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REPRESENTATIONS OF SUBMARINE TOPOGRAPHY IN OCEANIC CARTOGRAPHY MAINLY USED IN JAPAN*

J.C.A. Commission on Oceanic Cartography**

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Abstract

The representations of submarine topography were studied and summarized, as a first paper of intended series of "Studies on the representations in oceanic cartography". The maps concerning submarine topography and geomorphology are classified as follows; sounding chart, contoured bathymetric chart, data reliability chart, topographic profile, geomorphological chart, submarine summit level map, shading contour chart, relief contour chart, block diagram and others. Besides, the elements of representation such as scales, projections, colors and symbols were briefly discussed.

1. Introduction

On the occasion of the Seventh International Conference on Cartography at Madrid in 1974, the meeting of Working Group on Oceanic Cartography was held under the chairmanship of Mr. A. J. Kerr. Discussions were made on the desirability of preparation of a reference book or series of reference papers describing the cartographic technique used for charting different oceanographic parameters.

Although any guideline for preparation of the reference papers or for definition of kinds of the parameters is not decided yet, T. Sato, one of the authors, has organized the Commission on Oceanic Cartography in Japan Cartographers Association (J.C.A.) to discuss this problem. The members of the Commission have agreed to the proposal to make a research on various representation methods of submarine topography mainly employed in Japanese marine charts. The present paper is a summary of the report written in Japanese with the same title and published in a recent issue of the Journal of the Japan Cartographers Association. This is also to serve as the first paper of the intended reference paper series.

If there were a definite classification of oceanic cartography, it would be very convenient for classifying oceanographic parameters. The preliminary classification of ocanic cartography conceivable is as follows:

Natural geography { Sea bottom / Sea water / Marine organisms / Marine meteorology

* Version in Japanese has been published in *Map* (Journal of the Japan Cartographers Assosiation) 13 (1975), 30~41

** O. ATOBE, H. CHUJO, M. HORIKOSHI, M. HOSOI, K. IGARASHI, K. IMAI, B. IMAYOSHI, A. IRAHARA, K. IRIE, K. ISHII (Secretary), F. ITO, K. KANAZAWA, M. KOGA, A. NISHIDA, T. OYAMADA, T. SATO (Chairman), I. TAJIMA, S. YOSHIDA, and K. YUBATA

Human geography: History; Industry; Transportation; Others

Each item in the right hand column is divisible further into small items. For example, the item of sea bottom may be divided into topography, geology, geophysics, etc.

There were two ideas how to prepare the reference paper; the first was the method adopted in the present paper, while the second was as follows: There are three major groups in the field of oceanic cartography, i. e. map, atlas and scientific article, which are different one another in purpose and restriction for representation in connection with the scale, color, etc. Therefore, researches should be made as to each group.

However, the first method was preferred for adoption because all of oceanographic parameters or techniques of representation are not always included in each group.

This paper was prepared primarily according to the parameters, supplemented by additional discussions on the scales, projections, colors, symbols, abbreviations etc.

2. Representation of submarine topography

(1) Plotting sheet (or sounding chart)

The most basic data in submarine topography is the plotting sheet including numerous soundings, which is ordinarily provided with scales, borders, graticules and coast lines. The soundings adopted are usually corrected for the elements such as the sound velocity in sea water, etc., but sometimes there are some plotting sheets on which uncorrected soundings are shown. Basic representation of a plotting sheet

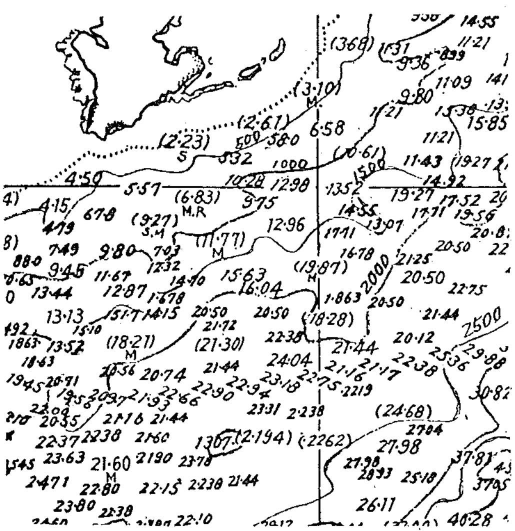


Figure 1 Example of plotting sheet (a part of 1/1 mil. GEBCO Plotting sheet J.H.D. No. G 1305)

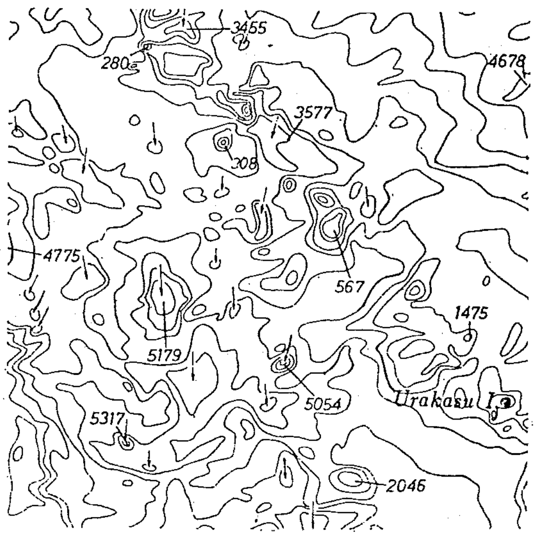


Figure 2 Contoured bathymetric with chart sounding figures at the deepest and shallowest points, and with arrow symbol indicating depression (a part of J.H.D. No. 6302)

should consist of the corrected soundings and isobaths (Fig. 1).

Some plotting sheets include the soundings of the same accuracy obtained by a survey or surveys with the same level of accuracy, but some others include soundings of different level of accuracy. Especially in the latter case, an index chart showing the data reliability is necessary.

In the conventional method, soundings on plotting sheets were taken at fixed time intervals. However, Japanese Hydrographic Department (J.H.D.) has recently adopted a new method where geomorphologically important soundings are used instead of those at fixed time intervals. Namely, the soundings to be adopted on the echogram are those which indicate the transition point of slope, the shallowest and deepest portion of bottom relieves as well as the point where a certain depth contour should pass when all correction values are taken into account (for example, adopt the point of 1, 021 meters sounding, which will become 1, 000 meters with correction value of −21 meters, thus the 1, 000 meter depth contour is to pass through this point).

Sounding charts or plotting sheets are the data sheets and usually not published.

(2) Contoured bathymetric chart

In the bathymetric chart represented by isobaths, various kinds of methods are used for easier and clearer representation of relieves.

The sounding figures shown in contoured bathymetric chart should be limited to topographically significant ones. The 1/10 mil. GEBCO sheets of 4th edition were criticized on its numerous meaningless soundings adopted (Laughton et al. 1971). Usually, sounding figures are to be shown at the deepest and shallowest points in closed isolated isobaths (Fig. 2).

The method to indicate the depression in a closed isobath is to use an arrow (Fig. 3a) or a symbol as Fig. 3c. Besides, down slope symbol shown in Fig. 3b is used for indication of trough or valley (Natural Resource Chart, Canada).

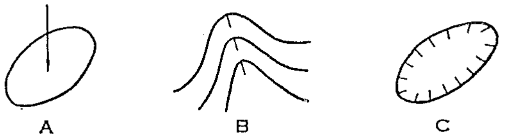


Figure 3 Several kinds of contour symbol (a; depression arrow, b; down slope symbol, c; depression hatchures)

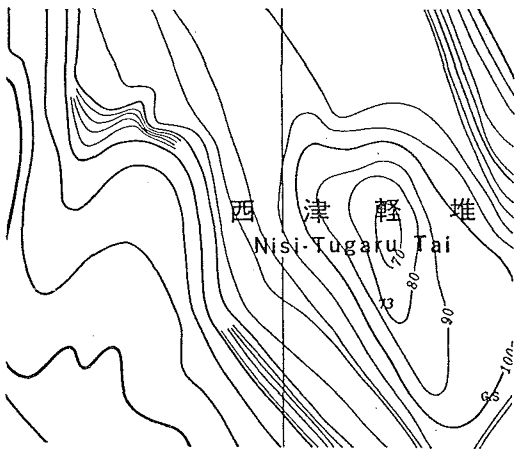


Figure 4 Omission of contours on steep slope (a part of 1/200, 000 bathymetric chart, J.H.D. No. 6327)

The interval of isobaths is usually not fixed but flexible on a bathymetric chart. Namely, intervening contours are shown in flat bottom areas at a lighter line weight than basic contours and the basic contours are sometimes omitted in steep slope bottom areas (Fig. 4). This custom of irregularity in isobath intervals on a bathymetric chart is very unfamiliar to geographers of land topography. There are indeed a number of bathymetric charts on larger scales with fixed interval of isobaths (J.H.D. No. 6410[61], No. 6420[1] and G.S.I. L.C. Map 1/25, 000). However, it is difficult to draw isobaths at fixed intervals on the bathymetric charts on smaller scales. The irregularity of isobath intervals may be attributed not only to the scale or basic interval of isobaths, but also related to the character of submarine topography itself. Table 1 shows the standard intervals of isobaths with respect to scales on existing bathymetric charts other than those used in scientifi articles.

Table 1 Intervals of isobath with respect to scales appeared in existing bathymetric charts in Japan

scale	fairly flat bottom	steep slope
1/10, 000	0.5 — 1 m	1 — 10 m
1/50, 000	5 — 10	50
1/200, 000	10 — 20	100
1/500, 000	20	200
1/1, 000, 000	50 — 100	500
1/10, 000, 000	500	1000

The isobaths shown on nautical charts have quite different character from those on bathymetric charts, because the former is defined as that "depth contours shall be drawn on charts in such a way that no sounding figure having exactly the same value as the contour line will appear on the deep-water side of the depth contour". The isobaths on nautical charts are not necessarily to be the topographic lines.

Concerning the interval of intervening isobaths, various intervals such as (1m, 2m, 2. 5m, 5m, ……) $\times 10^n$ are used, but desirable intervals should be 1m, 10m, and 100m for the convenience of reducing larger scale chart to smaller scale one.

The isobath is usually drawn in a firm line, but there are isobaths of broken lines which are sometimes used as the intervening isobath or the deducing isobath in the area of scarce sounding.

(i) Layer-colored bathymetric chart

Layered colors on a bathymetric chart are based on blue shades. There are two different kinds of purposes in this representation; the first is using regular coloring intervals to compensate effectively the irregularity of isobath intervals, and the second aims to clarify topographic features by the appropriate interval of layered colors.

(ii) Symbolized bathymetric chart

As the use of colors is restricted, the contoured bathymetric charts in scientific articles are sometimes shown by various kinds of symbols (Fig. 5). These are similar to layer-colored bathymetric chart of the second type representing topographic features.

(3) Data reliability chart

Soundings in old days were made by lead sounding and astronomical positioning, so that the results were shown in the form of spot soundings. Even in results of the latest surveys, echo sounding represents at most topographic profiles along tracks. The bathymetric chart is a representation of areal topographic features so that it must be drawn with the help of interpretation. Hence, a data reliability chart showing the quality, quantity and distribution of soundings is indispensable to the bathymetric chart. Furthermore, the data reliability chart is useful for replacing old soundings by new data as well as for finding out any necessity of survey in the area where data are scarce.

There are several kinds of representations for the data reliability chart. A sounding density chart shows the number of soundings for each unit area (Fig. 6). This is usually prepared as a small index chart. Track lines are also shown as an index chart or directly drawn on the bathymetric chart. Laughton et al. (1971) proposed a new method to show the area of detailed survey or the existence of precise bathymetric chart on larger scale. This is not adopted in Japanese bathymetric chart, but the areal representation of precise sounding has been adopted on nautical charts of J.H.D.

The source overlay of 1/1 mil. GEBCO plotting sheet prepared by J.H.D. includes track lines, names of surveying ships, date of survey, symbols for positioning methods, etc. (Fig. 7). Although it seems necessary, concerning this problem,

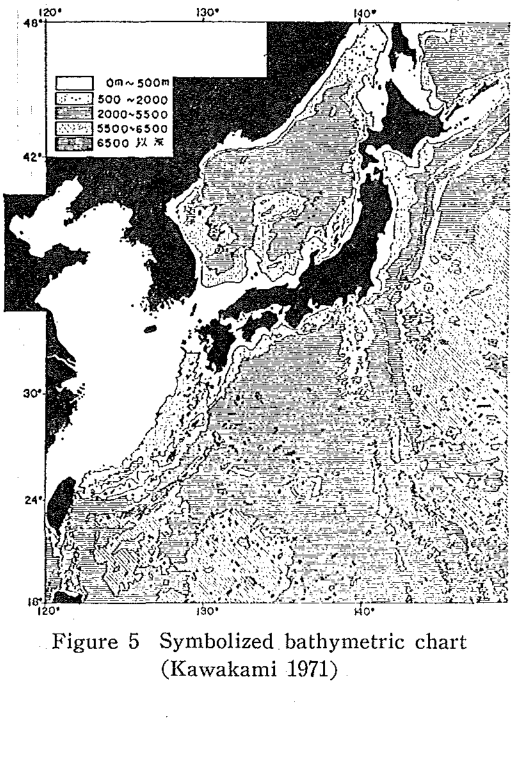
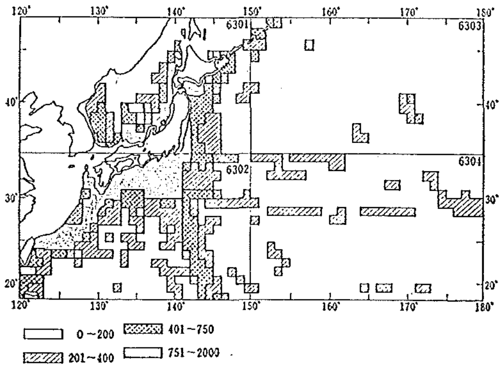


Figure 5 Symbolized bathymetric chart (Kawakami 1971)



日本近海海底地形図の水深密度図（1度毎）

Figure 6 Sounding density chart (a part of J.H.D. No. 6303) to clarify the ranks of oceanic sounding accuracy at present, there is no international agreement on the accuracy standardization of oceanic soundings.

(4) Topographic profiles

Topographic profiles are the basic data for submarine topography as well as plotting sheet itself. Whether the profile is a map or not is a little questionable, but we considered that cartographic representation should include graphic representation.

The most ordinary procedure to make a profile is plotting depths along track lines based on the sounding sheet. As the track line is usually not straight, a straight line is assumed along the track line. As is well known, emitted sound beam from transducer is not a line but a sound cone, echogram record does not always reveal real bottom profile, so that it is required to correct the slope effect. However, it is so difficult problem that sometimes tracing echogram records is prepared (Fig. 8).

On the occasion of systematic survey, track lines are parallel in many cases, and the profiles were lined up for giving three-dimensional images (Fig. 9a & 9b). Fig. 15 is an example of this method. In the profiles on a small scale showing large topographic features, the lower part beneath the sea bottom is sometimes expressed in black color (Fig. 10).

Concerning the vertical exaggeration of a profile, existing profiles were studied, the results of which is shown in Table 2. Generally, the exaggeration rate is larger in expressing small relieves and smaller in larger relieves. The vertical exaggeration of submarine topography is rather larger than that of land topography. It may be

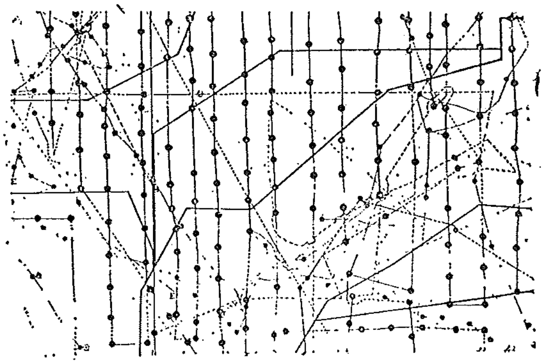


Figure 7 Example of source overlay (a part of 1/1 mil. GEBCO Source Overlay prepared by J.H.D.)

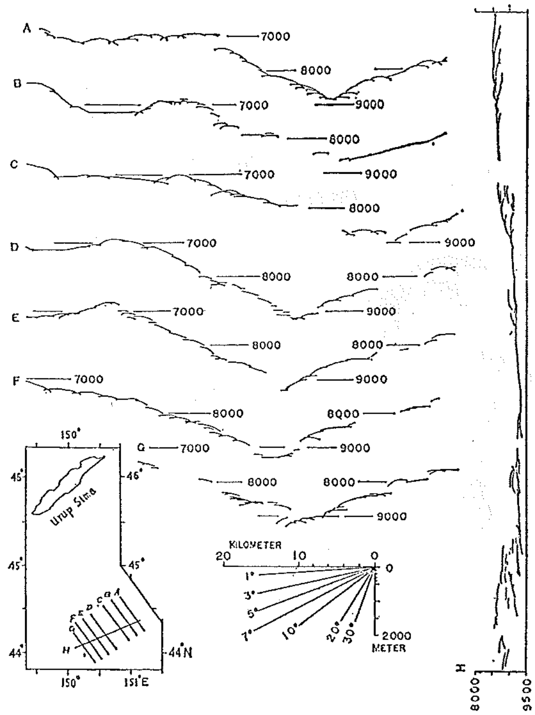


Figure 8 Submarine topographic profiles tracing echogram (Iwabuchi 1963)

(a) (b)

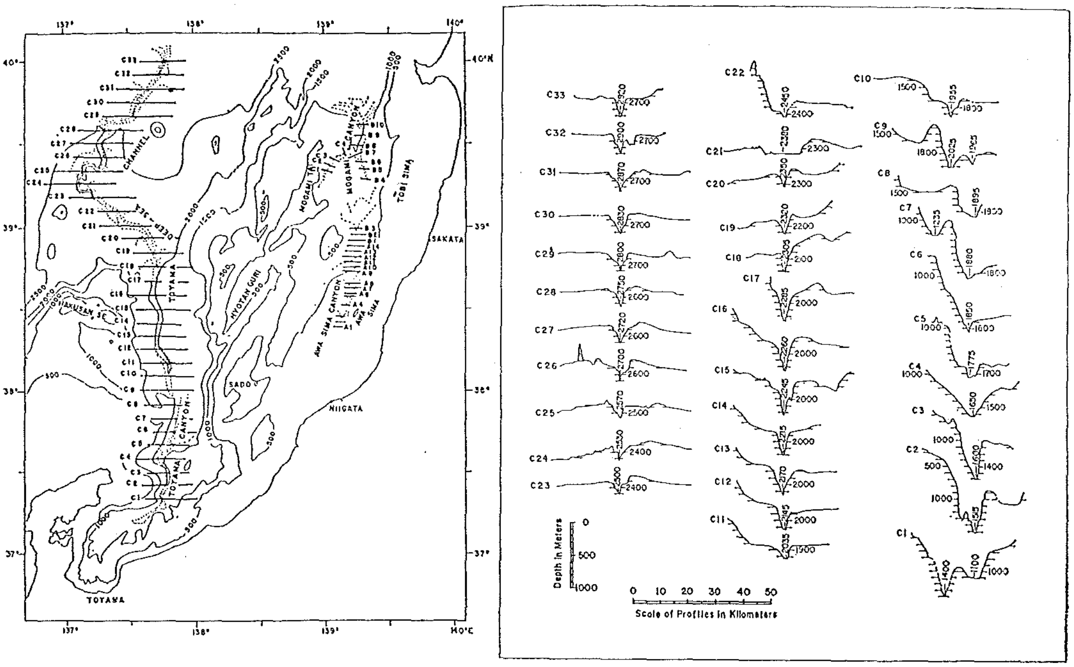


Figure 9 Expression by topographic profiles (a; Positions of profiles, b; Arranged profiles, Iwabuchi & Nakajima 1972)

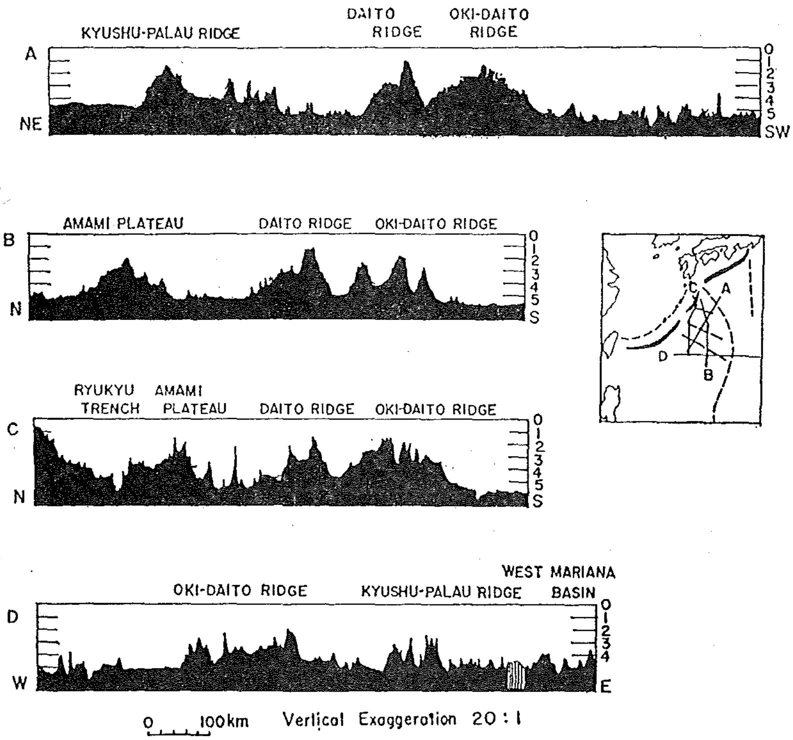


Figure 10 Topographic profiles on small scale (sea bottom is in black color, Mogi 1970)

related to the character of submarine topography; there is no erosional process on the sea bottom and initial relieves originated from tectonic movement are reserved for a

Table 2 Vertical exaggeration of profiles with respect to topography in existing submarine topographic profiles

morphological division		exaggeration
major	minor	
continental shelf	sand wave	25 — 50, 200
	caldron	10 — 20
	bank	10 — 40
	continental shelf	20 —160
continental slope	submarine canyon	about 10
	continental slope	5 — 10
ocean floor	seamount	about 5
	oceanic ridge	10 — 20
	trench	10 — 20
	marginal sea	10 — 20
	oceanic basin	10 — 20

long duration. The structural topography is of large extension compared with the relief. If submarine topographic profiles were made in no vertical exaggeration, many features could not be recognized. Of course, it must be careful not to confuse the exaggerated profile as a real relief.

(5) Geomorphological chart

Although contoured bathymetric chart is an expression of topographical inter-

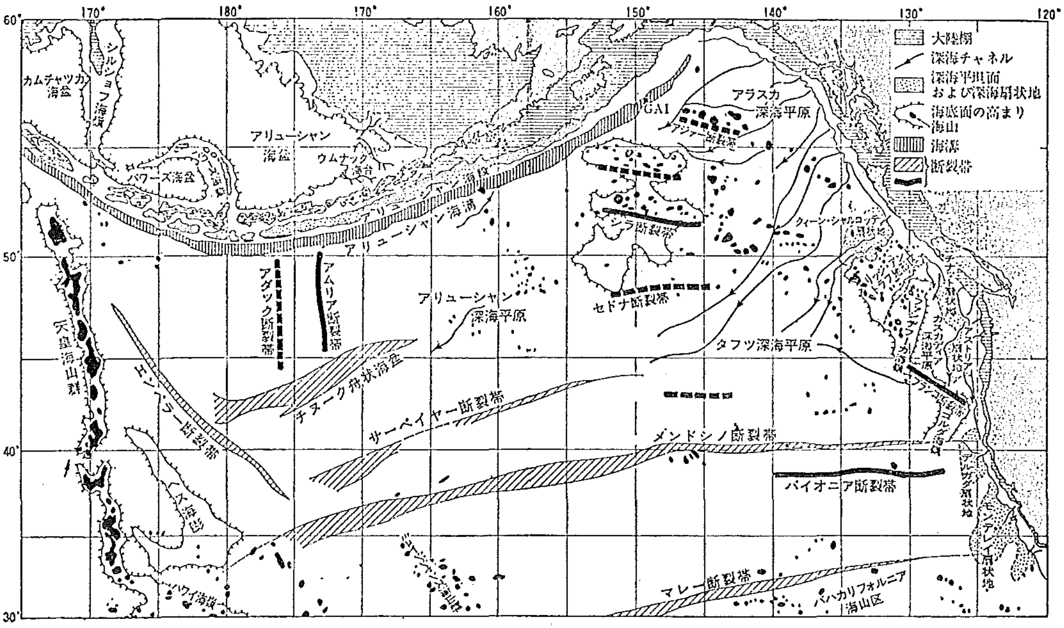


Figure 11 Geomorphological chart with geographical names (Sato 1974)

pretation, it has a descriptive character of sounding data. Geomorphological chart shows the classification of submarine topography based on the interpretation of contoured bathymetric chart (Fig. 11). For example, there may be several kinds of interpretation when a compiler establish a seamount chain for a group of isolated seamounts. Namely, a geomorphological chart is essentially based on the interpretation. Although there is no rule or custom to symbolize the classification of topographical features, geographical names are usually described on it.

(6) Three-dimensional exressions

For measuring gradient of slope or quantitative processing of relieves, the contoured bathymetric chart is very convenient for the specialists familiar to submarine topography, but it is difficult for other people so that many kinds of three-dimensional expressions have been invented also for the representation of minor relieves.

The shading method giving three-dimensional image by hatchures, dots or colors are often effectively employed on topographic maps on land, but these are not used on the bathymetric chart which has monotonous relieves and wide spacing of isobaths. If the intervals of isobaths would be closer, shading method would become more effective. In scientific articles, a large scale contoured bathymetric chart reduced to the limited size of a journal often gives unexpectedly good image of three-dimensional effect.

(i) Hatchured contour

Submarine topography is viewed obliquely and isobaths are shifted slightly towards the viewing direction according to their depths and shaded by hatchures (Fig. 12). This method is fairly effective in black color expression. Similar method was used in "Relief diagram of the continental margin" prepared by Canadian Hydrographic Service.

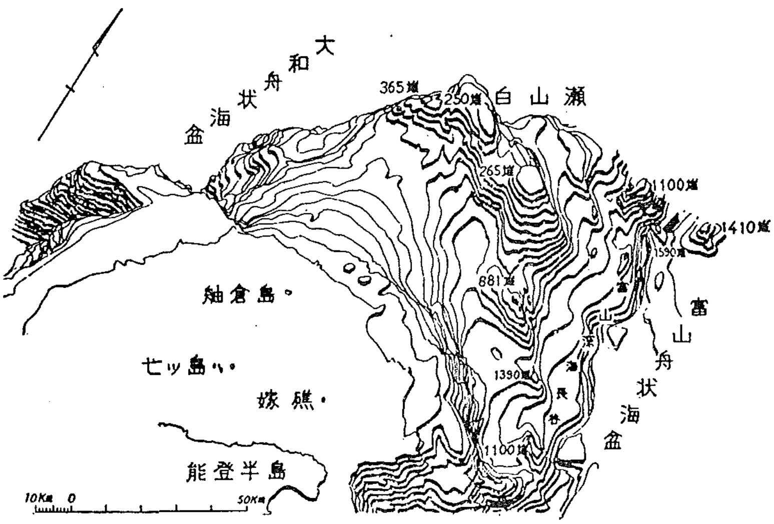


Figure 12 Example of hatchured-contour expression (Taguchi et al. 1973)

(ii) Shading

Shading is a popular representation in topography on land, but there is scarce example of shading method in submarine topography. "Submarine topography" sheet in the National Atlas in Japan is an example of adopting this method. On this sheet, layered colors and shading by blue tone are effectively used.

(iii) Relief contour method (Kitirō Method)

The method is based on the principle of shading by oblique illumination. The process of drawing may be explained with the aid of Fig. 13. The ground is first tinted grey, the contours in the light are then drawn in white, and those in the shade in black. The breadth of the contours varies with the cosine of the angle θ between the horizontal direction of the incident ray and the normal to the contour at the point under cosideration. The maximum breadth of the contour is at the direction of light and minimum one is at the normal direction to light. The breadth of contour may be theoretically decided in terms of the brightness of the ground and of the contours, but actually the brightness was used to determined according to the results of several trial printings after the maximum breadth was decided.

The bathymetric chart prepared by J.H.D. is a good example adopting this method (Fig. 14).

(iv) Parallel arrangement of profiles

Arranging profiles of constant intervals with a slight shifting position gives a good illusion of relief. Although it has been rarely applied to submarine topography, it seems very effective for moderate relieves (Fig. 15), but too many profiles are ineffective.

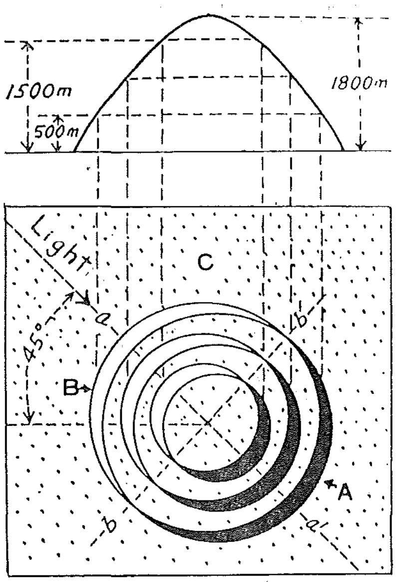


Figure 13 Principle of Relief Contour Metod

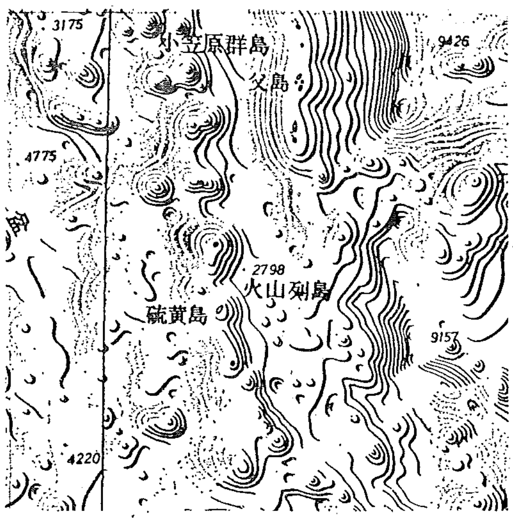


Figure 14 Relief Contour Method or Kitirō Method (a part of J.H.D. No. 6901)

(v) Physiographic diagram

This is a bird's eye view of submarine topography, which is used by Heezen et al. (1959) in the North Atlantic and Menard (1964) in the Northeastern Pacific. These charts were prepared based on numerous soundings with minor relieves expressed by hatchures, which could not be represented by a contoured bathymetric chart. Namely, it uses a pictorial technique.

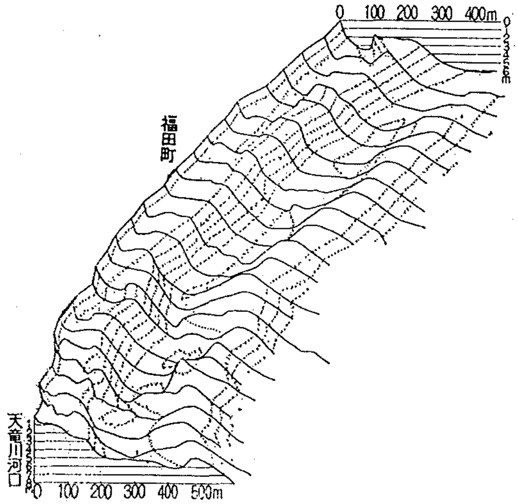


Figure 15 Parallel arrangement of profiles (Mogi 1963a)

The physiographic charts of the Pacific, Atlantic and Indian Oceans were prepared by American Geographical Society. These are very famous for effective use of colors and pictorial representations.

In Japan, Mogi (1973) has invented a simple and precise method to represent submarine topography in black color for easier understanding as well as to minimize cartographers individual difference. Contour lines in ordinary bathymetric chart are projected on a horizontal plane. In this method, on the other hand, they are projected on an inclined plane. As an actual process, isobaths are shifted towards viewing direction according to their depths. The contour lines on the front side slope are shifted backward and those on the backside slope are shifted foreward. The amount of shifting is related to the inclination of plotting plane and the height of relief. Then strong shading or hatchuring is added on the crowded contours and weak one on the sparse contour area (Fig. 16).

(vi) Block diagram

The method included in this category are panoramic representation, perspective expression for an idealized relief model, etc. which are convenient for easier understanding of submarine topography (Fig. 17). Lately three-dimensional representations applied for land relieves have been researched by means of an automated cartographic system, which may be applied to submarine topography in the near future.

Figure 16 Physiographic diagram by Mogi's method (Mogi 1974)

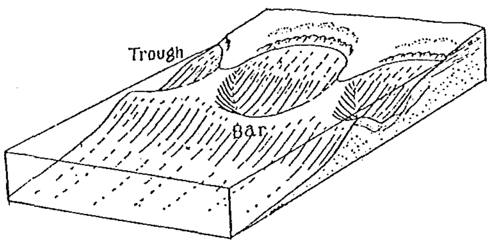


Figure 17 Block diagram of sea bottom (Mogi 1963b)

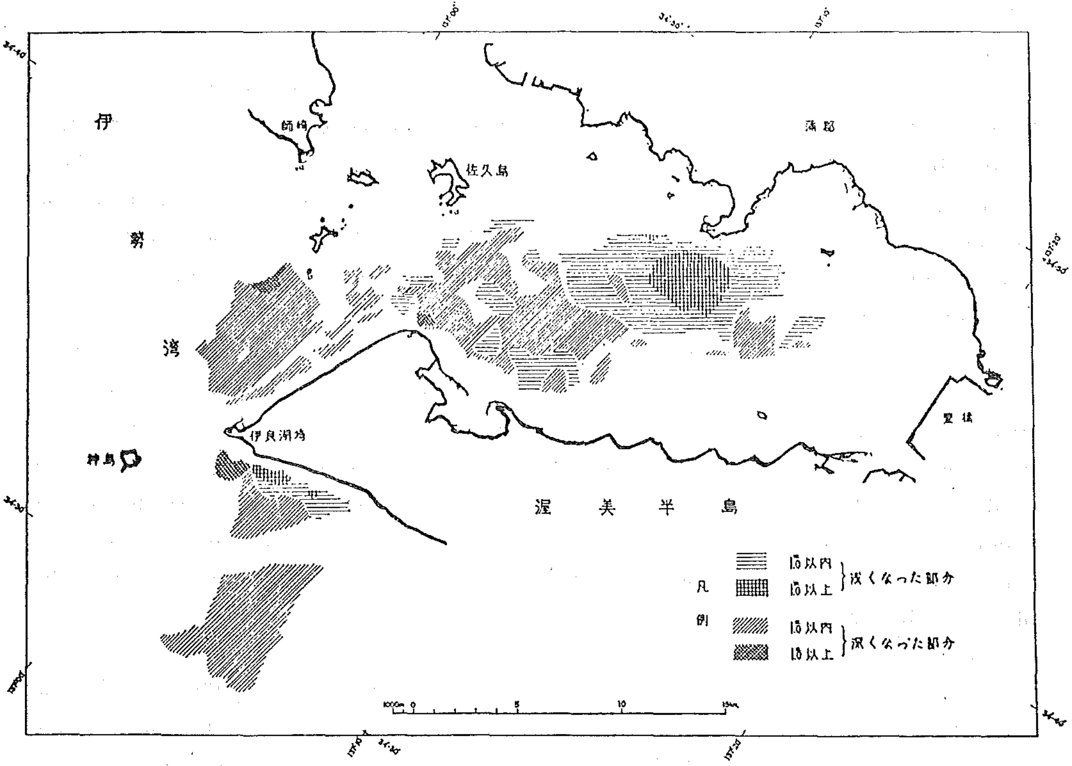


Figure 18 Chart showing depth change (J.H.D. 1968)

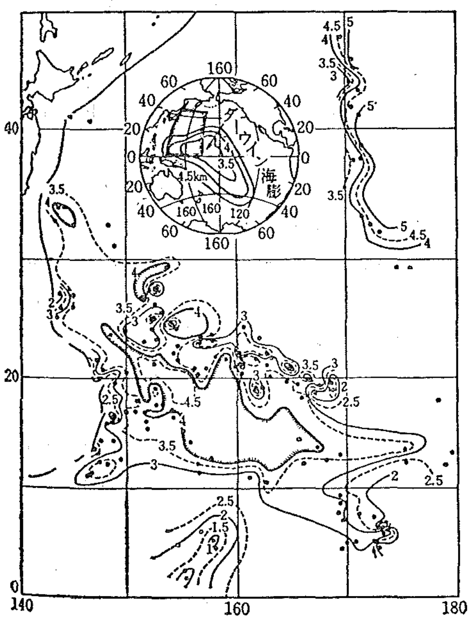


Figure 19 Paleobathymetric chart (Kobayashi et al. 1971)

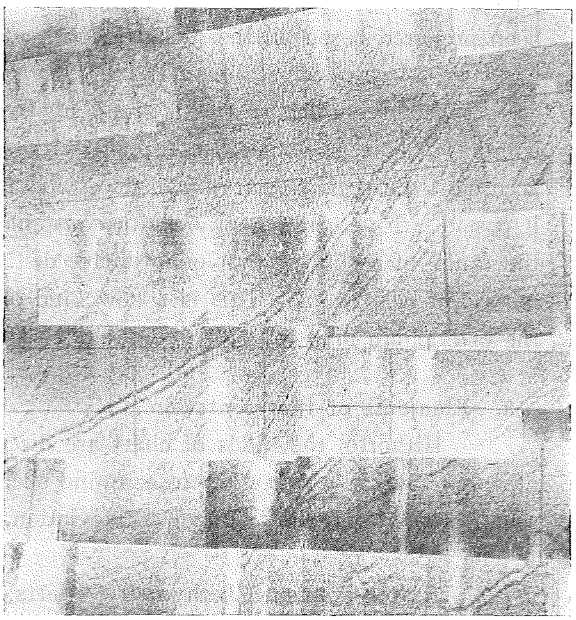


Figure 20 Mosaic side-scanning chart (umpublished data of Japanese Hydrographic Association)

(7) Others

(i) Mesh map

Summit level map and iso-relief map are usually applied for the analysis of land topography. These have been used for submarine topography; the former was applied by Tayama (1950) and the latter by Hoshino and Iwabuchi (1966). In these methods, a standard square mesh is assumed in which the shallowest depth in the former case and the difference between the shallowest and deepest depths in the latter case are measued, and the isopleth map is drawn according to the results.

(ii) Changing of submarine topography

Generally, the changing in depths is small in the sea, but there are many kinds of charts showing the changing of the sea bottom in shallow water as follows; coastal erosion, seasonal change of bar and trough, sea bottom and coastal change by typhoon, hightide and tsunami, migration of submarine sand waves, migration of sand bank in long duration, etc. Besides, the depth changes by earthquakes or submarine slides are researched in shallow and deep sea bottom. These charts are considered to be four dimensional cartographic representation. Fig. 18 is an example of depth change in long duration.

(iii) Paleo-bathymetric chart

Menard (1964) has restored the bathymetric chart before 100 m.y. in the Central Pacific Region according to the depths of guyots. Fig. 19 show paleo-bathymetry in the Western Pacific according to same procedure to the Menard's but using more detailed soundings, which did not reveal the Darwin Rise. Lately many charts showing the distribution of land and sea, or oceanic rises in old days have been prepared based on the global tectonics theory.

(iv) Mosaic side-scanning chart

Side-scanning or side-looking survey has been improved in the following points; variable paper speed accordant with ship's speed and variable sweep speed accordant with the height of transducer above sea bottom. These improvements make it possible to get an echogram with constant exaggeration to the distance covered and the range of record so that quantitative distribution of relieves can be shown by the mosaic of echograms. This is a new kind of bathymetric chart which is similar to the orthophoto map in aerophotographical survey (Fig. 20).

3. Elements of representation

Hitherto, the kinds of chart are discussed according to the purpose or theme of map. But it is necessary to examine such common elements of representation as scale, projection, color, symbol, abbreviation, etc.

(i) Scale

As for published bathymetric charts, excluding those accompanying articles or atlas, the relationship between the scale and the coverage is studied and the result is shown in Table 3.

(ii) Projection

The bathymetric chart covering global extent in a single sheet is used to be prepared in Mercator (U.S. DMAHC) or Winkel (Germany Atlas) projections. Serial charts covering global extent are generally prepared in Mercator and Polar Stereographic (GEBCO), Lambert Conformal Conic (the World Map), Oblique Secant Cylindrical (Germany Atlas) projections, etc.

Table 3 Scales of bathymetric chart with respect to coverage

coverage	scale
world	less than 1/39,000,000
three oceans	1/36,000,000—1/25,000,000
part of ocean	1/12,000,000—1/6,000,000
fundamental sheet in ocean	1/2,500,000—1/1,000,000
continental margin	1/500,000—1/4,000,000
continental shelf	1/250,000—1/200,000
coastal sea	1/125,000—1/50,000

The bathymetric charts for an ocean or a part of ocean are usually prepared in Mercator projection, but some of them are in Equal Area (USSR, Pacific), Normal Polyconic (J.H.D. No. 6901), Oblique Conformal Secant Conic (National Atlas, Japan) projections, etc.

For the series charts in continental margin, Transverse Mercator (U.S., Canada, Australia), Conformal Conic (Japan), Mercator (New Zealand) are in use. For coastal bathymetric chart, other projections than Mercator are usually in use, i.e. Conformal Conic (J.H.D.) and UTM (G.S.I. Japan) projections.

As bathymetric chart, the projections other than Mercator are generally favorable for less distortions of length or area. They are less in distortion of topography. However, Mercator projection has the merit for jointing of adjacent sheets.

(iii) Color

Almost all of bathymetric charts are printed in colors, but one color sheet is also necessary as the fundamental sheet. Layer coloring in blue tone is dominant in colored charts. The Relief Contour Method is the peculiar technique as for the use of blue color.

(iv) Symbols

There are not so many symbolizations of submarine topography in bathymetric chart, but examples shown in Fig. 21 are used other than the representations of isobaths before mentioned. Furthermore, symbols in nautical charts such as wreck or tidal elevation are often adopted in bathymetric charts.

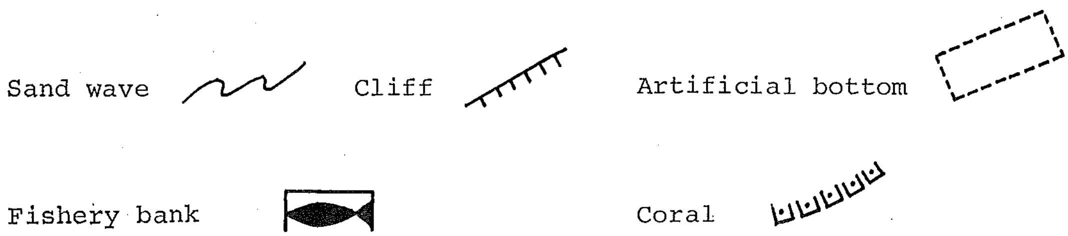


Figure 21 Several kinds of submarine topographic symbols

(v) Abbreviations

The abbreviations of submarine topography are very rare, but it seems that more and more abbreviations will be in use in the future. These in Table 4 have been adopted in nautical charts and used in bathymetric charts. Then, the international standardization of symbols and abbreviations in bathymetric and other oceanographic charts may be very important problem at present.

Table 4 Abbreviations adopted in nautical and bathymetric charts

SMt	Seamont	Rf	Reef	Le	Ledge
Bk	Bank	Sh	Shoal		

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