 6. — X-Y coordinates determined by view direction.

(1) Conversion of the mesh system's rectangular coordinates

The data used in this program is the mesh data produced in the on-shore contouring program. As shown in Figure 6, coordinate conversion is done relative to the direction in which the mesh system is viewed. The direction of due east is taken as the direction 0° and each of four kinds of 90° interval conversions is used relative to the view direction. Coordinate conversion is not necessary if the view direction of the mesh system is within a 270°-360° range.

(2) Producing sub-mesh systems and color coding

Meshes are processed in succession from left to right and from top to bottom. First, mesh systems in three columns at the left hand are stored in the memory and an approximate equation of a quadratic curved surface is obtained from the data in the upper three ranks. And then the values for sub-mesh systems which are obtained by dividing a mesh into 1 to 16 are found. As shown in Figure 7, the values for X, Y and Z of each mesh are projected on a vertical plane in the direction of viewing. The value for Z is obtained by exaggerating the height of depth point above the standard depth level.

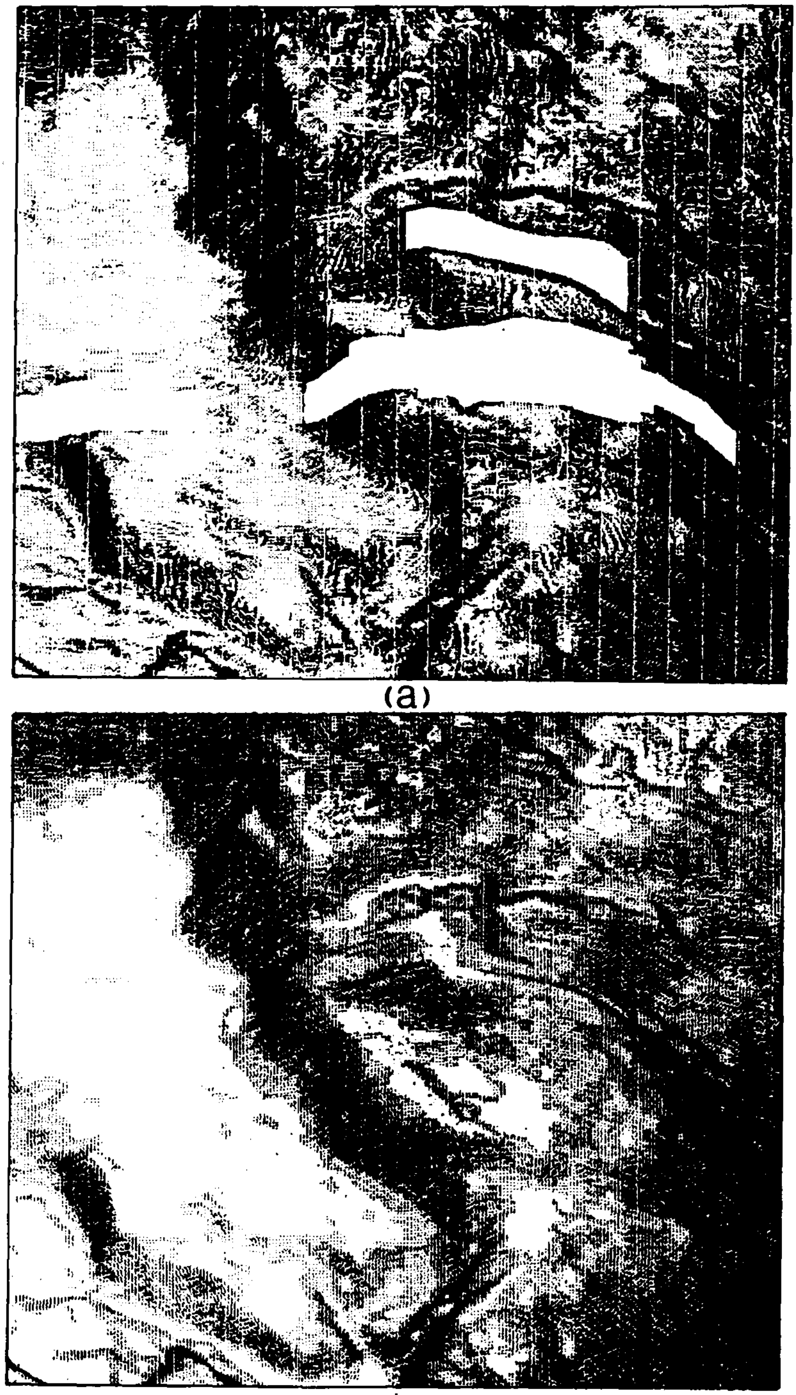


(X ,Y ,Z) : 3-D topographic data
(X',Y',Z') : α rotation of the X-Y Plane
(x ,y) : after projection (the x-y plane is vertical to the view direction)
α : difference between the view direction and the X direction on the X-Y plane
β : angle of elevation
a : exaggeration rate of depth (Z= (the basis depth − depth) · a)

$$\begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \sin\beta & \cos\beta \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix}$$

FIG. 7. — Projection of 3-D topographical data.



(a)

(b)

FIG. 8. — 3-D image views: (a) containing blank areas due to data loss and portions colored irregularly, and (b) improved.

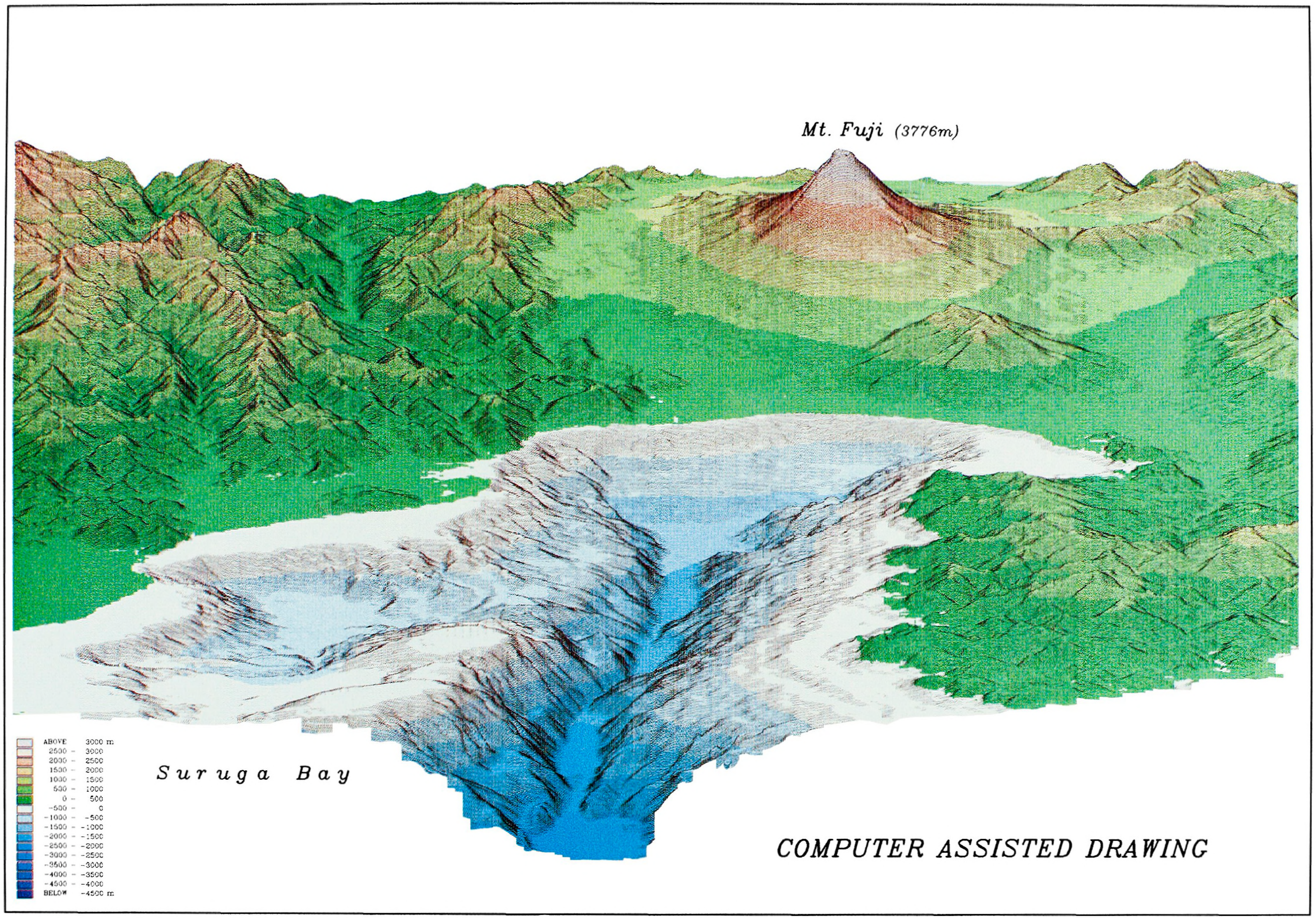


FIG. 9. – 3-D image view of Mt. Fuji and Suruga Bay.

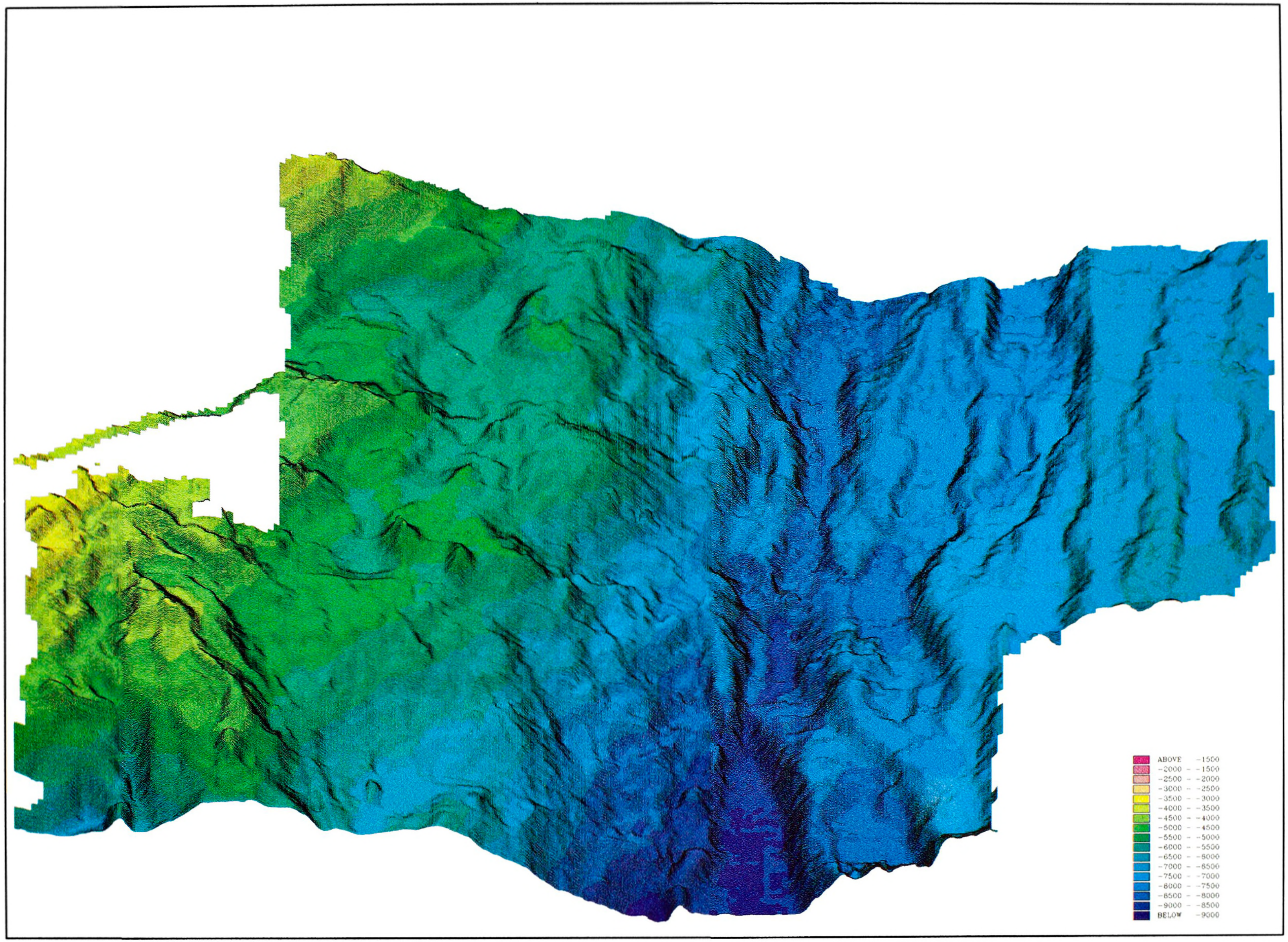


FIG. 10-①. – 3-D image view of ① in Figure 5

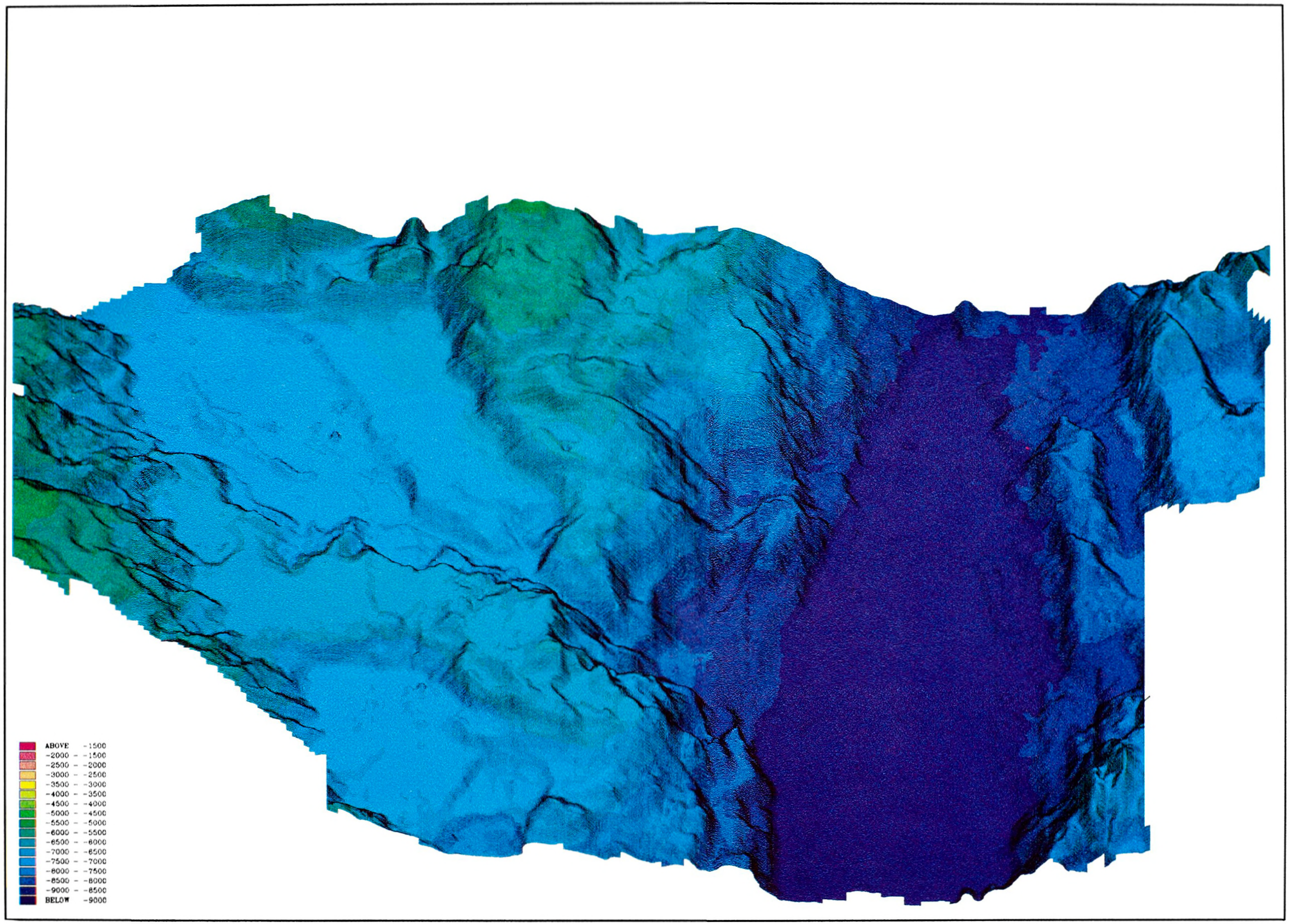


FIG. 10-②. — 3-D image view of ② in Figure 5

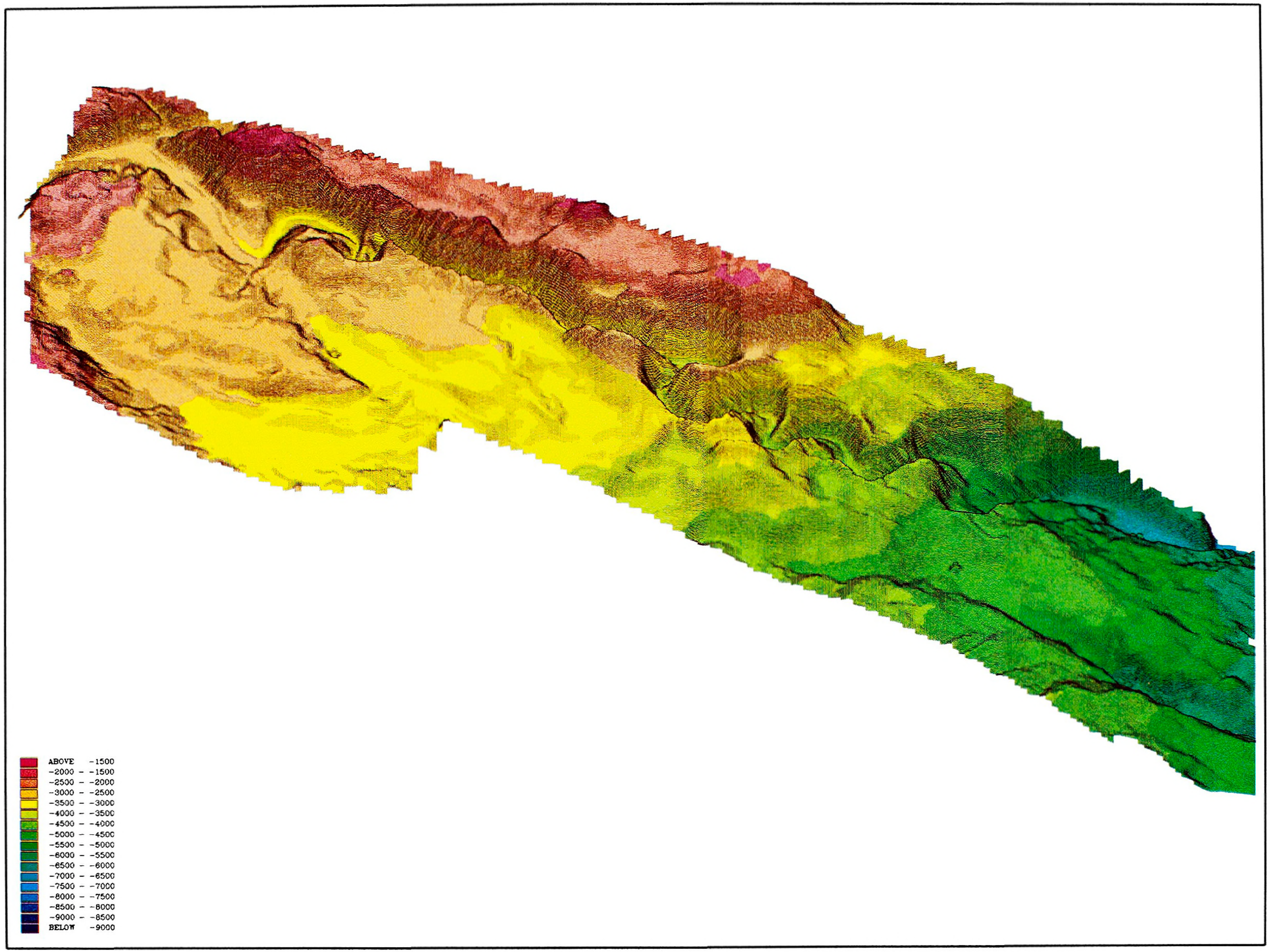


Fig. 10-③. – 3-D image view of ③ in Figure 5

Next, color coding of each sub-mesh within a mesh is done one by one from left to right and from top to bottom. A color code table for depth is used. A depth value in a sub-mesh is the mean value for the four grids. Sub-meshes within meshes in the next column are then colored. This processing order of meshes and sub-meshes makes it possible to hide back-lower configurations behind front-higher configurations.

(3) Shading sub-meshes

Sub-meshes are shaded in addition to being colored. A plane's inclination is calculated on the basis of the actual size of sub-meshes and the depth values for the four grids. According to the plane inclination, 0 to 16 black dots are plotted within a sub-mesh.

(4) Adjustment of view maps

Aplicon's ink-jet scanning color plotter is used as the output device. This plotter's minimum resolution is 0.2 mm. The size of a dot is also 0.2 mm. This plotter is able to produce more than 17,000 colors, by the use of red, blue and yellow only. In such cases color resolution is about 0.2 to 1 mm. This problem of color resolution sometimes causes irregular coloring. Figure 8 shows an example of irregular coloring and that of corrected one. It is possible to resolve considerably the problem of irregular coloring by adjusting the plot size of the sub-mesh, the order of plotting black dots and the relation of a plane's inclination and black dots.

CONCLUSION

The on-board contouring program represents seafloor configuration very clearly. It also provides much information on portions of the seafloor where defective data exist or where data are lacking as well as on the conformity of data between survey lines, the quality of data and so on. Availability of these charts aboard the survey vessel greatly contributes to the enhancement of the quality of survey activities themselves. Further, the on-shore contouring program is also very significant and is capable of providing very accurate and precise bathymetric charts. In addition, it was found that this program could also be used for processing data from a single beam echo-sounder.

Figures 10(1) to 10(3) are three-dimensional image views. Figure 10(1) shows the Izu/Ogasawara Trench and its vicinity. On the eastern side of the trench is the Pacific Plate and on the western side the North American Plate. Its eastern side subsides from south to north forming a number of faults and grabens near the bottom of the trench. Figure 10(2) shows the junction area of the Izu/Ogasawara Trench and Sagami Trough. Figure 10(3) shows a large meandering valley discovered near the Sagami Trough. Thus the three-dimensional image view map is capable of clearly representing the shapes and features of faults, seafloor undulations, valleys, grabens and other physiographic phenomena.

References

[1] CARTER, D.J.T. (1980): Echo-sounding Correction Tables, NP139, third edition, The Hydrographic Department, Ministry of Defence, Taunton.

[2] NAKANISHI, A. (1985): New Japanese Survey Vessel *Takuyo*, *Int. Hydrog. Rev.*, Vol. LXII(2), pp. 51-57.