THE BELL SYSTEM
TECHNICAL JOURNAL

VOLUME XXXVI SEPTEMBER 1957 NUMBER 5

Oceanographic Information for Engineering Submarine Cable Systems*

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(Manuscript received June 4, 1957)

Information on the environment in which submarine cable systems are placed is of vital interest in designing, selecting routes for, placing, and repairing this type of communications facility. Existing data are summarized and evaluated, and their application to submarine cable systems is considered.

I. INTRODUCTION

1.1 *General*

Oceanography, broadly defined, includes the study of all aspects of the oceans. As a science, it is concerned with gathering data and devising theories which describe and explain the past, present, and the future of the oceans. Oceanography includes physical description of the topography, sediments, and temperature of the ocean bottom; investi-

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gation of currents and circulation; study of the geology of the earth's crust under the ocean; and investigation of biological factors.

In designing, in finding the best route for, in laying, and in repairing a submarine cable system one can benefit from as detailed a knowledge of the ocean floor as can be obtained. However, the vastness, complexity, and inaccessibility of the ocean bottom make its study difficult. One must depend on limited data, interpreted with the aid of a knowledge of the earth sciences. The acquisition of specific engineering information is further complicated by the inaccuracies of much of the existing data, and the rudimentary nature of many present theories. Yet, by culling, codifying, interpolating, and interpreting the data gathered during the past hundred years, much can be learned that is applicable to particular cable routes. Further, methods now exist for surveying and describing a route with a thoroughness and accuracy that will permit many refinements in the engineering of future submarine cable systems.

In this paper specific problems of immediate interest in the engineering of submarine cable systems are discussed in order to give a perspective of the use of such data in current applications. Emphasis is placed on the state of existing knowledge and on the accuracy of available data. The work reported forms a foundation for more detailed studies of specific routes and for the application of knowledge which will be derived from rapidly expanding oceanographic studies to the particular problems of submarine cable systems.

1.2 *Application To Submarine Cable Systems*

How are oceanographic information and technique applied in the selection and description of the detailed path of a new cable? First, variations on a direct route must be examined to avoid ocean bottom conditions which may result in cable failures. Studies of telegraph cable fault records indicate that many of the deep sea cable breaks occur where cables pass over sea mounts, canyons and areas susceptible to turbidity currents, and an effort must be made to avoid such hazards. Topographic studies form the basis for both initial route selection planning and for a preliminary description of the selected route.

This description will include, where data are available, an exaggerated depth profile uncorrected for angle of the sound beam of the sonic depth recorder, a corrected 1:1 depth profile where necessary, and a temperature profile. Also, bottom characteristics, including photographs, can be collected for the particular route. These data will be essential in planning a detailed survey of the route, and they will provide preliminary information for the determination of the amount of cable required, for system transmission planning and for studies of cable-placing techniques.

One of the fundamental requirements in cable laying is the deposit of a sufficient amount of cable to cover irregularities of the bottom without introducing dangerous suspensions and without laying a wasteful amount of excess slack. Satisfaction of this requirement will require the most detailed possible knowledge of bottom topography, coupled with knowledge of the kinematics of the cable laying process.[1]

A determination of required cable strength does not directly call for an extremely accurate knowledge of bottom depth and contour. The required cable strength is determined by cable tension during recovery, which is two or more times that experienced during laying. Although the required strength is directly proportional to the depth, it is also affected to a major degree by the ship speed, cable angle during recovery, and the ship motion caused by waves. The ship motion can be controlled to some extent by seamanship and choice of the time at which the recovery is to be made.

Further, the design strength of the cable is in large measure determined by the strength of available steel and the amount of steel that can be accommodated in an economical over-all design. Thus, uncertainties of 5 to 10 per cent in the maximum depth of the water on a route would not affect the cable design. Yet, during a critical recovery situation, a more accurate knowledge of depth would be useful in planning and executing the operation.

The integrity of the cable will depend on the choice of materials to withstand biological factors and wear on the ocean bottom. A companion paper[2] discusses the resistance of likely cable-sheath materials to attack by marine borers and bacteria.

II. TOPOGRAPHY

2.1 *General*

Mapping the ocean bottom involves depth measurements coupled with a knowledge of the location on the earth's surface of the points at which these measurements are made. There exists a vast store of data on the depths of the oceans taken by hundreds of observers and expeditions over the past hundred years. It is not surprising that many of these data are of questionable accuracy due to errors in navigation, soundings, plotting, and interpretation. Thus, before existing data can be used for the engineering of submarine cable systems, it is essential

TABLE I — MARINE NAVIGATION SYSTEMS

Name	Description	Range	Accuracy	Coverage
LORAN	Measures time difference between pulses transmitted by two or more shore station groups.	900 miles*	$\pm\frac{1}{2}$ mile at short range	Good over N. Atlantic steamer routes; spotty elsewhere.
SHORAN	Radar system: shipboard equipment triggers two shore stations to determine position.	Line of sight	±50 feet	Nil
DECCA NAVIGATOR	Measures phase difference in continuous waves transmitted by two or more shore stations.	240 miles	±100 yards	Good around British Isles practically nil elsewhere.
LORAC	Measures phase difference in continuous waves transmitted by three shore stations.	100 miles	±50 yards	Used as a temporary installation for special purposes.
CONSOL	Radio determination of great circle bearing of transmitting station.	1500 miles	±0.2° to 1°	Eastern North Atlantic
SOFAR	Experimental underwater sound system; shore stations determine distance to under-water explosion.	4000 miles†	±4 miles	Eastern Pacific only
E. P. I.	An electronic position indicator which measures distances from ship to each of two shore stations, using a pulse technique.	350 to 500 miles (max.)	±75 yards (in measured distances)	Developed by U.S.C. & G.S. for surveying purposes, temporary installations.
TACAN	Provides range and bearing from transmitter.	Line of sight	Range $\pm\frac{1}{2}$ mile, bearing $\pm\frac{3}{4}°$	Experimental only

* Ground wave; Sky wave range up to 1400 miles with decreased accuracy (15 miles at max. range).
† Range limited by size of basin and topographic obstructions.

that it be compiled, evaluated, and culled with due regard for the sources, inherent errors, and possible misinterpretations. The data remaining after this type of review can then be combined with other knowledge from the earth sciences to provide the best available maps and profiles.

2.2 *Instrumentation for Topographic Studies*

2.2.1 *Navigation*

Celestial navigation, depending on hand sextant sights of heavenly bodies and subsequent solution of an astronomical triangle, is the only method available in all parts of the world. It is, of course, useless during periods of poor visibility. Positional accuracy of $\pm\frac{1}{2}$ mile can be obtained, although the usual accuracy is ± 2 to 5 miles. During the interval between sights, an estimated position is computed by dead-reckoning methods, assuming the ship's speed and course to be known. Speed determined by propeller revolutions or by a pitometer log is subject to the influence of winds, seas, and currents. The ship's heading is indicated by compass, but the course actually traveled by the vessel is affected by all the same variables that affect the speed. Starting from a celestial or radio fix, a good navigator can plot a dead-reckoning track with little error over short periods of time under ideal conditions. The probable error increases rapidly with elapsed time under less than ideal conditions.

Some of the existing radio navigational systems and their limitations are listed in Table I.

2.2.2 *Echo Sounding Errors and Corrections*

Present-day echo sounders, operating with a total beam angle of about 60 degrees, indicate the distance to the best reflectors within the effective cone of sound. Neglecting scattering layers, which can usually be eliminated from consideration by interpretation, the best reflector will coincide with the bottom immediately below the transducer if the bottom is horizontal or if the highest point on the bottom is immediately below the transducer. Under any other condition the echo sounder indicates less than the true depth. Where the bottom is very uneven or rocky, a multiplicity of echoes are returned and recorded. These considerations necessitate careful evaluation of the data and its correction for slope.

Since the echo sounder actually measures the time interval between transmission of a pulse and receipt of an echo, the timing mechanism is the heart of the indicating and recording equipment. However, many types of echo sounders have poor timing mechanisms which depend upon mechanical governors, poorly regulated AC power supplies, and friction drives. Recently, a Precision Depth Recorder (PDR) having an instrument accuracy of better than one fathom in 3,000 has been developed.[3] The equipment is used with standard deep-sea sounding equipment. This PDR will perform the timing function with an accuracy better than one part in a million.

After obtaining a record of the time between the outgoing and received pulses the data must be converted to depth, employing velocity corrections and slope corrections. True sound velocity is obtained by

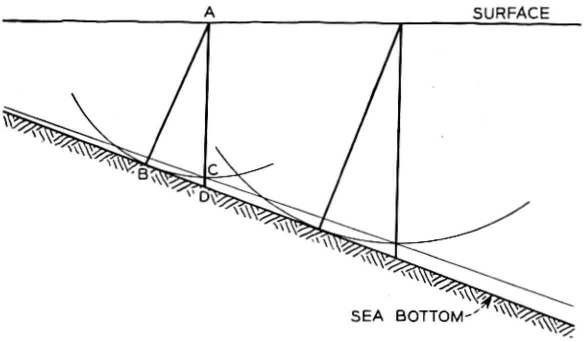


Fig. 1 — Slope correction of echo soundings.

reference to tables, or by computation based on simultaneous sea water temperature and salinity measurements. The distance traveled by the echo, obtained from the velocity-corrected data, is converted to depth by the slope correction.

The PDR sends out a ping and records an echo once each second. If the sounding vessel is under way at 10 knots, the individual soundings are about 17 feet apart. When the outgoing ping exactly coincides with the returning echo, a gating circuit reduces the frequency of soundings to once in 2 seconds corresponding to a spacing of about 34 feet at 10 knots.

Fig. 1 illustrates the problem of slope correction on an ideal slope, where the ship is steaming at right angles to the slope. At sounding position A, the echo is returned from B, the nearest point on the bottom. On the uncorrected profile, this would be interpreted as a vertical sounding AC. To obtain the true vertical depth at A, an amount CD must be added to the depth read from the echo trace. This is done graphically by swinging arcs representing the echo distances, using the distance between soundings as the arc center spacings. The envelope of a succession of such arcs is the best approximation to the actual bottom configuration that can be made. This method, of course, requires that the sounding track be run approximately at right angles to the slope, and thus, that the trend of the topography be determined. In addition, when the relief becomes more complicated, constructing and interpreting the envelope becomes much more difficult. Although all hills are shown on echograms, small valleys are often completely missed because their width is much less than the breadth of the cone of sound. This problem is partly eliminated by the use of a PDR, where second echoes indicate the existence of valleys not recognized on standard echo sounders.

Fig. 2 (a) shows the trace made by a PDR in passing over a rugged slope in mid-Atlantic. The multiple echo on the left hand side of the figure illustrates how echoes from the wide sound cone are returned from different parts of a steep slope. Similarly, the multiple echoes in the center show a deep valley with energy from the same pulse reflected from the steep slopes as well as the bottom. Fig. 2 (b) shows a corrected profile constructed from the echogram illustrated in Fig. 2 (a), and Fig. 2 (c) is a profile of the same track with 40:1 vertical exaggeration, which is typically used in describing bottom topography.

To construct a profile and interpret each sounding taken would require a prohibitive amount of work. Thus, in preparing contours and uncorrected profiles for ordinary mapping purposes, a sufficient number of the initial echoes are taken to allow a reasonably accurate profile to be constructed. Where 1:1 corrected profiles are required, all the echoes are used and the best possible envelope representing the bottom is constructed.

2.3 CHARACTERISTICS OF AVAILABLE INFORMATION

2.3.1 *Sources of Data*

The vast majority of data for a study of submarine topography are obtained as a series of "soundings," or depths below sea level.* Prior to the development of echo sounding apparatus, soundings were made by measuring the length of either a weighted piano wire or hemp line which was lowered to the bottom. This method of line or wire sounding

* Features to be studied by detailed soundings can often be located by measurements of the earth's magnetic and gravitational fields and by acoustic methods.

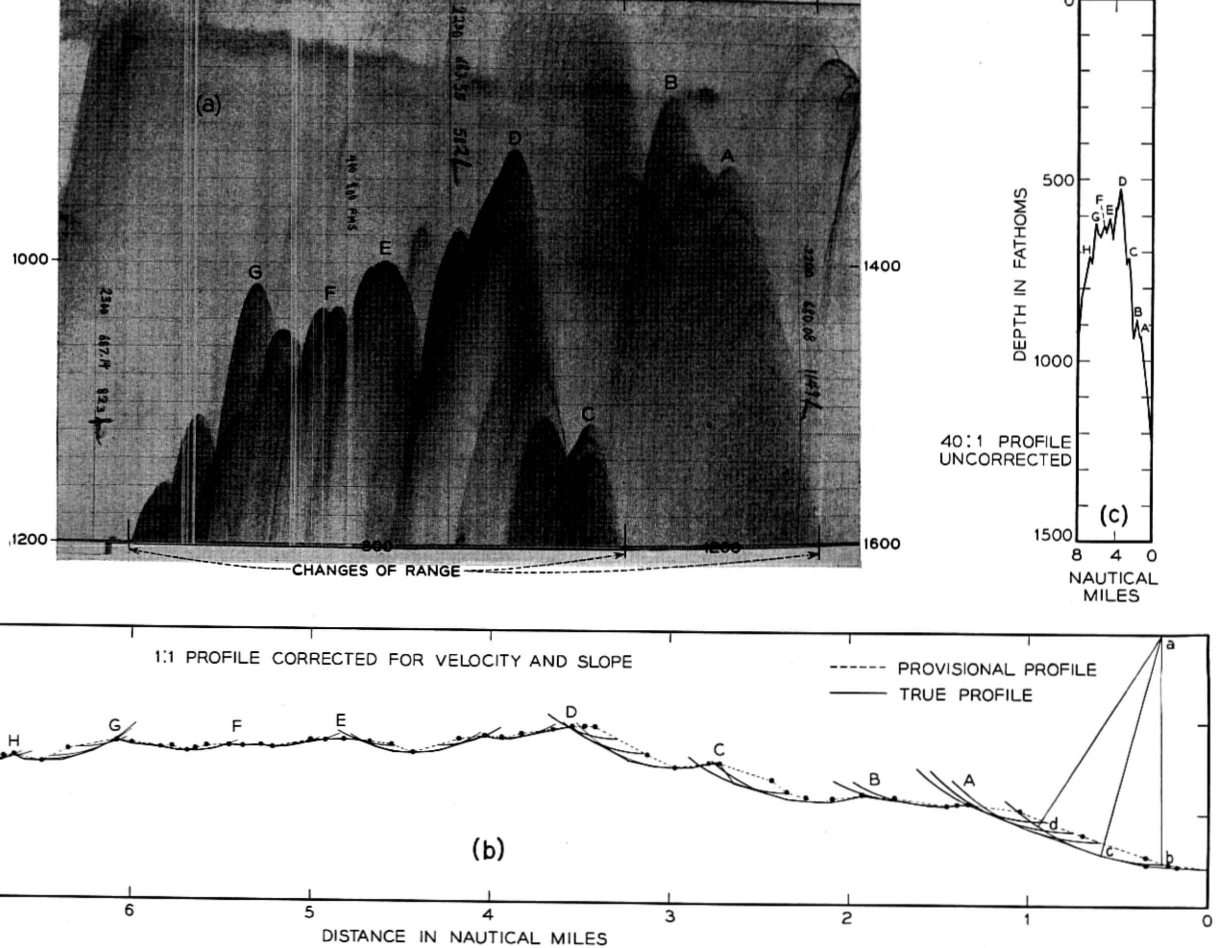


Fig. 2 — (a) Precision-Depth-Recorder record of a peak in the Mid-Atlantic Ridge. Record shows multiple 400-fathom scales. On original record 400-fathom range is represented by 18 inches and one hour or about 10 miles by 24 inches. Light horizontal lines are at 20-fathom intervals. (b) Same profile with no vertical exaggeration, with corrections for slope. (c) Profile at 40:1 exaggeration plotted from first echoes shown in (a).

was fraught with error because there was no adequate sensing device to indicate when the bottom was reached, and because the sounding line might be swept far from a true vertical by the action of currents between the surface and the bottom. These difficulties could cause errors as great as 50 per cent. Echo sounding was thus a tremendous improvement despite its own inherent inaccuracies.

Ocean bottom soundings are available from a number of sources including, in this country, government agencies such as the Navy's Hydrographic Office and the U. S. Coast and Geodetic Survey, and private oceanographic institutions. Abroad, national hydrographic offices, such as the British Admiralty's Hydrographic Department, the Japanese Hydrographic Office, and the International Hydrographic Bureau, collect and publish soundings.

Depending upon the organization which compiles the soundings, various corrections are applied to the raw data, each organization selecting both the corrections it wishes to apply and the method of application. If all soundings for an area off the continental shelf of the United States were compiled, there might be available soundings in feet, corrected for velocity, supplied by the U. S. Coast and Geodetic Survey; uncorrected soundings in fathoms supplied by the U. S. Navy Hydrographic Office; similar soundings supplied by Lamont Geological Observatory; corrected soundings in fathoms supplied by the British Admiralty; and corrected soundings in meters supplied by the International Hydrographic Bureau. In addition, there would be a quantity of hemp, wire and discrete echo soundings on published charts. One difficulty in using the soundings printed on the published charts arises from the fact that hemp line, wire, and echo soundings of all types, both corrected and uncorrected, are all plotted on the same chart usually without designation as to method or corrections.

Table II summarizes the methods of presenting sounding data used by various agencies.

Several methods of recording continuous depth records are used. The most common, and least satisfactory, is to read the echo sounder and plot the sounding at the appropriate point on the chart at discrete intervals, say every 10 or 20 minutes. This achieves an orderliness in printing but has the disadvantage that canyons, mountains, or other features which cannot be adequately represented by such spacing are ignored and obscured in the plotted soundings. Better results are obtained by use of the "texture method," where soundings are recorded at each crest, valley, or change of slope, and soundings at uniform time intervals are only used in areas where a continuous slope extends for

TABLE II — METHODS OF PRESENTING SOUNDING DATA

Source	Depth Units	Sounding Velocity	Velocity Correction	Slope Correction
Coast and Geodetic Survey, U. S. Dept. of Commerce	Fathoms	820 or 800 fm/sec	Note A	Note B
Hydrographic Office, U. S. Navy	Fathoms	800 fm/sec	No	No
Lamont Geological Observatory	Fathoms	800 fm/sec	No — Note E	No — Note E
British Admiralty Hydrographic Dept.	Fathoms	820 fm/sec	Yes — Note C	No
International Hydrographic Bureau	Meters	Note D	Yes	Note D
Japanese Hydrographic Office	Meters	1500 meters/sec	?	?

1. All agencies use Mercator projection charts.
2. All deep sea soundings on 4″ = 1° longitude charts; various larger scales used near shore.

A. USC & GS usually makes velocity correction according to data taken at time of sounding.
B. USC & GS makes slope and drift corrections where deemed necessary.
C. Admiralty data velocity corrections are made according to D. J. Matthews.[4]
D. International Hydrographic Bureau takes no data of its own, but publishes data received from various surveyors.
E. Although corrections are made in surveys of specific areas, soundings are first compiled in uncorrected form.

many miles. This produces an uneven spacing of numbers on the chart, and in some areas the soundings have to be crowded together to show all crests and valleys. In this method the sounding is written alongside a dot which represents the location of the sounding. Another method is to write the sounding without a dot but centered over the place where the sounding was taken. This produces a more pleasing drawing but all detail must be left out in complicated areas since the physical size of the letters limits the number of soundings that can be so recorded on the chart.

2.3.2 *Methods of Evaluation*

Evaluation of topographic data starts with a comparison of data from all the different sources, with all the soundings plotted to the same scale on one set of charts. Soundings from different sources must be reduced to a common base.

When the soundings from all sources are compiled on the same sheet, many obvious discrepancies will be noted. A great number of these cases can be traced to either gross mistakes in plotting or poor accuracy in navigation which may cause errors in position of up to 25 miles. Usually these gross errors are fairly easy to spot. For example, a large shoal area was shown for many years in deep water east of Georgia, but it now appears that this particular shoal resulted from the misplotting, by one-half degree of longitude, of a series of continental shelf soundings.

Lines of soundings from different sources should indicate the same depth at their intersections, providing a check on the reliability of both or an indication that one or both is suspect. Where there is lack of agreement the sounding and navigational methods should be checked in an effort to find a basis for choosing one set of soundings rather than the other. However, without special knowledge about the individual sounding lines, it is often impossible to decide which line is correct. Uncertainties of 2 to 25 miles in position combined with possible errors in depth determination of 10 per cent and possible gross errors in plotting are indicative of the difficulties that may be encountered.

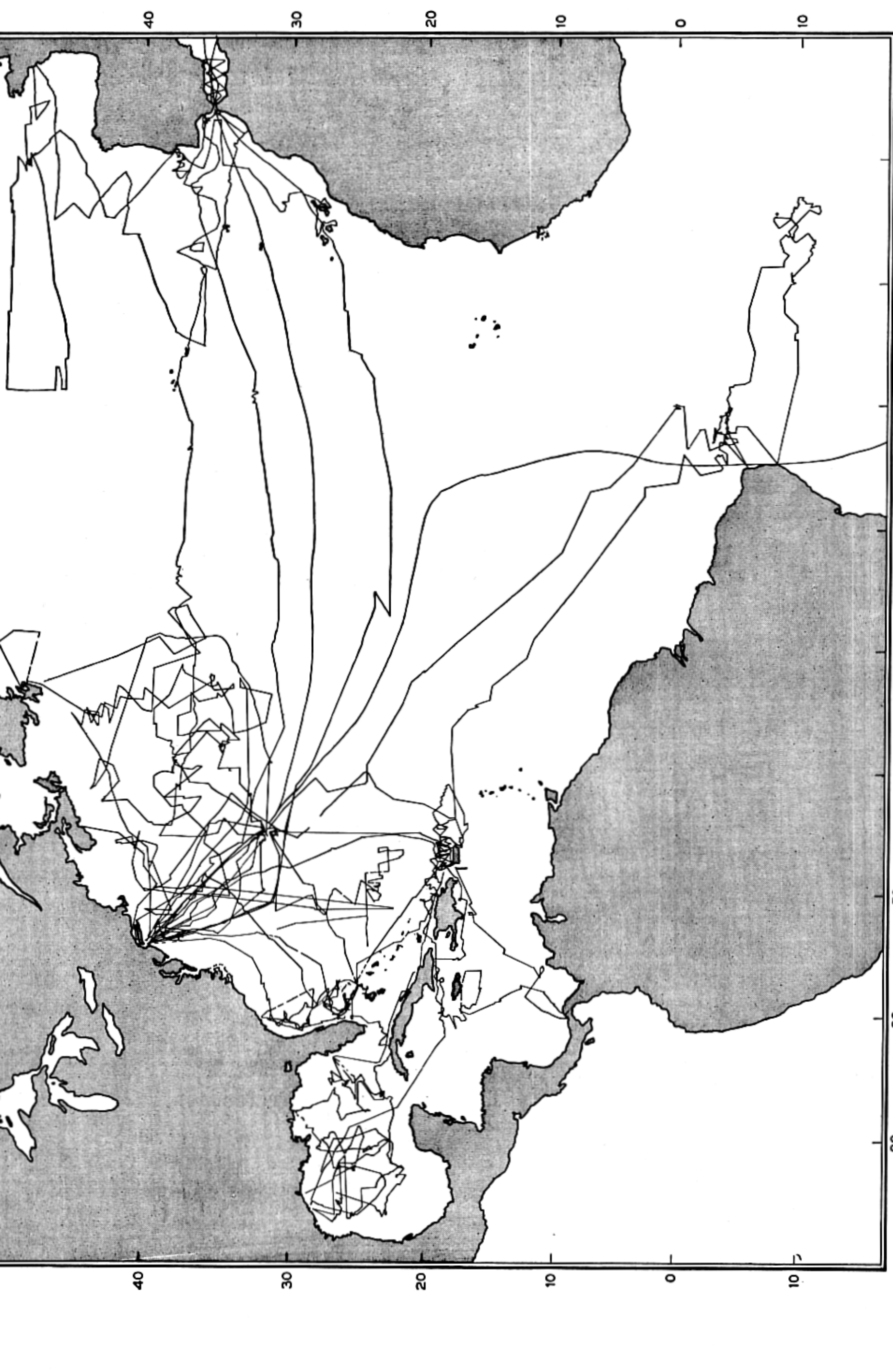
The extent of the coverage of the Atlantic Ocean with precision sounding tracks is shown on Fig. 3. Sounding tracks taken by the Lamont staff prior to the availability of the PDR are shown on Fig. 4.

2.3.3 *Methods of Presentation*

Relief is usually indicated on maps and charts by any one of a number of devices, including contour lines, profile views, and physiographic sketches. In contouring, after surveying a number of control points and obtaining their exact elevations, the land surveyor sketches in the contour lines between control points while standing on a vantage point such that he can actually see the terrain. In contrast, the oceanographer must sketch contour lines by applying his own interpretation of the submarine processes responsible for the relief in the areas between soundings. The accuracy of contour is, of course, determined by both the number, spacing, and accuracy of the soundings, and the skill and knowledge of the oceanographer.

The International Hydrographic Bureau in Monaco publishes a colored contour chart for the entire world on a scale of 1:10 million, individual sheets of which are revised and republished at 10–25 year intervals.

Profiles, or elevation views along particular tracks, provide a detailed outline of the bottom. The usual practice is to construct exaggerated profiles (40:1 or greater vertical to horizontal scale ratio), such as those illustrated in Figs. 2(c) and 5. Where accuracy of the highest order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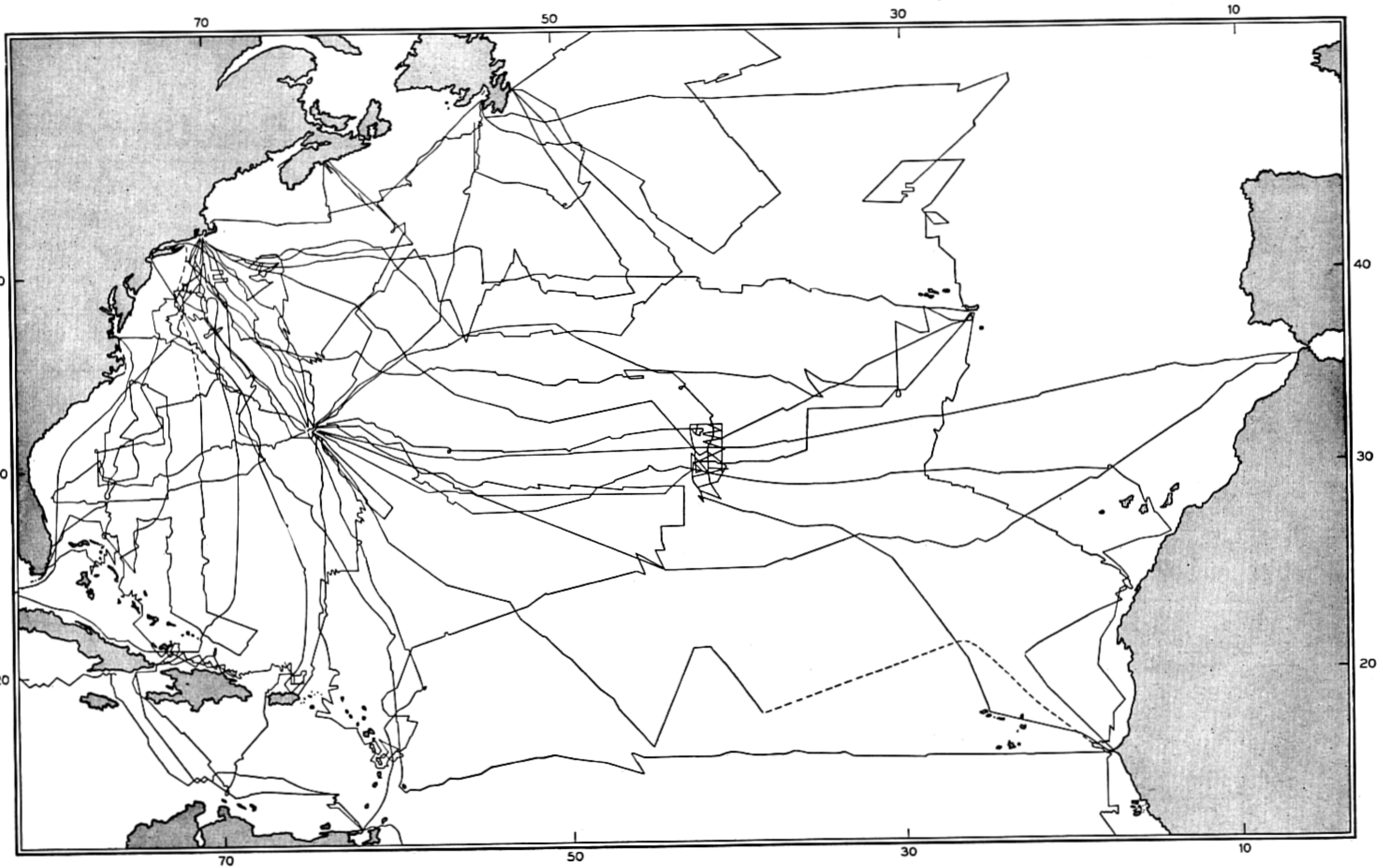

Fig. 4 — Tracks of research vessels employing fairly good but nonprecision depth recorders. Tracks mainly of R. V. *Atlantis*, 1946–1952.

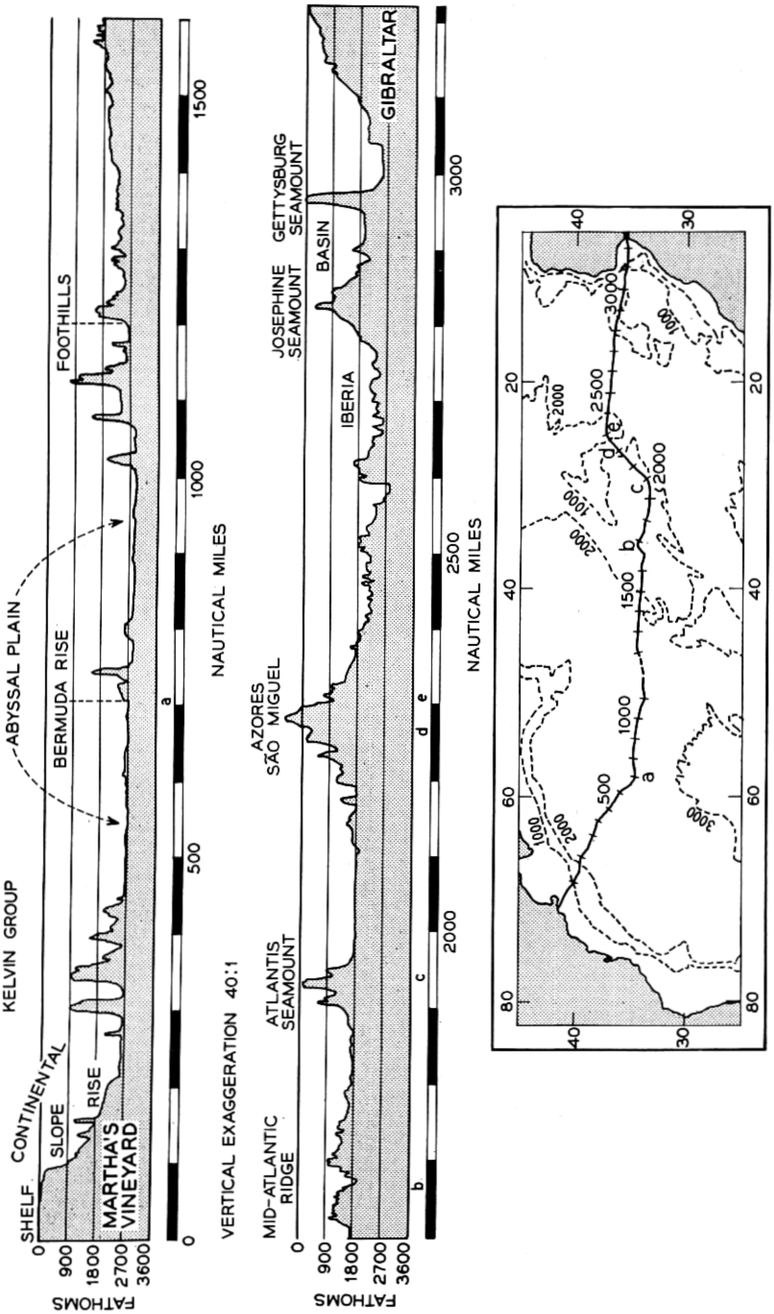

Fig. 5 — Transatlantic topographic profile, Massachusetts to Gibraltar. Vertical exaggeration 40:1.

is required, 1:1 profiles as illustrated in Fig. 2(b) are prepared by careful interpretation of precision depth records and their correction for actual sound velocity and slope.

The physiographic diagram (in envelope inside rear cover) was prepared by combining evaluated and corrected depth measurements with all other ocean bottom and geological information. The construction of these diagrams is preceded by the preparation of 40:1 exaggerated profiles along all available sounding tracks through the region under consideration. After study and evaluation of the profiles, areas of different texture are defined, and the various physiographic provinces are outlined. The relief shown on the profiles is then drawn in perspective view along the appropriate track of the chart. After all available tracks have been drawn, the remaining blank areas are sketched in, basing the interpretation on geological information.

Fig. 6 shows the physiographic provinces of the North Atlantic and the existing submarine cables on a great circle chart. A plot such as this is useful in preliminary studies of new routes. More detailed charts to a scale of 1:1 million showing contours, actual sounding tracks, existing cable routes and cable fault records can be prepared for specific engineering of new cable routes.

2.4 *North Atlantic Topography*

The relief of the continents naturally divides itself into mountain ranges, plateaus, and plains — physiographic provinces which can be recognized by distinct differences in topography, form and texture. Geologists recognize these differences as directly related to underlying geological structures. The topography of the ocean floor can also be divided into physiographic provinces similar to those familiar on land. In general, the relief of the deep sea topography is greater than on land due to the fact that the smoothing effects of erosion are less under the deep sea. Fig. 7 shows the relief along a continuous line extending from Peru across South America and thence across the South Atlantic.

The three major divisions of the Atlantic Ocean — Continental Margins, Ocean Basins, and Mid-Atlantic Ridge — each occupy about one third of the ocean floor. Since detailed topographic information is available for so little of the area covered by the oceans, the following descriptions of the relief must of necessity be general. Where specific details are available, they are presented as examples. The area to be described, the North Atlantic, is well outlined on the Physiographic Diagram. Frequent reference to this illustration should help to make the word descriptions more meaningful.

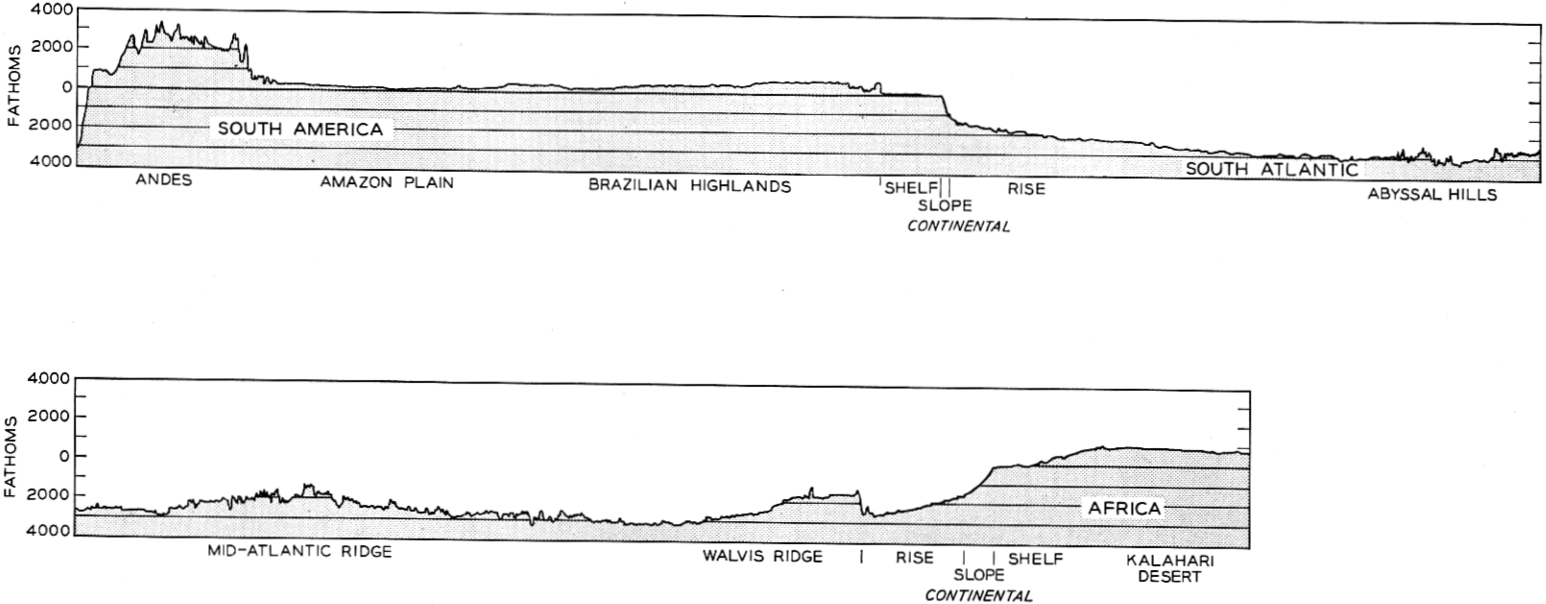

Fig. 7 — Topographic profile from the Pacific across South America and the South Atlantic to Africa. 40:1 exaggeration.

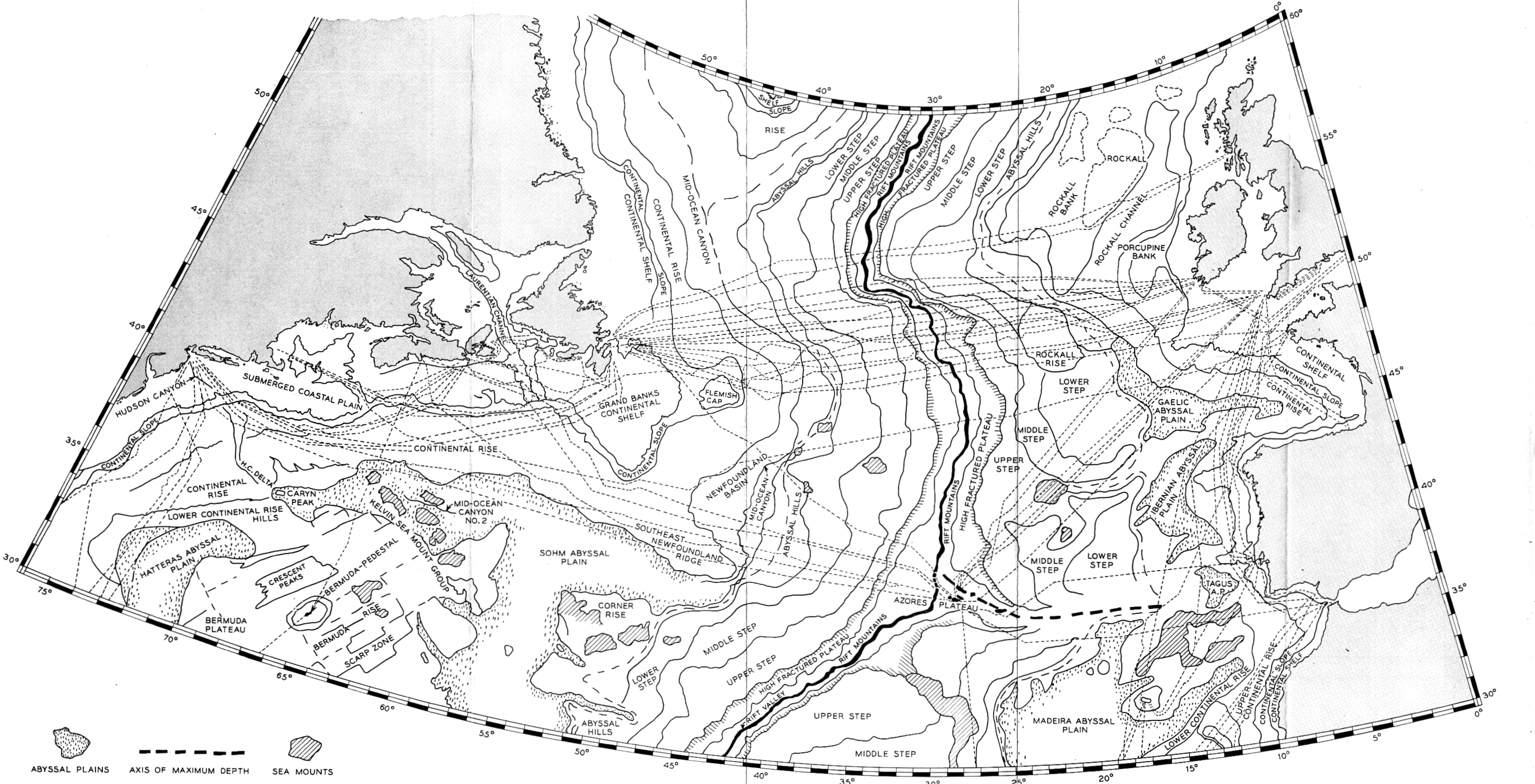

Fig. 6 — Great-circle chart showing physiographic provinces and existing submarine cable routes (dotted lines). (On this chart any straight line represents a great circle.)

2.4.1 *Continental Margins*

The first area considered is the continental shelf which may be characterized as the shallow (0–100 fathoms) submarine terrace bordering the continents, extending seaward hundreds of miles in some localities. The shelf terminates where the bottom gradient increases suddenly from the shelf average of approximately 0.1° to the continental slope average of more than 4°. This change occurs in depths ranging from 20 to more than 100 fathoms. The shelf is a continuation of the coastal plain and displays the same numerous small irregularities as the plain. For example, off the United States east coast — from Cape Cod south — the shelf is relatively flat, but with many small (10-fathom) hills and ridges. This shelf varies in width from about 150 miles off Cape Cod to its virtual disappearance off the east coast of Florida. This region of smooth shelf terminates in depths of about 60 fathoms between Cape Cod and Cape Hatteras, but in only 20–30 fathoms south of Hatteras. It is crossed by at least three submerged valleys, off the Hudson River and Delaware and Chesapeake Bays.

North of Cape Cod the shelf presents a somewhat different pattern with many basins and troughs pitting the shelf whose width increases to 240 miles off Newfoundland. Characteristic of this region are the extensive off-shore shoals (the "Banks"), with depths of about 30 fathoms, which are found to seaward of areas with depths up to 100 fathoms.

Outside the continental shelf the bottom drops comparatively rapidly down the continental slope. The top of the continental slope usually lies near the 100-fathom contour but the base lies in depths varying from 700–2,000 fathoms, depending on the area. The typical slope has a gradient of approximately 1:13 (about $4\frac{1}{4}°$). The base is marked by a sharp change in the seaward gradient, from values greater than 1:50 (1°) to values less than 1:200 ($\frac{1}{4}°$). The continental slope is dissected by numerous submarine canyons, comparable in dimensions to the canyons of mountain slopes. In some cases these canyons connect with shelf channels but generally just slightly indent the shelf edge. Some of the canyons continue across the continental rise (at the foot of the slope), but most of them apparently flatten out and disappear in the rise.

The continental rise located at the foot of the continental slope is a gently sloping apron with gradients varying from about 1:200 (0°17′) to nearly 1:1,000 ($0°3\frac{1}{2}′$). Minor relief features are rare although there are submarine canyons and occasional protruding seamounts. The submarine canyons having steep, V-shaped walls which may approach the vertical generally resemble land canyons cut in the sides of mountain ranges. These canyons, some with tributaries, usually follow gently curving to straight courses down the slope from their origins on the shelf and gradually disappear on the ocean floor. Most exhibit sediment filling on their floors, and many have rocky walls. In some areas the base of the continental rise is marked by a range of hills 100 fathoms or less in height and one mile wide or less at the base.

2.4.2 *Ocean Basins*

The continental rise gives way to the abyssal plains which occupy a sizable proportion of the ocean basins. The smooth, nearly flat topography of the abyssal plains was apparently produced by deposition of sands and silts which were carried by turbidity currents from the continental margins via the submarine canyons.

Sea mounts which rise from the abyssal plain have an appearance of being partially buried. The small sea mounts and hills which protrude from the abyssal plain increase in number toward the seaward limit of the plain. The seaward extremity of the abyssal plains frequently occurs where the small hills become so numerous that they occupy the entire area. The margin of the abyssal plain along certain positive features such as the east or west margin of the Bermuda Rise is marked by a sharp rise of the sea floor where the depositional floor has built up against the topographic rise. The larger sea mounts that occur scattered through the abyssal plain also show the same partially buried appearance.

Besides the two lines of large sea mounts which parallel the Mid-Atlantic Ridge on the east and west, there is another major trend of sea mounts, the Kelvin Group, running southeast from New England.

The eastern and western basins of the Atlantic are quite similar but there are several significant differences. The European continental slopes are in general higher, steeper, and more rugged and irregular than those off the North American coast. The continental rise is often absent or poorly developed; in some areas the continental slope descends almost directly to the abyssal plain. In the area north of the Azores the abyssal plains are less well developed than on the west side of the ridge. Rockall, Bill Bailey's, and Lousy Banks, rocky spines running south from the Iceland-Faeroe Ridge, represent features which have no direct analogies in the western basin. In the area between the Azores and Gibraltar numerous sea mounts of large size are encountered more frequently than in the western basin. The northwest margin of Africa bears the closest similarity to the northeast coast of the United States, with an extensive abyssal plain and a well-developed continental rise.

A mid-ocean canyon three miles wide with precipitous walls which drop fifty fathoms to the canyon floor runs down the length of the Labrador and Newfoundland Basins as shown on Fig. 8. Profiles across this canyon are shown in Fig. 9. Other mid-ocean canyons have recently been discovered in the equatorial Atlantic as well as in the basin south of Nova Scotia. Studies of sediments obtained in these canyons suggest that they were cut by turbidity currents.

2.4.3 *Mid-Atlantic Ridge*

The principal topographic feature of the Atlantic is the Mid-Atlantic Ridge which runs the entire length of the Atlantic and continues into the Indian and Arctic Oceans. The ridge is about 1,200 miles wide and can be thought of as a broad swell or arch with varied and generally extremely irregular topography. Along the axis of the ridge is a narrow crest about 60 miles wide with a characteristic median depression which cleaves the crest zone. Depths in the median depression exceed the maximum depths of the adjacent flanks of the ridge out to 100 miles or more. In some cases they reach depths equal to those of the abyssal plains. The tops of the highest peaks of the ridge, excluding those which emerge as islands, lie at about 800 fathoms while the median rift falls to depths of about 2,000 fathoms and locally to depths as great as 2,800 fathoms.

Near the outer margins of the ridge there is a discontinuous line of sea mounts which rise as isolated peaks. The major part of the ridge lies at depths intermediate between the abyssal plains and the central highlands, with extensive areas of flat intermountain basins, particularly in the area just south of the Azores. The earthquake epicenter belt accurately follows the median rift throughout the length of the ridge.

Other areas of the Atlantic which have topography similar to the Mid-Atlantic Ridge include an oval area trending northeast-southwest from Bermuda with a long axis of about 800 miles and a short axis of about 500 miles. The area is characterized, in part, by low irregular relief, but with a number of large sea mounts.

III. NATURE OF THE SEA BOTTOM

3.1 *Methods of Investigation*

There are four principal methods of investigating the nature of the bottom:

(a) Visual inspections and photographs.
(b) Physical sampling.

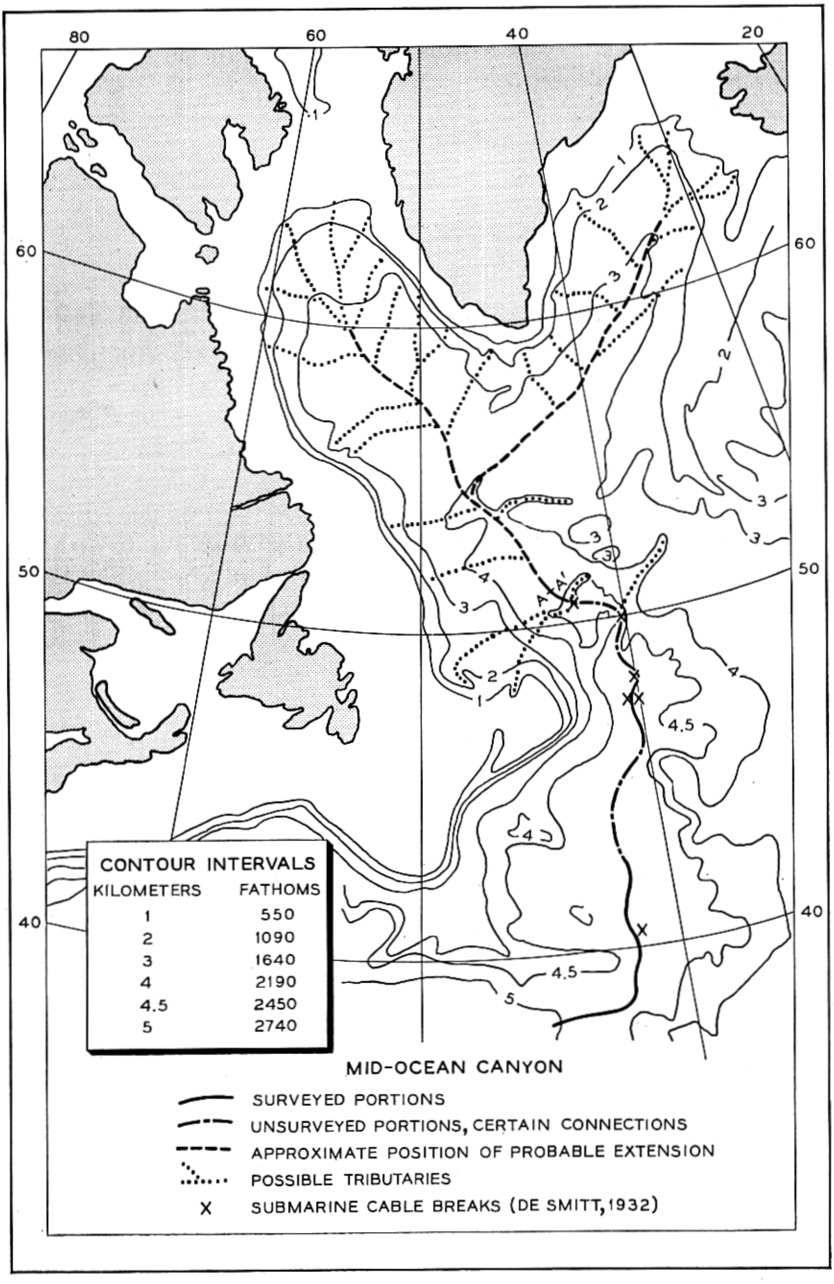

Fig. 8 — Mid-ocean canyon of the Northwest Atlantic.

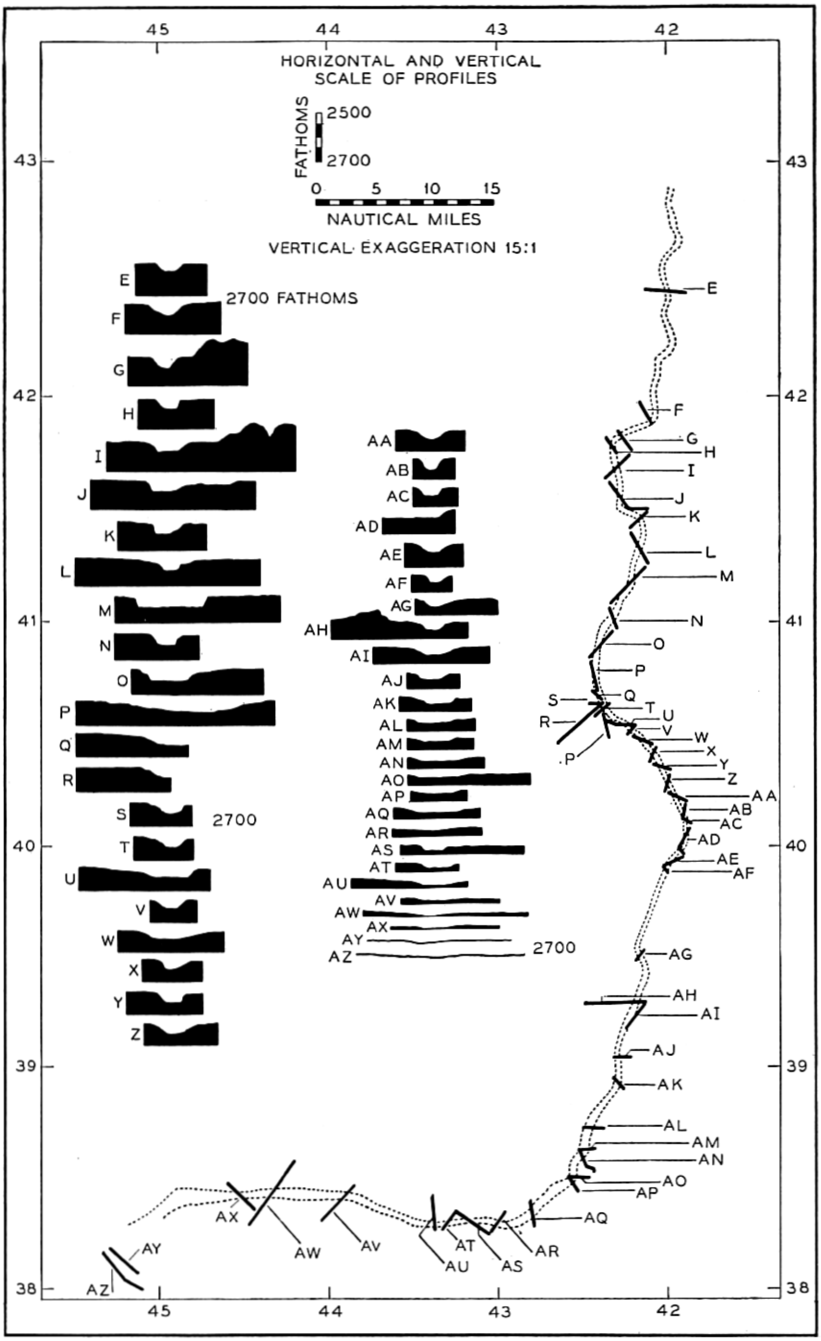

Fig. 9 — Profiles across the mid-ocean canyon.

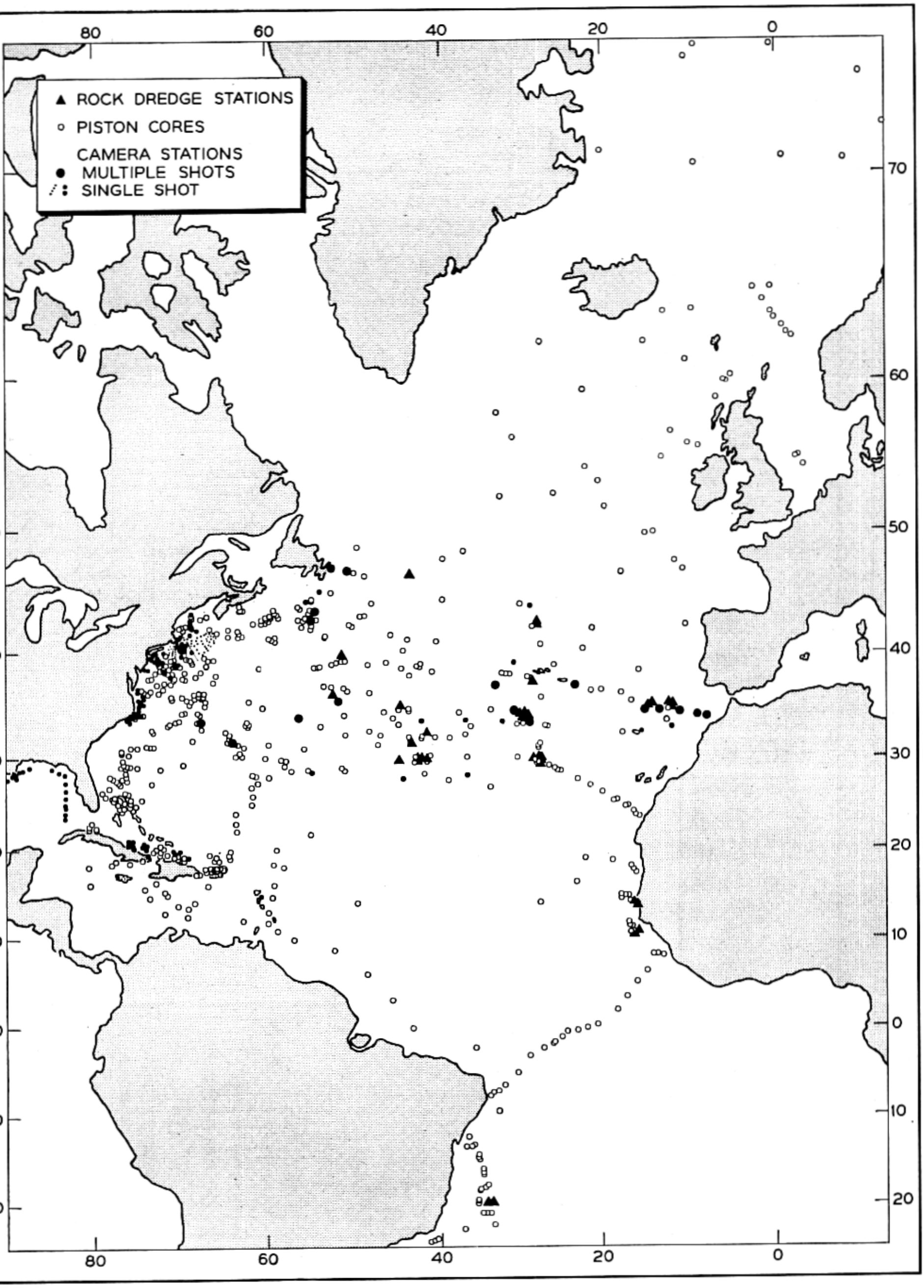

Fig. 10 — Location of cores, rock dredges, and bottom-photograph sites of Columbia University expeditions in the North Atlantic, 1946–1956.

(c) Sound investigations.

(d) Investigations of magnetic and gravity fields, and heat flow.

Visual inspections have been performed by divers in depths up to only about two hundred feet. Vessels such as the bathyscaphe must be employed for greater depths but their design precludes any extensive observation of the sea floor.

Bottom photographs in shallow waters are fairly numerous but those taken in depths greater than 1,000 fathoms are still rare. Good photographs usually show an area approximately 5 ft by 8 ft and are focussed well enough to make objects and organisms $\frac{1}{8}$ inch in diameter clearly identifiable. A compass and a current indicator are often lowered with the camera and included in the photograph. These provide indications of current velocity and direction and a means of orienting the bottom features. Locations of almost all deep water photograph stations in the Atlantic are shown on Fig. 10, and a typical deep sea camera rig is depicted in Fig. 11.

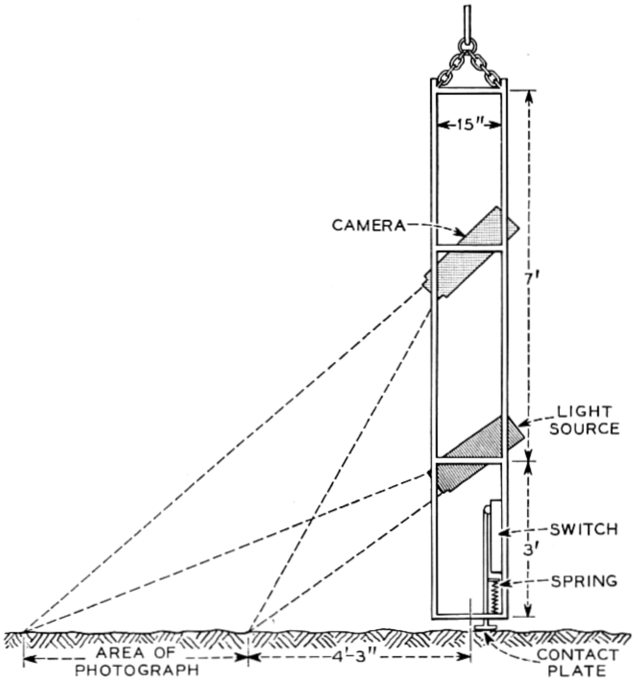

Fig. 11 — Diagram of multiple-shot underwater camera taking a bottom picture.

Television is being used in shallow waters by various organizations. However, picture resolution is poorer than that obtained photographically, and nothing has been done in depths greater than 110 fathoms.

Physical sampling is accomplished by corers, grab samplers, and rock dredgers. Earliest samples were obtained by "arming" a sounding lead with tallow, to which some of the bottom sediment would adhere. Coring is the most important source of bottom composition data. Specimens up to 70 feet in length are obtained by dropping a weighted tube vertically into the bottom sediments. About 1,200 sediment cores have been obtained in the Atlantic. The locations of most of these stations are shown in Fig. 10. Rock dredging has produced much evidence on the nature of the continental slope, the Mid-Atlantic Ridge, and on the various seamounts. Lamont's rock dredge stations are shown in Fig. 10. Not shown are a large number taken by French workers off the Bay of Biscay and off Georges Banks.

Sounding data can provide a wealth of detail in addition to the depth if an experienced operator evaluates the fathogram. The least skilled operator can differentiate between rough and smooth bottoms, while the most experienced can interpret a fathogram in terms of bottom smoothness, sediment thickness, and the location of interfaces in the sediment.

3.2 *Present Knowledge*

3.2.1 *General Characteristics*

Navigation charts sometimes include a short notation alongside a sounding, indicating the type of bottom, ranging from common terms such as sand, mud, or ooze, through the less familiar foraminifera or globigerina ooze (shells of microscopic marine life). These notations are most abundant in shallow coastal waters where they provide information for piloting and anchorages. In the less frequented depths, bottom notations on navigation charts are very rare—charts of bottom sediments commonly published are based on sparse and incomplete data and, as a result, are generalized.

Deep sea sediments have been divided into two main classes, terrigenous and pelagic. Terrigenous sediments are those derived from the erosion of the land and are found adjacent to the land masses, while the pelagic deposits are found in the deep sea and are distinguished as either organic ooze or inorganic clay. The organic oozes are composed principally of fossil remains of planktonic animals. Distribution of types of sediment is by no means static. Such factors as deposition by turbidity currents, land slides or slumps, bottom scour by ocean currents, and climatic changes continually cause changes.

3.2.2 *Sediment Densities*

Quite accurate density determination can be made by laboratory analysis of sediment from core tubes. Densities of 1.35 to 1.55 gm/cc are characteristic of the gray and red clays which cover most of the deeper parts of the ocean. The globigerina oozes which are abundant on the Mid-Atlantic ridge have densities from 1.60 to 1.75 gm/cc. Sand layers which may occur in abyssal plains at or near the sediment surface range in density from 1.65 to 2.00 gm/cc.

An increase in density as a function of depth in the core would be expected. However, after an initial increase in the first 1 or 2 meters the density usually fails to show further regular increase in cores up to 10 meters in length, and deep in the core the density often falls to within 0.1 gm/cc of the initial value.

The sediment averages about 300 fathoms in thickness over the deep ocean floor, except for the bare rock surfaces on the steeper parts of the continental slopes and submarine peaks where sediment is thin or absent. Thicknesses exceeding 100 fathoms may be reached on the continental rises.

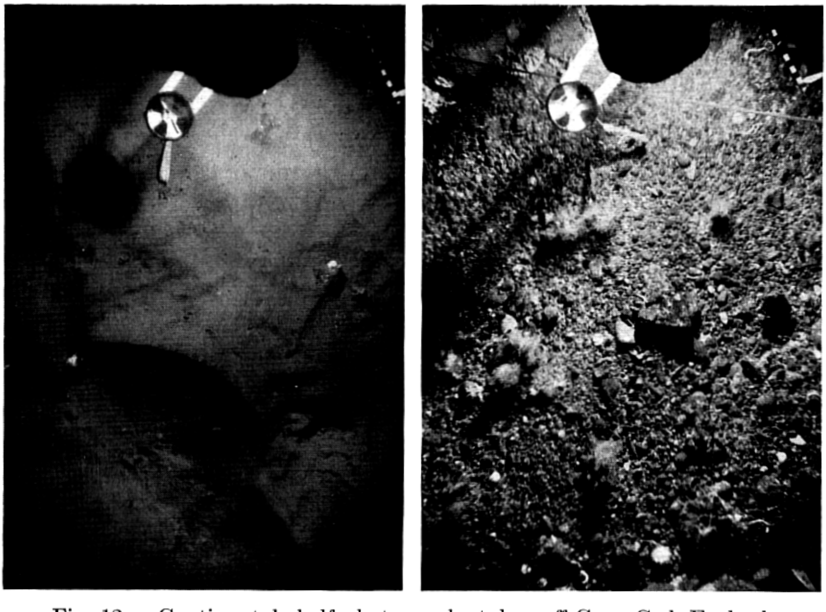

Fig. 12 — Continental-shelf photographs taken off Cape Cod. Each photograph shows an area of approximately 2.4 ft by 3.3 ft. Dials are compasses. Tassel beneath dial indicates current. Note small ripple marks in left photograph. Depths: 64 and 54 fathoms, respectively.

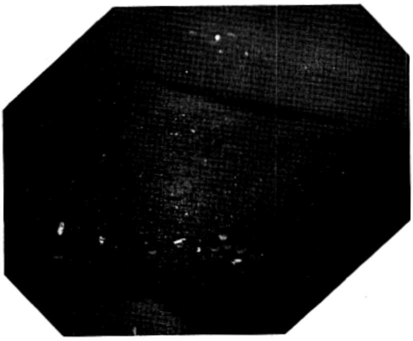

Fig. 13 — Continental-slope photograph taken at 550-fathom depth at 44°43′N, 54°30′W. Area shown in each photograph in Figs. 13–16 is about 40 square feet.

3.2.3 *The Bottom in the North Atlantic*

The continental shelf at depths less than about 70 fathoms was dry land for a considerable period prior to 11,000 years ago. Thus, the sediments of the continental shelf resembled the sediments of the coastal plain from Cape Hatteras to Cape Cod. A deposit of sand continues along the shelf edge and is generally thought to be an old beach. Landward of this is a series of irregularities generally considered to be old dunes and beaches. Photographs of the continental shelf are shown in Fig. 12.

Hardened sandstones and limestone have been recovered from the walls of submarine canyons off Georges, Browns and Banquero Banks. A rock outcrop has been photographed at a depth of 500 fathoms in a small gully south of Block Island. In other areas the continental slope is covered with low-density gray clay in which the coring rig completely buries itself. Gravel and sand form the floors of some continental slope canyons while others are deeply covered with low density mud. In many areas ancient, partly consolidated clay crops out on canyon walls.

The Western Union Company, when plowing in their continental-slope cables, had widely different experience along closely parallel cables.[5] Presumably the differences in the depth to which the plow would penetrate were due to differences between ancient and recent compaction of sediments. Although rock was probably not encountered on these runs, it is known from dredging experience that rock can be expected.

A photograph (Fig. 13) of the bottom at 550 fathoms depth south of the Grand Banks reveals huge ripple marks. It is not difficult to imagine that cable chafe would be appreciable in such an area.

Beneath the nearly flat abyssal plains alternate layers of sand, silt, and red clay make up the approximately 300 fathoms of sediment. A photograph (Fig. 14) shows the bottom at a depth of 3,000 fathoms in the abyssal hills. This remarkable shot shows ball-shaped objects that have been identified as manganese nodules. The most interesting feature of this photo is the scour marks around the objects, implying an appreciable current at a depth of 3,000 fathoms.

Seamounts present extremely varied conditions. Rocks, from crystalline basalt through hardened limestone to soft marl, are encountered. Sediments, including sticky ancient formations, deep sea oozes, and shell sand are found. Photographs show all types from tranquil mud bottom through wave-rippled silt and sand to craggy rock. Some of these types are illustrated in Fig. 15.

The flanks of the Mid-Atlantic Ridge are areas of irregular topography. The steeper slopes are probably bare rock and the sediment removed from these slopes probably is deposited in the intermountain basins. Cores are usually of globigerina ooze, but the different rates of sedimentation on steep slopes and on basin floors cause changes in thickness of sediment and relatively great changes in physical properties over short distances. The deeper flanks of the ridge are covered by red clay. A very similar bottom is found on the Bermuda Rise.

Fig. 14 — Abyssal-hills photograph taken at 3,190-fathom depth at 29°17′N, 57°22′W.

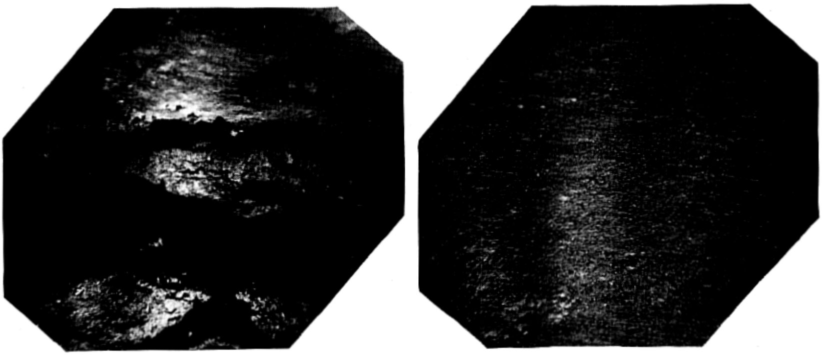

Fig. 15 — Seamount photographs taken near summit of seamount on Bermuda Rise at 34°38′N, 56°53′W at depth of 1,370 fathoms. The two photos were taken about 100 feet apart, indicating the rapid alternation of ooze and rock bottom over short distances.

The crest of the Mid-Atlantic Ridge is similar, as a bottom type, to the seamounts previously described. Dredge hauls have brought up mostly basalt, although a few fragments of limestone have also been retrieved. The photographs shown in Fig. 16 were taken about 60 feet apart on the Mid-Atlantic Ridge. They illustrate a change from smooth to rocky conditions in this short distance.

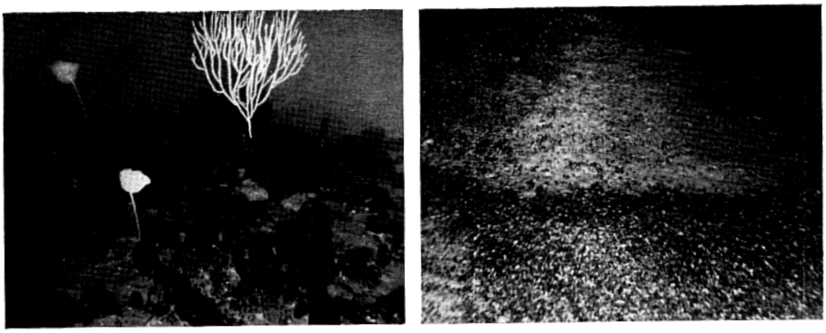

Fig. 16 — Mid-Atlantic Ridge photographs (1,500-fathom depth at 48°30′N, 28°48′W). The two pictures were taken about 60 feet apart. Out of 60 photographs taken at similar intervals in this location three were similar to that on the left and the remainder resembled that on the right. The dark band in the right-hand picture is probably composed of gravel and sand of the dark-colored rock of the peaks, while the white underlying layer is clay or ooze. The dark band was produced by a current which swept the dark material over the light-colored material.

IV. TEMPERATURES*

4.1 *General*

The temperature of a given point on the deep sea floor is determined by the system of ocean circulation. Study of deep sea circulation is still in an early stage and theories which would permit prediction of changes are still in a rudimentary form. In addition, observations of actual bottom temperature are few. Thus, a study of the temperature environment of submarine cables must proceed by evaluating those data that exist and striving for increased understanding of the underlying circulation processes.

The new electronic thermometer under development at the Lamont Geological Observatory determines temperature with an accuracy of 0.01°C by the frequency of an oscillator employing thermistors in an RC network. The oscillator is lowered on the end of a cable and its frequency is monitored by equipment installed aboard ship.

Bottom-temperature changes might be predicted if the rate and direction of circulation of the sea water could be determined. This is being studied by sonar tracking of a submerged blimp designed so that it has negative buoyancy at the surface but is neutrally buoyant at the level where the measurement is desired. This method has been used down to depths of 3,000 meters. Results have indicated much higher velocities than hitherto suspected. Near the base of the continental slope off the eastern United States near-bottom currents of $\frac{1}{3}$ knot have recently been observed by this method.

Another method depends on the measurement of the time elapsed since a given water mass was at the surface by radiocarbon dating of sea-water samples. At the surface, water is in free exchange with the atmosphere and acquires a radiocarbon concentration in equilibrium with that of the atmosphere. As the water sinks from the surface to enter the deep sea circulation system, it is cut off from the supply of fresh radiocarbon, and radioactive decay reduces the content of Carbon 14 at a rate given by its half life. Thus, the measurement of the radiocarbon content of a given sea water sample ideally will give the time at which this sample left the surface of the ocean.

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* In this section dealing with temperature, depths are given in meters rather than in fathoms. Temperature has largely been of interest in physical oceanography where volume is of concern. This has led to the use of meters. Since a nautical mile is approximately 1,000 fathoms, the fathom has been widely used in topographic work. One fathom equals approximately two meters.

4.2 *Characteristics of Available Information*

4.2.1 *Sources of Data*

Observations of temperature in the deep sea were first made in the mid-nineteenth century. The early observations were made with crude instruments and are now of purely historical value. The *Challenger* expedition of 1872–1876 made several hundred observations but with maximum-minimum thermometers unprotected from pressure. In the late nineteenth century the Richter reversing thermometer was invented and by the turn of the century they were used by nearly all scientific expeditions. Cable ships have taken many observations but almost always with maximum-minimum thermometers.

Major expeditions have published volumes which included tabulated lists of temperature, salinity, oxygen, etc., for each station occupied, while the shorter expeditions and those institutions which continually collect oceanographic data in the North Atlantic publish their observations in the "Bulletin Hydrographique," a journal published by the International Commission for the Exploration of the Sea, Copenhagen. In addition, unpublished data are available from the files of oceanographic institutions.

Expedition reports give estimates of the reliability and accuracy of their data and usually describe the calibration tests used to determine the accuracy. The "Bulletin Hydrographique" merely publishes the data without comment. The scarcity of data and the tendency to systematic errors in single sets of data coupled with the temperature changes now being demonstrated for deep ocean water masses tend to frustrate efforts to evaluate the accuracy of data.

4.2.2 *Methods of Evaluation*

Evaluation of temperature data involves comparison of nearby observations, verification of the original data sheet, and checking for errors in computation. The calibration of the thermometers is ordinarily done with great care, and observations are generally accurate to $\pm .05°C$. When the thermometer fails to function properly, the temperature is usually so far off that the observation is not reported. The main error comes in the determination of depth of observations. The length of wire paid out to reach a stated depth varies with the magnitude of winds and currents in the area. On early expeditions this led to large errors in observation. The use of two thermometers, one in a pressure case and one unprotected from pressure, allows the calculation of depth of observations with relatively great accuracy.

One method of understanding temperature changes is to consider the movement of the water masses. These movements depend on density gradients which are directly dependent on the salinity and temperature. This type of study is applicable in shallow water where circulation of the surface layers is brisk. For the deep sea, however, dynamic calculations are ambiguous; different investigators using the same data not only arrive at different values for velocity but often arrive at opposite directions of flow. Thus, continuity considerations and the conservation of volume are the primary factors in studies of the deep-water circulation. It is important when evaluating temperature data and studying temperature change and rate of bottom water circulation to study the entire process and not be limited to temperature observations, even though the temperature is the desired final answer.

4.3 *Temperature in the North Atlantic*

4.3.1 *General*

Ocean-bottom temperatures in shallow water (less than 200 meters deep) are affected by seasonal air temperatures and movements of local masses of water. Thus, each specific area exhibits its own pattern of temperature changes. Data are fairly abundant in shallow water areas, so that despite the large and often erratic changes, it is generally possible to determine roughly the bottom-temperature cycle from existing data. However, the local nature of the phenomena makes it desirable to concentrate any detailed studies on areas of immediate interest rather than to attempt broad generalizations.

In deep water (depth greater than 200 meters) bottom temperatures and their variations result from large-scale, oceanwide topographical and circulation phenomena. At the same time, the paucity of data makes an analysis of any particular locale quite difficult. Thus, a general study of deep-water bottom temperatures in the North Atlantic presents the best hope of obtaining at least some useful data.

4.3.2 *Shallow Water (Depth less than 200 Meters)*

In many shallow-water areas near shore (depth less than 50 meters) there are predictable seasonal changes in temperature of the order of 10°C. In harbors and bays where interchange with open ocean water is restricted the seasonal temperature curve will approximate the seasonal air-temperature curves except that the amplitude of the sea bottom temperature changes will be smaller and the peaks and troughs will be slightly retarded. In the open water of the continental shelf there is often a strong stratification of water masses and the vernal cycle is either strongly retarded (by several months) or completely obscured.

On the open shelf the bottom-temperature cycle is controlled by shifting currents and wedges of water which flow in along the bottom from the open ocean. In some areas these changes go through essentially the same cycle each year. The Irish Sea and the continental shelf west of Scotland are areas where the cycle is so regular that one can safely predict the bottom temperature for a given month within an accuracy of ±1.5–2°C. On the other hand, the bottom temperature on the Grand Banks changes radically from day to day and week to week. It is possible to show that on the Grand Banks summer temperatures are on an average 2° colder than winter bottom temperatures. The day-to-day temperature changes can amount to 5°C or more.

In one particularly well-studied area off Halifax, Nova Scotia, an interesting complication has been discovered. In this 10,000-square mile area the bottom temperatures had been studied for about twenty-five years, observations having been taken at different times of the year. The bottom temperature was considered known to 1°C. It has more recently been found that on occasion, the 8°C water is displaced upward by an underflow (incursion) of 2°C water which suddenly lowers the bottom temperature by 6°C. However, after a few weeks the bottom temperature again approaches the usual value of 8°C. Such incursions of contrasting water (both cold and warm) from the open ocean are as yet only partially understood.

The maximum amplitude of temperature changes in bays and near shore areas of both seasonal and erratic nature often approaches 20°C. On the outer shelves 8°C would be the maximum change expected.

It is now well established that the average temperature over wide areas in the North Atlantic has undergone a gradual increase for the past one hundred and fifty years. The average bottom temperature on the Nova Scotian shelf increased 2°C between the early and mid-nineteen thirties and the late nineteen forties. Similar changes have been reported for the area near Iceland. At present, no sure way of predicting the future longterm changes of temperature is available. Changes of 1° per decade may be experienced.

4.3.3 *Deep Water (Depth more than 200 Meters)*

A search was made for all deep sea temperature measurements taken with accurate thermometers in depths greater than 2,000 meters, from

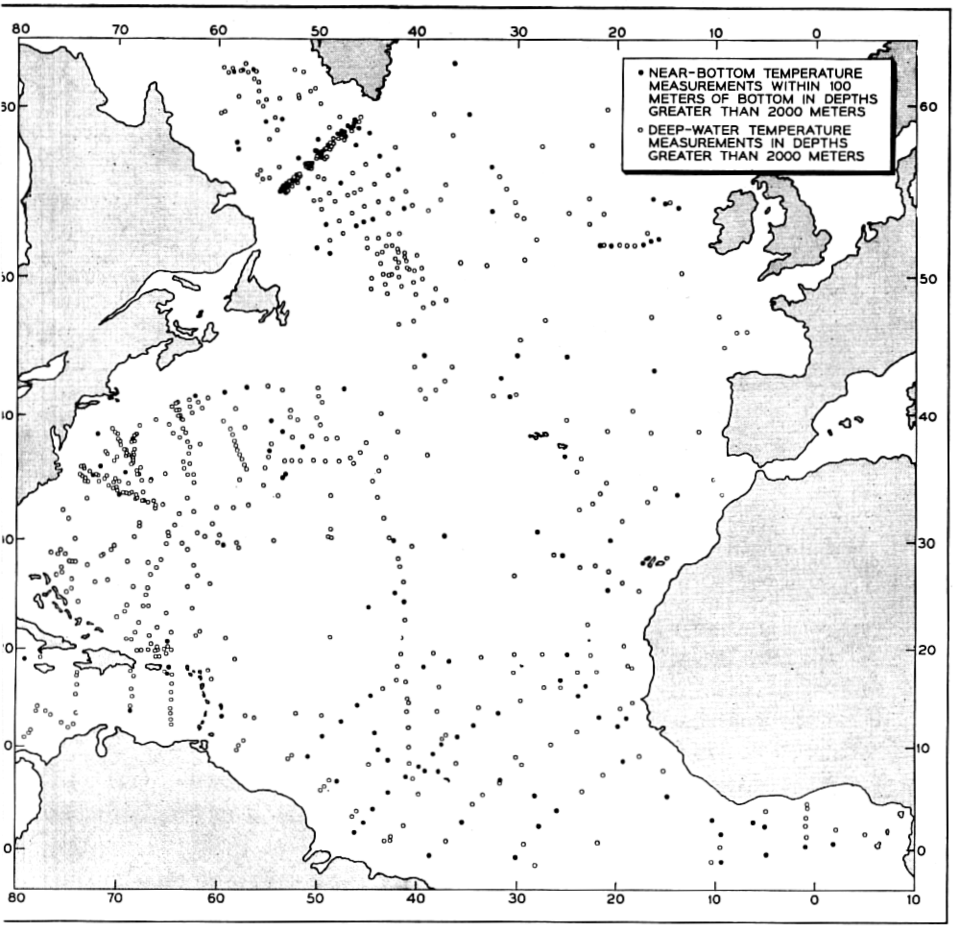

Fig. 17 — Accurate deep-water temperature measurements in depths greater than 2,000 eters. Points marked by solid circles indicate observations within 100 meters of the bottom.

the Equator to the Iceland-Faeroe-Greenland Ridge (which divides the Atlantic Ocean from the Norwegian Sea). Approximately 600 observations (Fig. 17) were found after a search of all data up to 1950 and much of the data up to 1954. (The "Bulletin Hydrographique" is 5 to 6 years behind in publication.) Since the temperature at intermediate depths is of interest to the cable engineer only to the extent that he can use it to determine bottom temperatures, the observations in depths greater than 2,000 meters which lay within 100 meters of the bottom were sorted out. Only about 150 observations (Fig. 17) were found in this

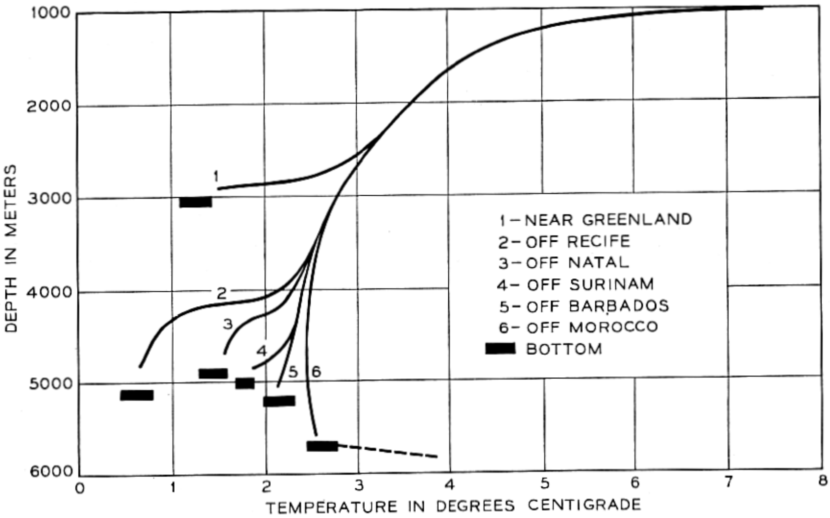

Fig. 18 — Deep-sea temperature gradients. Mean gradient in the sediments is indicated by the dashed line.

category and most of these were either between Greenland and Labrador or near the Equator. The number of actual bottom observations is limited by inability to determine when the bottom was reached and a reluctance on the part of observers to risk losing expensive equipment by having it snagged on the bottom.

At the present time there are insufficient data or knowledge of the mechanism involved to permit reliable extrapolation of bottom temperatures from a series of mid-depth observations. Fig. 18 illustrates the problem. Here are six different near-bottom gradients observed in different parts of the Atlantic. Assuming these gradients terminated 500 meters above the bottom (as do many of the observed data), it is apparent that extrapolating such data to the bottom is not feasible. Measurements of gradients to the bottom at stations for which near-bottom data exist, coupled with a knowledge of the processes causing the gradient, may make it possible in the future to make use of many of the old mid-depth observations in studying bottom temperature.

From the compilation of available data, the three profiles (Figs. 20–22) whose locations are shown in Fig. 19 were prepared. More recent studies indicating that deep water temperatures may vary a few tenths of a degree Centigrade with time make it probable that some of the ripples in the isotherms are not real but instead reflect the fact that the data were taken at widely different times. The data for Profile 1 were taken in the same year and do not show these effects. The large fluctuation on Profile 3 is probably due to variations with time.

At a certain depth, often about 1,200 meters, a sharp change in temperature takes place. An interface known as the main thermocline separates the warm surface waters from the cold (2°–4°C) deep water. This boundary shifts slightly from time to time and is affected by subsurface (internal) tidal waves. Thus, cable laid near the main thermocline may undergo temperature changes of a few degrees. These changes may be of different periods depending on their causes, e.g., subsurface waves, seasonal changes, or long term changes in ocean regime. It is not known if a long-term change in depth of the thermocline has occurred but such change seems probable.

The greatest percentage of any transatlantic cable route lies in depths greater than 2,000 meters and thus the temperature changes in the deep sea are of primary importance to the engineering of a cable. The temperatures are low, averaging 3°C, and the temperature changes are

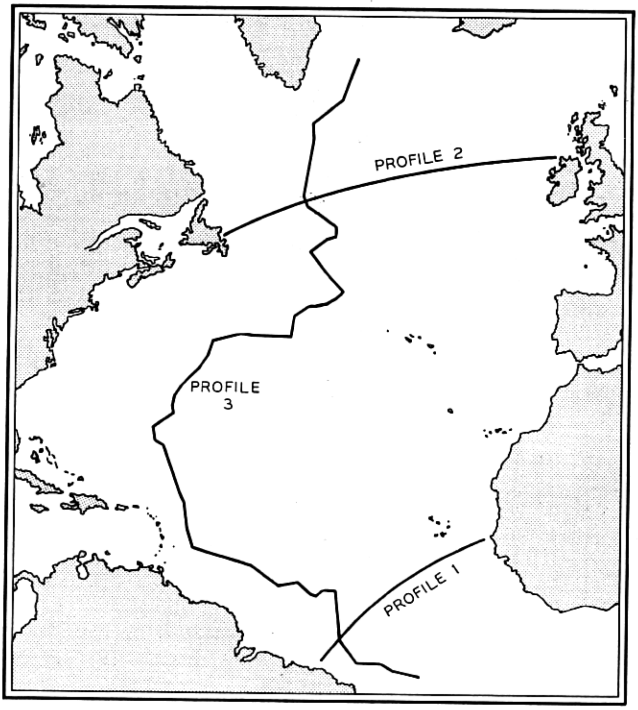

Fig. 19 — Positions of Temperature Profiles 1, 2, and 3.

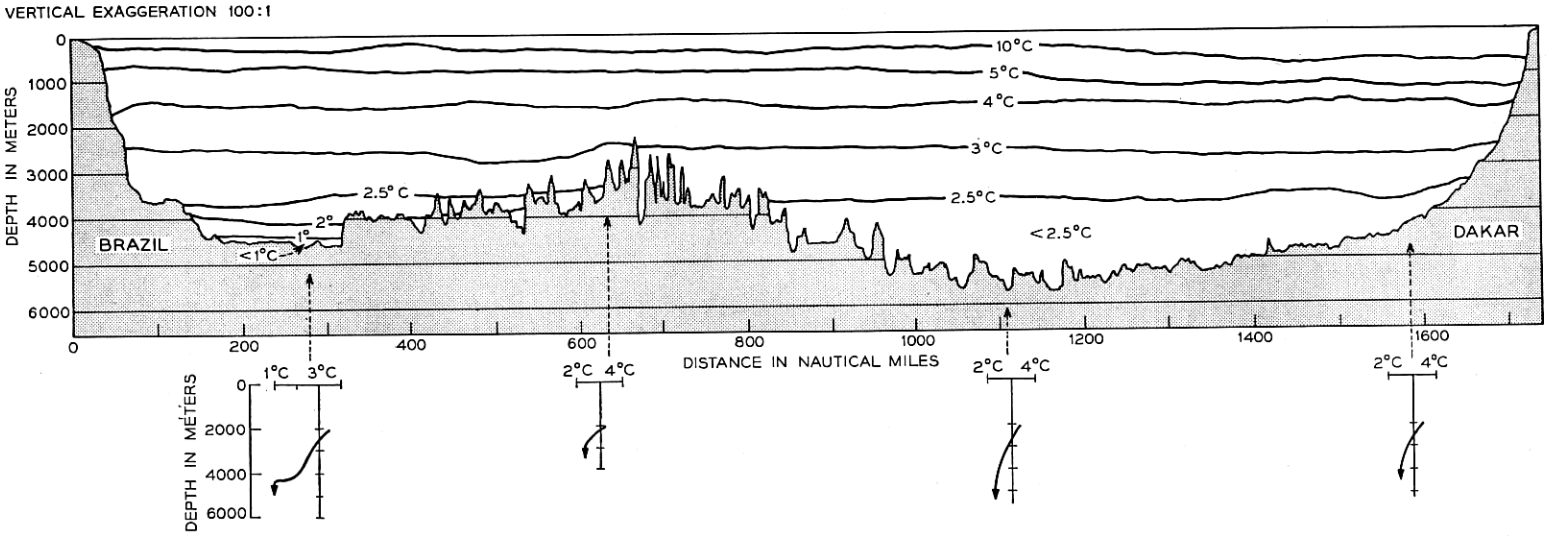

Fig. 20 — Profile 1, Northeast Brazil to Dakar, Africa. Isotherms in degrees Centigrade. Data from 1928.

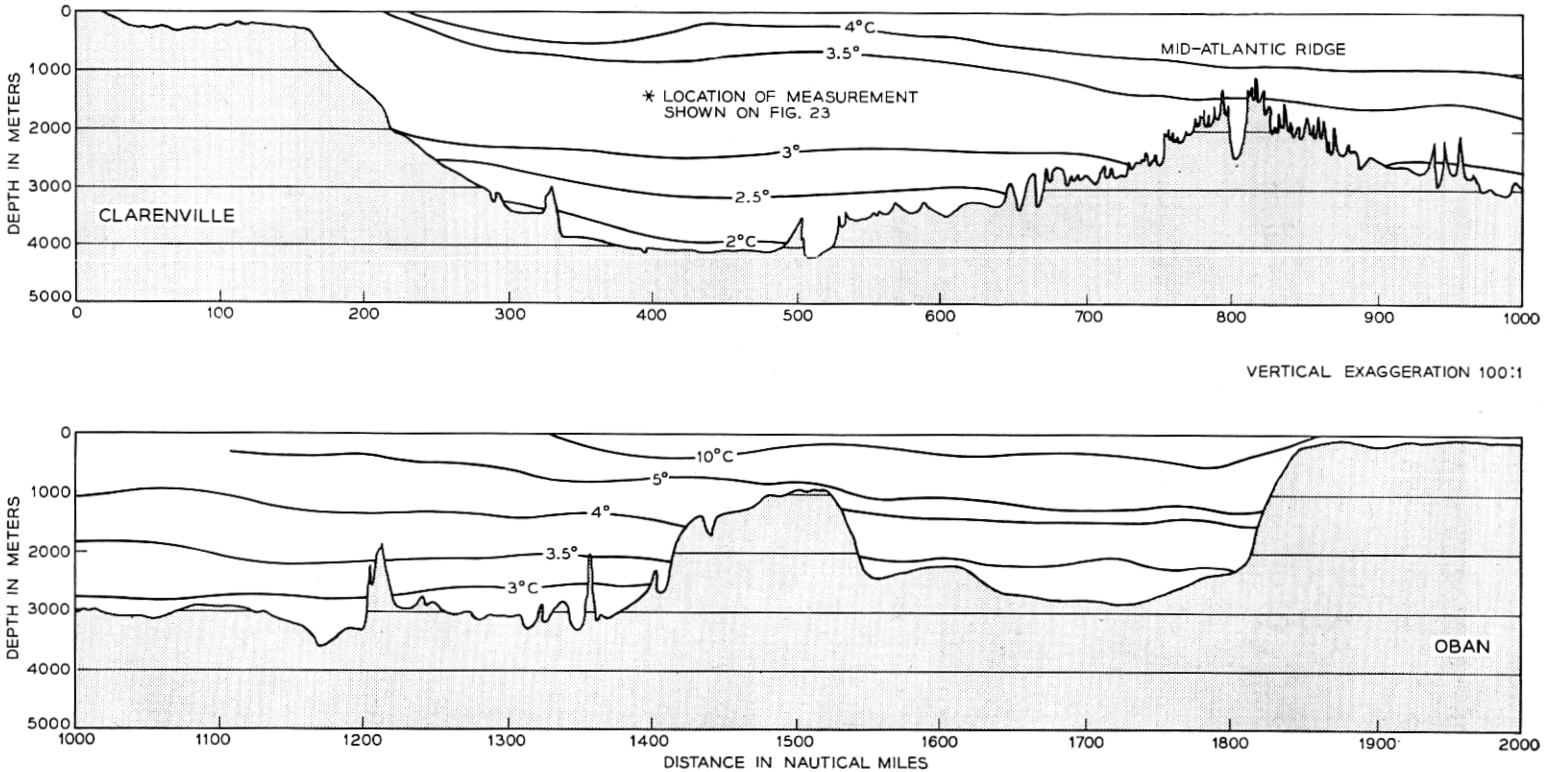

Fig. 21 — Profile 2, Clarenville, Newfoundland, to Oban, Scotland. Isotherms in degrees Centigrade. Data from several years.

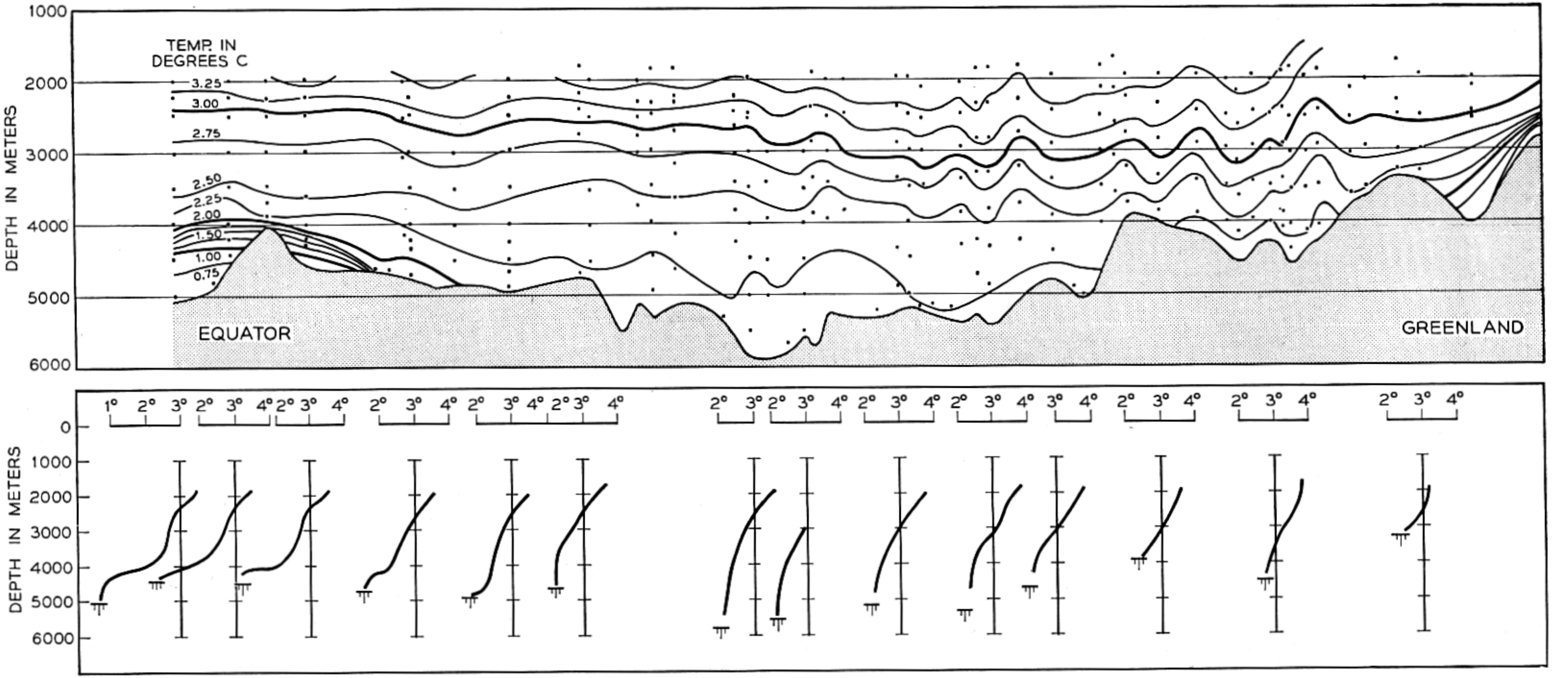

Fig. 22 — Profile 3, Equator to Greenland west of Mid-Atlantic Ridge. Top, isotherms in degrees Centigrade; bottom, gradients at corresponding locations. Data from 1920 to 1955.

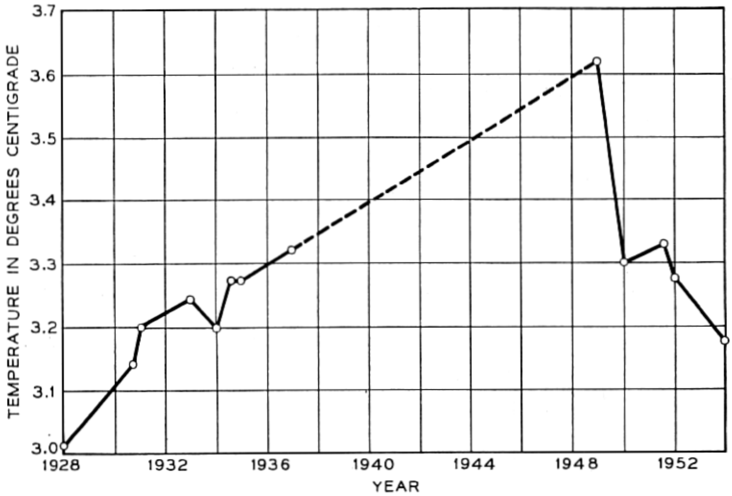

Fig. 23 — Variation of mean temperature at 1,500-meter depth in the southern Labrador Sea at about the point indicated in Profile 2, Fig. 21.

probably small. At one time it was assumed that the ocean temperature in depths exceeding 1,000 meters remained constant. As more information is gathered it is becoming evident that changes in temperatures have occurred in deep water, but neither the mechanism nor the time scale of the changes is as yet completely understood.

Due to the virtual absence of deep sea bottom temperature observations it is not possible to determine changes in temperatures by comparison of repeated measurements at approximately the same position. In a few limited areas repeated observations have been taken to depths of about 3,000 meters. All observations for one such area northeast of Newfoundland have been studied in search of long-term trends. It has been found that the water temperature between 500 and 2,000 meters in this area is nearly constant, both vertically and laterally over a wide area during any one year. It is thus meaningful to compare the temperature at 1,500 meters depth for a series of years. Fig. 23 shows the results of this comparison which indicates a 0.6°C increase between 1928 and 1949, and a 0.4°C drop from 1949 to 1954. This curve resembles the air- and sea-surface temperature averages for Atlantic-coast stations during the same years.

In the area between Labrador and Greenland a moderate number of near-bottom temperature measurements have been made since 1928. No systematic curve can be drawn but it seems fairly certain that bottom-temperature changes of 1°C have occurred in this area. These temperature changes are apparently caused by cold water cascading down the continental slope from the shelf off Greenland. It can be presumed that this water will flow south along the deep ocean basin. Depending on its velocity it will be more or less displaced towards the western margin of the basin. As the water masses flow south, lateral mixing should reduce the temperature contrast with the surrounding water.

In one area south of Newfoundland a study of scattered temperature observations made since the year 1900 indicates that water above 3,000 meters has shown a temperature increase and that the water below 3,000 meters has gradually decreased in temperature. The decrease at the bottom at a depth of 5,000 meters appears to have amounted to 0.2°C in fifty years and the maximum increase at depths less than 3,000 meters to about 0.5°C. In the high latitudes of the North Atlantic, temperature changes probably rarely exceed 1°C at depths greater than 2,000 meters and changes of a few tenths of a degree are more common.

V. CATASTROPHIC CHANGES IN THE OCEAN BOTTOM

5.1 *Earthquakes*

Earthquakes may cause damage to submarine cables by triggering the movements of rock and sediments (turbidity currents) and possibly through the effect of the actual earth vibration itself. The most serious threat to cables arises not from the direct effect of the earthquake's energy on the cable but from its ability to generate slumps, slides, and turbidity currents. It can be shown that, in an area of high seismic activity, the slopes will be nearly bare of loose sediment so that earthquakes in such an area will not result in gravitational displacements of sufficient size to cause serious damage to cable.

However, in areas such as the continental slopes of the Atlantic where few shocks have been recorded and where loose sediment has therefore accumulated, it can be expected that any quake of moderate or even small size will be sufficient to generate a turbidity current. Thus, quakes on continental slopes adjacent to cable routes are likely to be extremely destructive. There is no known method of predicting where earthquakes will occur *outside* the major seismic belts.

Fig. 24 shows the distribution of earthquakes in the North Atlantic. The North Atlantic is the best-monitored ocean because of the extensive network of seismograph stations closely adjacent in North America and Europe. All earthquakes reported for the Atlantic Ocean between 1910 and 1956 have been compiled and plotted together with the best bathymetric information. The study resulted in conclusions which are of great geological significance, as well as of interest in cable engineering. It was found that the narrow earthquake belt which runs the length of the ocean accurately follows a median trench or rift in the central highland zone of the Mid-Atlantic Ridge, see Fig. 25. (The Mid-Atlantic Rift

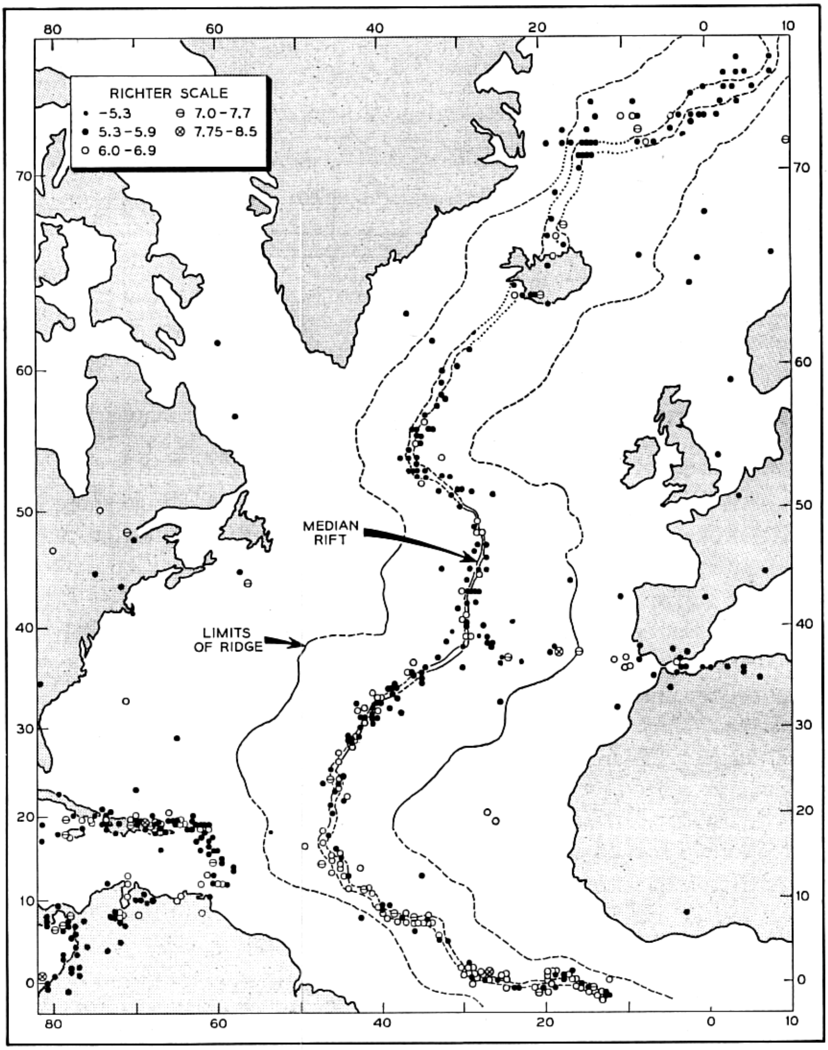

Fig. 24 — Earthquake epicenters in the North Atlantic 1910–1956. Magnitudes according to the Richter scale.

seismic belt is of secondary importance when compared with the intense seismic belt associated with the deep trenches of the Pacific.)

There is a second belt which extends from the Azores to the Iberian Peninsula, and there is a major earthquake belt which follows the West Indies Island Arc along part of the western boundary of the Atlantic. In addition to these belts there are a few scattered earthquakes around the margin of the ocean basin.

The locations of earthquakes in the ocean are in general poorly determined, and an accuracy of $\pm\frac{1}{2}°$ ($\sim$30 miles) is about all that is ever claimed. Within this measurement accuracy, all quakes in the central

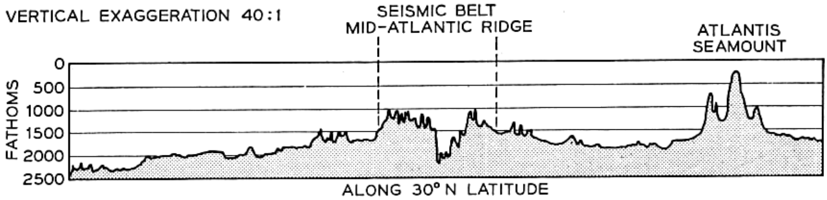

Fig. 25 — Profile of Mid-Atlantic Median Rift showing maximum limits of seismic belt.

part of the Atlantic fall in the Mid-Atlantic rift zone. Thus, there is a strong probability that all quakes on the Mid-Atlantic Ridge fall in this median trench. (Earthquakes of small magnitude are often detected when the signals are not sufficiently clear to allow a position to be determined. There are undoubtedly other quakes that are altogether undetected.) All cables to Europe must cross this rift zone and thus will undoubtedly undergo earthquake shocks from time to time. There is no positive evidence that quakes have broken telegraph cables where they cross the rift. There are, however, several cases where the telegraph cables have parted in or near the rift.

In the western Atlantic there have been recorded only six earthquakes that fall outside the belts described above. Two of these quakes occurred on the Bermuda Rise well away from cable routes. One quake occurred on the continental slope south of Newfoundland (the famous destructive Grand Banks earthquake); a second small shock nearby apparently caused no damage to cables. Two more quakes were centered off the Labrador Coast. Many cases have been recorded along the Pacific coast of Central and South America where the cables failed in deep water following an earthquake.

5.2 *Turbidity Currents — Slumps*

The turbidity current is a flow of sediment-laden water which occurs when an unstable mass of sediment at the top of a relatively steep slope is jarred loose and slides down the slope. As the slide or slump travels down the slope, more and more water becomes mixed in the mass, giving it high fluidity combined with its high density. The currents reach very high velocities, enabling them to spread for vast distances across the abyssal plains. Such slides occur at the edge of continental slopes, in particular, in the vicinity of river mouths, off prominent capes, or near banks. They are triggered by earthquakes, hurricanes, or floods.

Three excellent pieces of evidence support the turbidity-current theory and all have important implications for submarine cables. The turbidity-current hypothesis was first introduced to explain the erosion of submarine canyons in the continental slopes. Supporting evidence was found in submarine cable breakage following the Grand Banks earthquake of 1929[6] and the Orleansville (Algeria) earthquake of 1954.[7] In both cases, submarine cables were broken consecutively in the order of increasing distance *downslope* from the epicenter of the earthquake. All of the cables were broken in at least two widely separated places (100 miles or more apart). The sections between breaks were swept away and/or buried beneath sediment deposited by the current so that repair ships were never able to locate a large proportion of these sections. Fig. 26 shows the area of the Grand Banks turbidity current.

After study of this evidence, Heezen and Ewing concluded that the area covered by the current would show graded sediments as a result of deposition by the turbidity current. This was substantiated by the evidence of cores obtained from the locations shown on Fig. 26.

Cable damage resulting from turbidity currents due to slumps at a river mouth is well illustrated by that off the mouth of the Magdalena River (Columbia, S. A.). On August 30, 1935, the disappearance of 480 meters of the western breakwater and most of the river bar resulted from a slide which produced a 36-foot channel across the bar. The same night, tension breaks occurred in the submarine cable from Barranquilla to Maracaibo, which crosses the submarine canyon 15 miles off the mouth of the Magdalena in a depth of about 700 fathoms. The cable, when brought up for repair, was tightly wrapped with green grass of a type which grows in the marshes near the jetties.

The same pattern has been repeated 15 times since the cable was laid in 1930. The breakage of the cables has occurred most frequently in August and late November to early December; the two periods of the highest water of the river and of the strongest trade winds — conditions favorable for the triggering of turbidity currents. A chart of the area showing the cable breakage on the steep continental slope is shown in Fig. 27.

Fig. 28 shows areas of the world inaccessible to shallow-water-derived turbidity currents, because of their elevation or because of protective

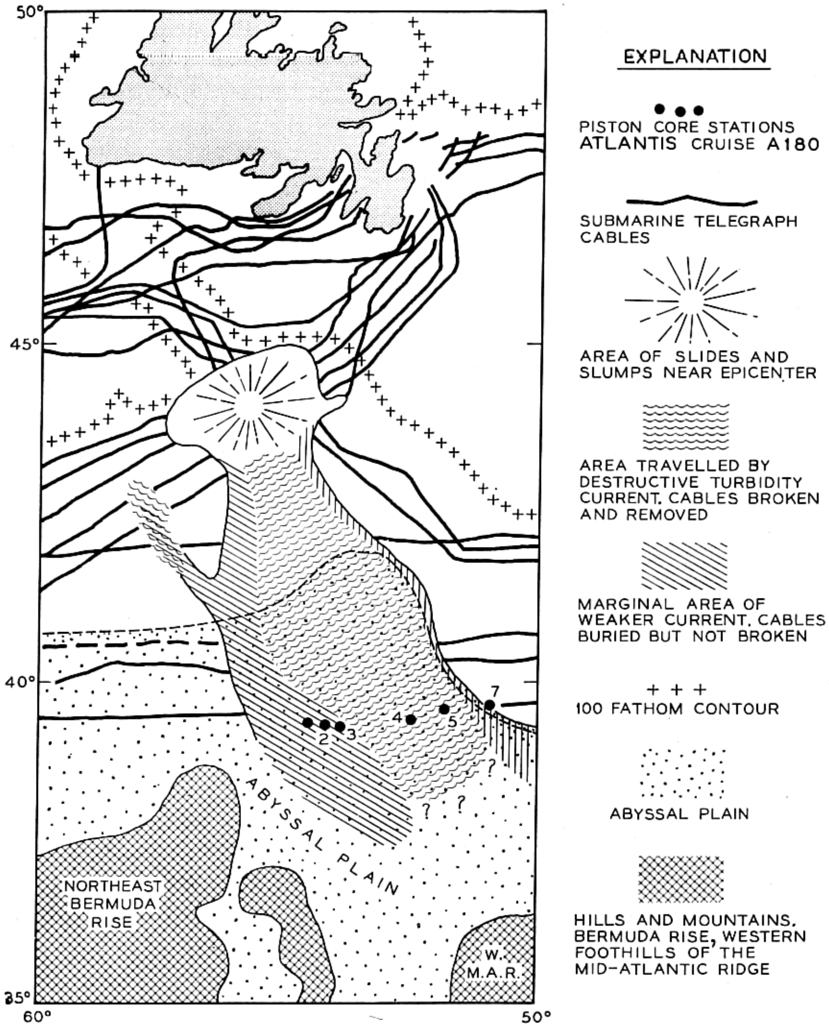

Fig. 26 — The 1929 Grand Banks turbidity current.

barriers. The arrows show some modern turbidity currents which have been documented through the breakage of telegraph cables. This chart is not yet complete and it is expected that many more arrows can be added, each representing one or more currents, and some representing as many as 20 documented cases.

Areas which have experienced turbidity current flows in the past can be determined by a careful study of the nature of the bottom. From a study of sediments and topography of areas along a proposed route it is possible to delimit areas where turbidity current could and could not

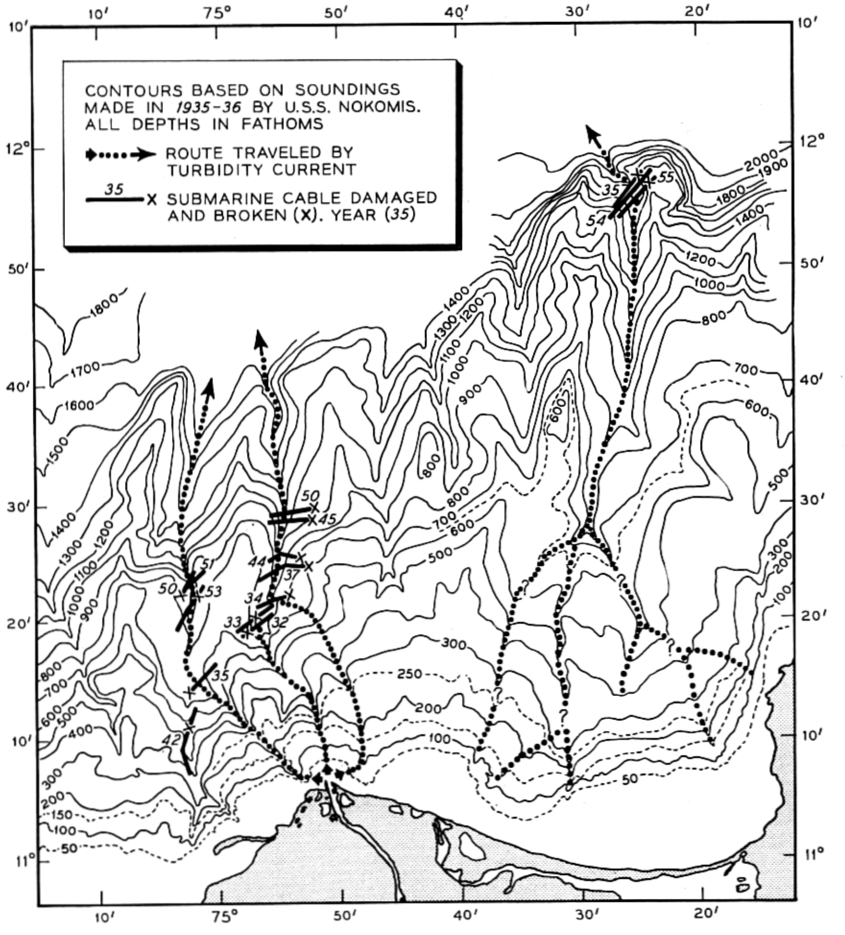

Fig. 27 — Cable breaks in the submarine canyons off the Magdalena River, Colombia, South America.

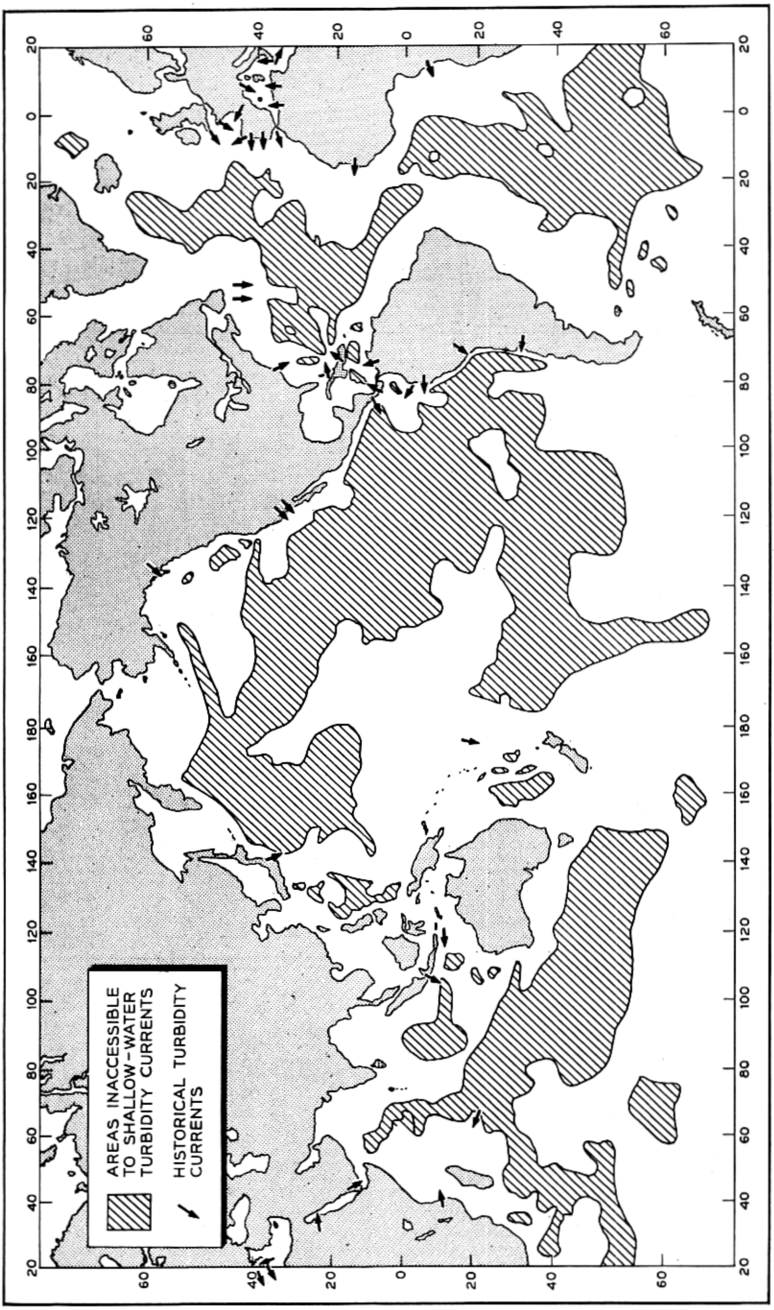

Fig. 28 — Areas of the world inaccessible to turbidity currents from shallow water.

occur, and in some cases to outline areas where they occur at frequent intervals. If, after the completion of such a study, it is decided to take the risk of laying a cable across a dangerous area and at a later date a turbidity current does occur, it will be possible to predict the length of cable to be replaced under various conditions.

VI. CONCLUSIONS

The application of the rapidly developing science of oceanography to the development and engineering of submarine cable systems will permit refinements in design, cable placing techniques, route selection, and repair operations. Existing knowledge, when evaluated and codified, provides many useful data for immediate application. Continuing study of topography, the nature of the bottom, causes of cable failures, and deep sea circulation will permit further advances in the engineering of submarine cable systems. It is to be expected that the value and usefulness of submarine cable oceanographic studies will be substantially extended as geologic and oceanographic researchers broaden the understanding of the natural laws and processes which govern and produce the ocean-bottom environment. Through such knowledge, the data of many fields can be coordinated, permitting better explanation of past events and more accurate prediction of future conditions.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Marie Tharp, W. Fedukowicz, and H. Foster of Lamont Geological Observatory, and A. L. Hale and H. W. Anson of Bell Telephone Laboratories. The encouragement and guidance of Dr. Maurice Ewing has been of great value.

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PHYSIOGRAPHIC DIAGRAM
ATLANTIC OCEAN
(Sheet I)
BY BRUCE C. HEEZEN AND MARIE THARP
Vertical Exaggeration About 20:1
20-200 Fathom Relief
200-500 Fathom Relief
500-1000 Fathom Relief
1000-1500 Fathom Relief
CANARY ISLANDS
CAPE VERDE ISLANDS
GREAT METEOR
80°
75°
70°
65°
60°
55°
50°
45°
40°
35°
30°
25°
20°
15°
10°
5°
0°