

TOPOGRAPHY AND SUBMARINE MOUNTAINS : A SPECIAL PROBLEM OF TERRAIN REPRESENTATION

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INTRODUCTION

This paper, quite frankly, represents an argument for greater participation by a larger number of professional cartographers in helping to solve problems of cartographic representations of oceanic environmental parameters and characteristics. Particular attention is given to the representation of submarine terrain, but it is obvious that almost the whole gamut of cartographic research, be it presentational or analytical, has important implications to what should be called "oceanographic cartography". For the oceans, as for land surfaces, we are concerned with first collecting various types of data and then developing spatial graphics (along with other analytical tools) which represent descriptions or data storage units from which a variety of users can retrieve special information or gain new understandings. By placing these data in a spatial context we can help men comprehend the character of the oceans and to analyze and, hopefully, understand the dynamic processes which determine the spatial and temporal characteristics of the data. Through comparison, correlation and the testing of hypotheses some of the inter-relationships between phenomena will become clear.

The shape, nature and associated structure of the ocean basins represents first-order prerequisites for oceanographers and other ocean-oriented disciplinary specialists. While tremendous effort has been and is being devoted to gathering data and discovering the processes which govern the character and dynamics of the water mass, the mutual interactions and interrelations between the water and the basin surface are of tremendous importance. Thus it is that methods for expressing the nature of submarine

terrain are an inevitable need, particularly as the data base is improved. Historically, man's attention to sea bottom characteristics was almost entirely confined to the coastal margin where storm and tidal change made them important factors in the navigation of ships. In time this concern came to include a wider zone when it became obvious that depth and bottom characteristics along with the physical and environmental attributes of the overlying water had important relations to biotic life forms, particularly fish.

The need for knowledge about the oceans now encompasses the entire system of oceanic basins and the water mass that fills them. As on land, the character of submarine terrain is a major key to the interpretation of underlying structure which, in turn, helps us to begin to understand the physical (geological) processes which continue to shape the earth. Axial orientation of terrain features, the location of trenches, fault scarps and submarine canyons, relative relief and the characteristics of slopes are a few of the types of knowledge which are needed to achieve these understandings. The graphic expression of sea bottom terrain data in a form which is compatible with the interpretive needs of oceanographers and others is thus a logical concern and responsibility of cartographers. The United States Geological Survey, the National Oceanographic Survey, the Naval Oceanographic Office and a relatively small number of scientists have been active in programs of cartographic research concerned with mapping submarine terrain. The number of cartographers involved has not been large and attention is still directed somewhat more to the techniques of data gathering than to the cartographic presentation of those data. User needs have broadened enormously in recent years and the greater diversity of the user group has increased the demand for a larger variety of alternative methods of graphic presentation.

While cartographers need to be concerned with the bottom data-gathering techniques, such as echo sounding (Sonar and side-looking sonar, or SLS), photogrammetric procedures (using aerial photography as well as new underwater camera systems [1], [2] and the new developments in surface position fixing (including satellite aids); their role and function always involves the processing and presentation of the resultant data in a variety of graphic forms and scales. The synthesis of data concerning submarine topography is probably more necessary today than ever before because of the multiplicity of needs which must be served. If, for example, oceanographers are to maximize the availability of synoptic imagery of the surface of the sea, obtained by means of multispectral sensors aboard earth orbiting satellites, comparable synoptic images should be created of other characteristics (not visible or imageable from space), especially submarine terrain. Data presentations at various scales and degrees of generalization are needed for underwater navigation, mineral exploration and exploitation, biological environmental studies and many other purposes.

FUNCTION AND DESIGN OF SUBMARINE TERRAIN MAPS

Based on the assumption that the functions of terrain maps of the ocean bottom are essentially the same as for land areas, at least in an analytical context, we have for some years been concerned with the development of techniques for submarine terrain representation. Thus, while we have been concerned with a largely invisible landscape, the function of maps of this landscape are well summed up by IMHOF [3], even though he was talking about dry land areas. Four functional factors have entered into our study :

- 1) Spatial symbology which retains the quantitative character of the data obtained by soundings (simulation of the data surface).
- 2) Symbology which is pictorial in character and thus makes possible rapid qualitative judgements as to the nature of the sea bottom.
- 3) Symbology which is efficiently compatible with current production and reproduction.
- 4) A system which is correlated with the growing family of automated methods of data gathering and processing for mapping purposes.

We have attempted to be open-minded with regard to our experimental designs in order, hopefully, to develop more functionally effective map formats. For example, we would argue that it is not necessary to symbolize the water which fills an oceanic basin if we are attempting to design a map for geomorphological analysis of bottom terrain or were intending to show the distribution of bottom sediments. We would ignore the water over-burden, as far as map symbology is concerned just as we ignore the polluted or cloudy atmosphere in representing land terrain. In this way and for selected purposes we can make full use of the gamut of symbology, especially color, to better portray the features of the ocean bottom. The tendency to use a single hue, blue, for marine areas is very strong and thus cartographers have struggled to produce differentiation by changes in tone only. If there are numerous classes for the user to distinguish between, this use of a tone scale results in areas so dark that all other symbols are obscured and in many cases the user's ability to differentiate areas is lost.

Because most of our experimental work has had to do with coastal areas(*) and as it seems logical to see submarine and land terrain in association rather than visually separated, we have usually utilized the same technique for both types of terrain surfaces. Such an approach is obviously related to the scale and the purpose of the map being designed but at small scale; the result might aid significantly in carrying out broad

(*) Most maps containing detailed bottom-terrain data cover the continental shelf areas since, to date, these are the areas for which the most detailed surveys have been carried out.

structural analyses to discover the processes which are shaping both submarine and land areas. We have utilized a sequence of merged altitudinal tints, a system developed long ago (the old idea of "the higher the lighter"). Combined with shaded relief, it is applied to both submarine and land-terrain maps. Two datum planes were assumed, mean sea level for land and a plane representing the deepest part of the ocean portrayed on the map. The contrast level between the highest elevational (shallowest depth) tint, lemon yellow, in the water and the lowest tint, olive green, for land area is distinct and strong. This symbology does not provide for the perception of water and, as a result, a low percentage tint of blue was tried as an overlay to modify, at least, the oceanic area colors and increase the visual difference between water and land areas. In this map, as is often the case, the data density is much coarser for the marine terrain than that for the land area. If users, in general, could accept representations of ocean bottom character which do not contain symbology for water, the variety of design potential for such maps could be significantly increased. Monochrome versions of submarine shaded relief might be used, where functional, as a base upon which to portray other kinds of data and information, i.e., bottom sediments or mineral occurrences. It would also allow freer introduction of other traditional or new symbolic methods to enhance the data and information content of maps of the oceanic basins.

It is obvious that maps, such as the one we produced, could be manipulated to produce an alternate version of the submarine terrain in monochrome blue or any other color. It is also possible to combine this image with other symbols, such as illuminated contours. Contours in this form might enhance the three-dimensional effect and make quantitative analysis easier and more accurate. We thus attempted to develop a map utilizing illuminated bathymetric contours [4]. Both illuminated and shaded contours are uniform in line thickness, making scribing possible or photo-mechanical masking of scribed contour plates. From one point of view, the graphic impression of three dimensions, achieved by means of illuminated contours, is logical despite the step-like nature of the image. Our knowledge of all the processes affecting and shaping submarine terrain is not complete and as a result we may mislead if we interpret data in the same manner as for land surfaces. In a sense this element, in considering symbolic alternatives, may argue against the use of shaded relief. One of numerous experimental maps, produced in the Naval Oceanographic Office, is illustrated in figure 1. These combinations of illuminated contours and shading are effective in many ways, similar to the symbolic combinations used in experimental sheets (*) for the U.S. Geological Survey, produced by Hal SHELTON and his group in Denver, Colorado. These particular symbol combinations will neither meet the preferences nor serve all the functions that varied users will require, but they do represent partial answers to the need for quantitative and pictorial symbols for submarine terrain representation.

(*) I refer specifically to experimental versions of the Santa Rosa Quadrangle at a scale of 1/24 000, which was produced by the experimental graphics group supervised by SHELTON.

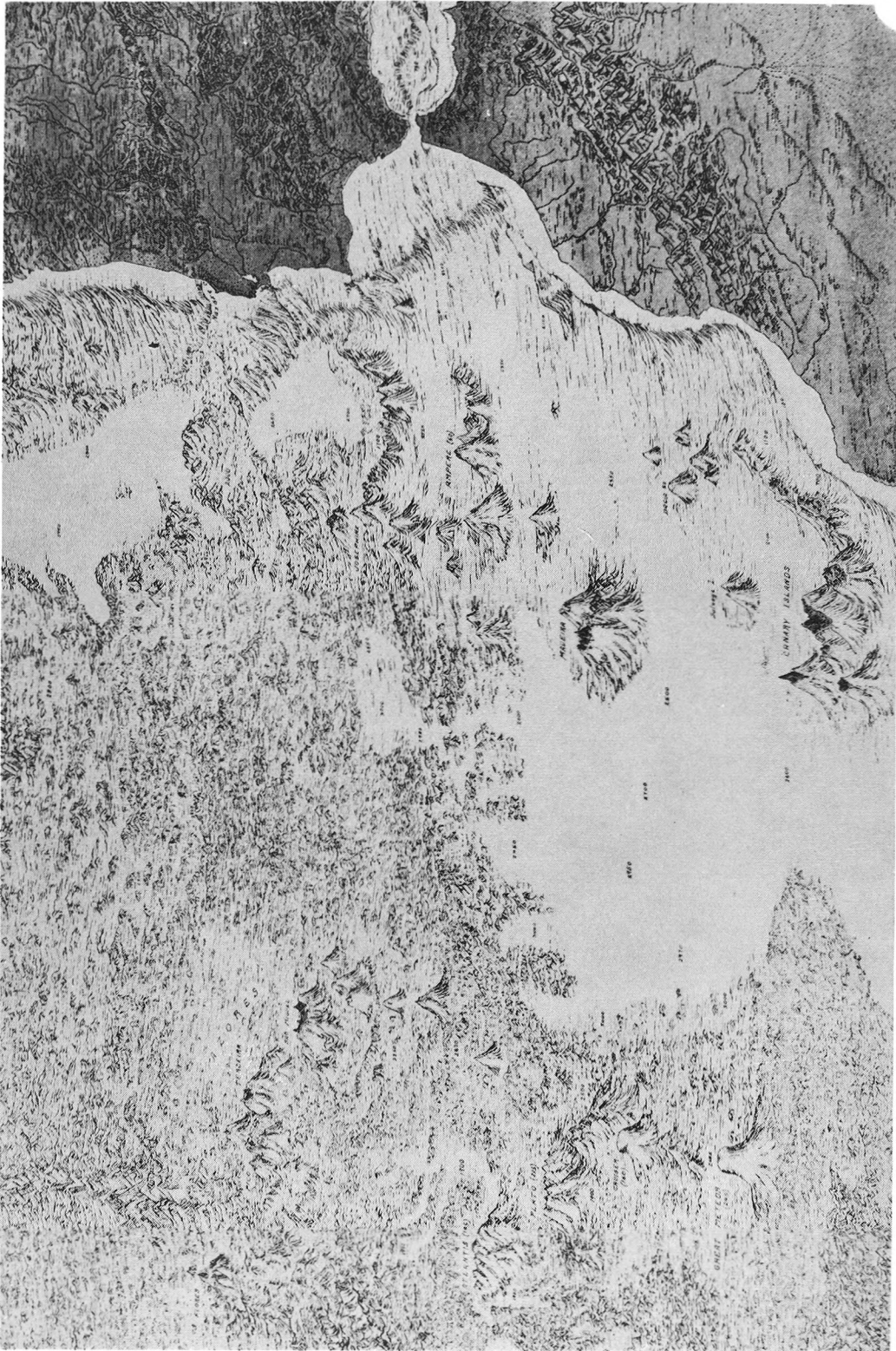


FIG. 1. — Detail from map produced by U.S. Naval Oceanographic Office.

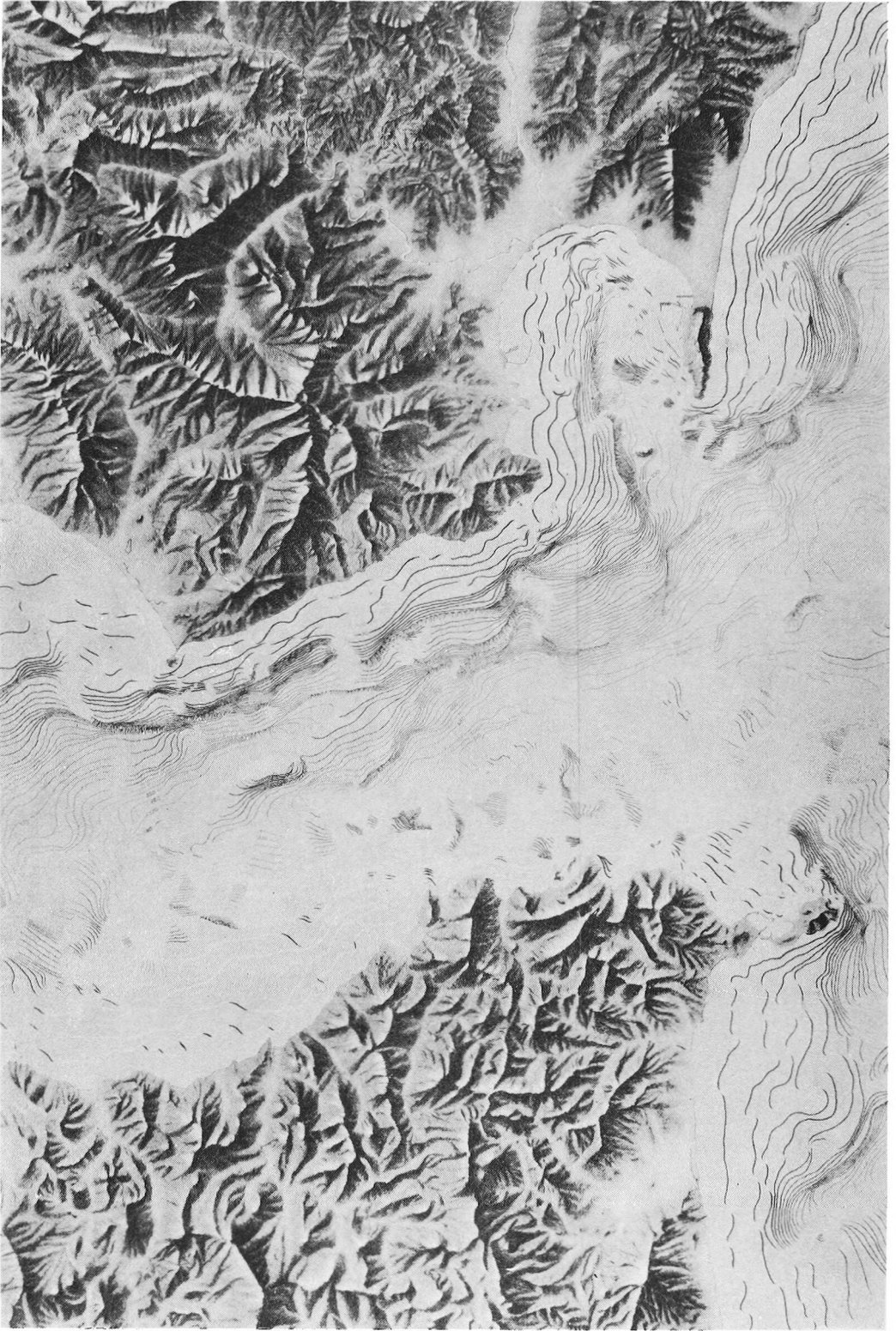


FIG. 2. — Detail from map of eastern Atlantic Sea Floor drawn
by HEEZEN and THARP.



Fig. 3. — Detail from map of Pacific Ocean Floor produced by National Geographic Society (photograph reproduced by permission of the National Geographic Society).

Other symbolic alternatives for submarine terrain display include variations on the physiographic method (figure 2) [5] shaded relief without contours, pictorial representation (figure 3) [6] profile system, similar to that used by JENKS to display a variety of data surfaces and, of course, three-dimensional models. Other techniques could be used for representing terrain attributes, such as axial alignments, slope categories, relative relief, etc. The variety of symbolic techniques employed as well as the number of bottom characteristics which are displayed in submarine topographic maps will be closely related to the range and type of analytical role which maps will serve for oceanographers' and other scientists' needs.

Machine techniques, retrieval and processing of stored data together with plotter or CRT image output are obviously an enormous boon to "oceanographic cartography". It seems that relatively less attention has been directed to development of map images for ocean areas than has been the case for land. In time we visualize production of standard series of large-, intermediate- and small-scale maps of the ocean bottom, for many of the decisions that nations are going to have to make in the future will require them. Maps will constitute important aids in assessing the environmental impact as well as the viability of decisions which are made to help formulate international policy as applied to the sea. "Many of the concepts essential to the development of marine science already have been proved and widely accepted on the land. Nevertheless, projection of established techniques to a relatively new and, as yet, scarcely penetrated environment depends on entrepreneurial skill and demands imagination and new approaches" [7]. The many graphic techniques for the representation of statistical surfaces, including terrain, that cartographers have developed for land areas are probably directly, or with some modification, applicable to oceanographic problems. As mentioned, the variety of users and user functions of marine data is increasing at such a rate that we cartographers must accelerate the design, creation and analytic use of cartographic devices through cooperative work with marine specialists. The legal profession; policy formulators; legislative personnel; regional, national and international planners; in addition to the scientist oceanographers will increasingly need and demand data on the ocean in many forms, particularly maps designed for quantification and analysis, and others whose function is spatial description and quick qualitative judgements. Whether cartographers use black light and luminescent inks, three-dimensional models, or the range of conventional techniques developed largely for land terrain, the maps we produce should help all concerned specialists to know the characteristics of submarine terrain.

There is not space or time here to discuss the many ways in which imaginative and innovative cartographers can aid oceanographers through development of effective graphics displaying the multidimensional characteristics of the sea itself. The complex nature of processes and characteristics which vary through both the vertical and horizontal dimensions simultaneously are extremely difficult to represent graphically. Much of this is due to multidimensional space and some is due to the static nature of representations so far produced. Computer-generated imagery presented on CRT equipment may make it possible to portray spatial changes through

time, for the oceans, and thus cartographers may be able to significantly increase the effectiveness and utility of the graphic displays available to oceanographers.

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