File copy

2

Columbia University in the City of New York

Folder [illegible]

LAMONT GEOLOGICAL OBSERVATORY
PALISADES, NEW YORK

A PRECISION DEEP-OCEAN SEISMIC REFLECTION SURVEY

by

C. C. Windisch, J. I. Ewing and G. M. Bryan

Technical Report No. 6
CU-6-62 Contract NObsr 85077

November 1962

A PRECISION DEEP-OCEAN SEISMIC REFLECTION SURVEY

by

C. C. Windisch, J. I. Ewing, and G. M. Bryan

Technical Report No. 6

CU-6-62 Contract NObsr 85077

November 1962

INTRODUCTION

In the past, geological and geophysical investigations in the deep-ocean have usually been directed toward achieving a fairly broad picture of the structure and composition of the major provinces of the ocean and the physical relationships between these provinces. However, the increased application of acoustical methods to certain problems in marine research has emphasized the need of a more detailed knowledge of the sea bottom. In fact, the continued development of these methods could be greatly enhanced by working in areas where a specific knowledge of the physical properties of the bottom and sub-bottom features is available.

An area of this description has been provided through a detailed survey conducted from R/V VEMA in the North Atlantic basin from December 9-22, 1961. The area was selected for its convenient location and variety of bottom surfaces. Good weather and Loran coverage were further considerations in this choice. The measurements taken in this survey included the continuous recording of depth soundings, seismic reflections, magnetics and gravity data, and the gathering of core samples of the bottom sediments. This report deals primarily with the bottom soundings and the seismic data. Although the survey is far from complete, it is the most thorough of its kind in any deep-ocean area.

Location and Course Layout

The survey was conducted in the southwestern section of the Bermuda Rise and is topographically bounded on the west by the Hatteras Abyssal Plain, to the south by Vema Gap (a topographic and structural feature separating the Hatteras and Nares abyssal plains), and to the east and north by the remainder of the Bermuda Rise. This includes an area from 23°30'N to 28°30'N and from 67°00'W to 70°00'W, and represents approximately 50,000 square miles of ocean floor. A narrow extension of the survey was also completed from the grid area south-westward across the Hatteras Abyssal Plain to the outer ridge northeast of the Bahama Islands.

The general form of the grid is that of a rectangular spiral and is shown in Figure 1. Essentially it was conducted from the center outward with legs bearing approximately 65-70° and 335-340° true. Several fill-in legs of various trends were completed in the northern and southern sections in order to expand the coverage in these directions. The spacing of the legs varies from 7 to 31 miles with an average of 15 to 20 miles. There are ten course crossings in the area and a total of 2100 miles of track. The grid extension consists of two traverses of the Hatteras Abyssal Plain and represents an additional 400 miles of track.

Navigation

The accuracy of an investigation of this sort is greatly dependent upon the method of navigation. Loran C was used throughout the survey and checked periodically by celestial fixes. The quoted accuracy of the Loran system is 1000 ft in 1000 mi, or roughly .02%. Details on the equipment used and its theory of operation have been published (Sperry, 1961).

The value of the Loran C system is readily observed from the good agreement of bottom soundings at course crossings. Although differences of 22 and 35 fm were measured at two crossings, an average closure error of 9 fm was observed. Plotting errors probably account for most of this discrepancy since the accuracy of the sounding equipment is an order of magnitude greater than the mean closure error. The repeatability of sub-bottom reflections at course crossings is a further indication of the accuracy of the navigation. However, these records are difficult to read to less than .05 sec due to the shorter printing base of the seismic profiling equipment.

Echo Soundings

The depth soundings were accomplished by means of a MK-V Times Facsimile Precision Depth Recorder (PDR) in conjunction with an EDO AN/UQN 1-B echo sounder. The transducers for this system were keel-mounted on a quiet box in order to insure minimum turbulence noise in heavy seas. This system was originally described by Luskin, et al. (1954) and later improved to its present form (Luskin and Israel, 1956).

Aside from the inherent trouble-free nature of these components, the greatest advantage of this system is that its time base, recording speed, and record width allow legible and continuous records accurate to 1 fm in 3000 fm. Furthermore, its high resolving power allows excellent records of shallow sub-bottom reflections. These reflections are readily distinguished on the Bermuda Rise at depths of 2 to 30 fm below the sediment surface, but it is difficult to estimate their continuity since a single reflector can seldom be traced for more than 10 miles. They were not observed in the Hatteras Abyssal Plain. Recent studies of deep-ocean photographs in other areas have shown that the PDR can also distinguish the presence or absence of sediments on the surfaces of protruding basement structures.

A keying rate of one ping per second was used during the survey except when gating was necessary to prevent loss of echo because of coincident scattering layer reflections or near-surface reverberation.

Cores and Thermal Studies

Four piston cores, V-18-3 through V-18-6 were taken during the investigation. One was in the Hatteras Abyssal Plain and the other three were on the Bermuda Rise. The average core length was 12 meters. Careful megascopic examinations of the cores were made immediately after their extrusion and are summarized in the appendix. The general sediment type observed in the cores from the rise was a calcareous red clay of moderate (±3-5%) foraminiferal content. The core from the abyssal plain contained intercalated silty clay and clayey silts. These descriptions seem to agree with previous core studies in their respective provinces (Ericson, et al., 1955; Heezen, et al., 1959; and unpublished data). Two other cores, V-17-1 and V-17-2, were taken east of the grid area in a previous cruise. These contained uniform red clays with some manganese oxides and almost negligible carbonate.

At each of the four coring stations in the grid area heat-flow determinations were computed from measurements of temperature gradient and thermal conductivity. Gradients were measured with a Lamont thermograd to an accuracy of about 2%. Average thermal conductivities were measured with an estimated accuracy of 10%. The results are tabulated below.

Station Number	Position	Temp. Gradient (°C/m)	Average Conductivity (cal/cm°C sec x 10-3)	Heat Flow (μ cal/ cm^2 sec)
V-18-3	26°48'N 66°06'W	0.068	2.19	1.48
V-18-4	24°55'N 71° 47'W	0.054	2.42	1.31
V-18-5	27°08'N 68°03'W	0.058	2.35	1.36
V-18-6	28°00'N 68°11'W	0.078	2.36	1.85

These values are all slightly above the world average of observed heat flow (approximately 1.2 x 10^{-6} cal/cm^2 sec, Bullard, 1954). Station V-18-6, which was taken at the foot of a 400-fathom submarine peak, has a heat-flow value appreciably higher than normal. The high value is a consequence of a steeper gradient rather than greater conductivity of the material sampled. It is possible that the close proximity of the basement rock, which has a greater thermal conductivity than the surrounding sediment, is distorting the field and producing the steep gradient (M. Langseth, private communication).

Seismic Reflection Profiling

The basic profiling system and technique used in this survey have been outlined by J. I. Ewing and G. B. Tirey (1961), J. I. Ewing and J. E. Nafe (1961), and more recently by J. I. Ewing, J. L. Worzel, and M. Ewing (1962). A brief review of this method, the equipment, and their modifications follows.

For this survey a single crystal hydrophone (Research Manufacturing Co. R-100) and associated cathode follower preamplifier were used to feed two separate seismic amplifiers, band-pass filters, print amplifiers, and styli. This arrangement permits the simultaneous (side-by-side) print of two separate records on a Times Facsimile drum recorder with each record representing a part of the reflected energy spectrum determined by the filter settings. By means of a sound-actuated release system, the recording drum is held at zero time between shots and automatically released at each shot instant. The drum then turns at a constant speed, allowing the styli to print the shot instant and successive reflections in their proper time sequence on the papered drum surface. At the end of one revolution the release stops the drum at zero time until the next shot instant. Since the styli also travel the length of the drum with time, profiles of successive shot instants and their reflections are achieved.

In this study a band-pass setting of 20-60 cycles was found to give good records of the basement. A 100-200 cycle band-pass on the high-frequency print channel permitted better definition of sedimentary features.

The sound sources were 1/2-pound charges of TNT fired with safety fuse on a three-minute schedule. The charges were floated in order to shorten the total pulse length by eliminating the bubble pulse. The hydrophone was trailed approximately 300 feet behind the ship. The hydrophone cable was slacked by a B.T. winch shortly before each shot to insure minimum turbulence noise during the recording cycle. The ship's speed was approximately ten knots.

Grid Profile Plot

In Figure 1 the precision depth recordings and the seismic reflection profiles have been plotted in their proper positions along the ship's track. In vertical scale the course lines represent 7.0 seconds reflection time or 2800 fm uncorrected (2901 corrected, Matthews, 1939). The soundings are shown relative to this line as time functions. Stippling is used to indicate sedimentary composition and hachures to indicate basement material. Broken lines indicate ambiguity in the data on the presence or position of a reflecting horizon. The vertical exaggeration of the bottom features is approximately 25:1.

The topography of the Bermuda Rise has been thoroughly discussed by Heezen, Tharp and Ewing (1959). In the grid area the bottom surface is smooth and rolling with small 25-100 fm hills or knolls of sediment averaging 1-5 mi laterally. Where basement features are near to or protrude through the water-sediment interface, 100-500 fm peaks extending 5-15 mi may be seen. (Because of the three-minute shot schedule, basement features less than a mile in extent are not well defined). The average slope of the bottom is about 1:600 toward the west, and the surface roughness decreases in this direction, disappearing where the rise joins the

Hatteras Abyssal Plain. To the south, the average bottom slope decreases from approximately 1:1000 to a relatively flat surface in the abyssal gap between the Hatteras and Nares abyssal plains. However, protruding basement features are still evident in this area.

The relief of sub-bottom,and especially basement, features would be somewhat increased if the sediments were plotted to true thickness, but this would not significantly alter the overall interpretation of the data.

Refraction Profiles

A good idea of the velocity structure in the sediments can be obtained from four refraction profiles available in the grid area. These profiles, G-10, G-11, G-12, and G-13, were originally presented and discussed by J. Ewing and M. Ewing (1959). G-10 through G-12 lie in the grid area proper and are crossed by the recent reflection profiles. G-13 lies in the Hatteras Abyssal Plain and was crossed in one of the legs of the survey extension.

In the original presentation, the existence of a 4.5-5.5 km/sec layer was suggested but not made use of in computing structure sections. In the light of more recent findings, this layer is considered well established, and the profiles have been revised accordingly. The depth of this layer shows good agreement with the basement in the reflection profiles. A 2.0-2.5 km/sec layer was also identified in three of the refraction studies and agrees fairly well with a principal sub-bottom reflector in the sediments.* The results of these refraction studies indicate that an average sediment velocity of 1.7-2.0 km/sec will give a reasonable estimate of true thickness.

The Sediments

A study of the seismic reflection profiles and the PDR records indicates three specific types of bottom surfaces in the grid survey area and in the survey extension. The surface of the Hatteras plain is smooth and flat and composed of layered silts and silty clays deposited by turbidity currents. The PDR records from this surface show strong reverberating reflections but no discrete sub-bottom horizons. The deeper penetration by seismic reflection profiling, on the other hand, shows a fairly dense layering of strong sub-bottom reflections. The basement surface is poorly defined, apparently because of poor penetration of energy into the sediments due to the large number of reflecting layers. Increasing the size of the charges does not greatly improve the records, possibly indicating a weak acoustical contrast be-between the basement and the deeper sediments.

A second type of bottom surface is found in the smooth and hilly topography of the Bermuda Rise which characterizes most of the grid area. The PDR records of this surface show discrete and often rather weak bottom reflections. Sub-

---

* Recent investigation has raised some doubt of this velocity identification. It is possible that the points which have been interpreted as refracted arrivals, defining a layer of this velocity, may be sub-bottom reflections.

bottom reflections are observed in many of these records at depths ranging between 2 and 30 fm below the sediment surface. This condition is particularly true along the edge of the rise. In fact, the boundary between the provinces - the Bermuda Rise and the Hatteras Abyssal Plain - is readily distinguished both by the abrupt change in the character of the bottom reflections and by the change in the surface topography. The seismic profiles show an acoustically transparent column of sediments containing several strong reflecting horizons, and very well defined basement structure. The cores of surface sediments on the rise contained slightly calcareous red clay.

A third type of bottom surface is to be found on the faces of the numerous peaks and scarps evident in the central and eastern portions of the grid area. The seismic records indicate an absence of sediment cover on these features. These apparent absences are represented in approximately 15% of the seismic profiles. It is felt that in most cases the declivity of these rough features is not sufficient to exclude at least a thin covering of cohesive sediment which is too thin to be detected by the present seismic technique. In many cases the PDR records support this interpretation.

As many as six sub-bottom reflecting surfaces were observed within the sediments overlying the basement. Two of these, reflectors "A" and "B," appear to be of sufficient strength and extent to be considered continuous over most of the survey area. A deeper horizon, reflector "C," is found in locations where the sediments are especially thick (about 1.0 sec reflection time). The apparent lack of continuity of one or more of these reflectors in certain areas may be the result of local changes in the acoustical properties of the sediments and/or thinning of the sediments embraced by any of two reflecting boundaries.

Reflector "A" is observed in 70% of the area at an average depth of .26 sec reflection time below the water-sediment interface; reflector "B" is observed in 35% of the area at an average depth of .50 sec; and reflector "C" is observed in 3% of the area at an average depth of .77 sec. If the various reflectors are taken to define the interfaces of four major layers, the thicknesses of these layers, averaged over the entire grid area (which includes locations of apparent zero thickness), would be .21, .16, .08, and $<.01$ sec, respectively, or a total of .45 sec. The greatest single measurement is 1.25 sec.

It is not definitely known whether the various reflecting horizons represent the interfaces of major sedimentary units of different velocity and density characteristics or whether they are fairly thin members in an otherwise uniform column of sediment. With the presence of the Bermuda Pedestal and the Muir Seamount to the north, it is not unreasonable to suppose that some of the reflections may represent relatively thin layers of ash or other volcanic debris deposited during various stages of growth of these features. If this were the case, one would expect to observe the thickening of these layers or at least an increase in the strength of their reflections toward these sources. However, these conditions are not apparent in the seismic records. The reflections are generally quite clear within the 20-60 cps range and at higher frequencies. Since thin layers would tend to have indistinct low frequency signatures and gradational changes would be poorly resolved at high frequencies, it appears that these reflections represent fairly abrupt differences between sedimentary layers of some thickness. Further argument that the various reflecting surfaces may represent the boundaries of fairly large sedimentary units is to be found in the refraction records from the grid area which have indicated a layer with a velocity in the order of 2.0-2.5 km/sec, beginning at the approximate depth of the "A" reflections. It has been customary in the literature to associate velocities of this order with semi-consolidated or semi-lithified sediments.

In order to estimate the actual thickness of the sediments it is necessary to assume a velocity structure. If we tentatively assume a compressional wave velocity (V_O) at the surface of the sediments of 1.52 km/sec (Fry and Raitt, 1961), a minimum velocity below the "A" reflections (V'_0) of 2.10 km/sec, and a velocity gradient in the sediments of $K = 1\ \text{sec}^{-1}$ (M. N. Hill, 1957; Ewing and Nafe, 1961), then

$$H_t = \frac{V_0}{K}\left(e^{Kt_1} - 1\right) + \frac{V'_0}{K}\left(e^{Kt_2} - 1\right)$$

where H_t = total sediment thickness in km, t_1 = .10 sec or the thickness of the surface layer, and t_2 = .12 sec or the thickness of sediments beneath the "A" reflections, and we arrive at an average thickness of approximately 430 meters for the entire grid area and a mean velocity of 1.9 km/sec.

It is interesting that all of the sedimentary reflecting horizons are unconformable with the basement structure and with each other. Furthermore, the degree of this nonconformity is greatest in the younger sediments. Certainly tectonic activity on the Bermuda Rise presents the simplest explanation of these phenomena. However, recent bottom current measurements on the rise have suggested that deep-ocean currents may also have contributed to these unconformities, especially in the surface sediments.

Sub-Bottom Reflections (Basement)

Although the term "basement" has been variously defined in the literature, it will be used in this discussion to refer to the deepest continuous reflecting surface below which no coherent reflections are observed. Typical records of the basement and other reflections are shown in Figure 2. The characteristic strength of the basement returns indicates a strong and abrupt acoustical impedance change between this material and the overlying sediments. Furthermore, the long reverberating nature of these reflections and the fact that this surface fails to yield a well-defined pattern of bubble pulse reflections when sinking charges are used, suggests that it is quite rough.

It may be seen that the basement configuration is extremely irregular with features of the order of .12-.50 sec vertically and 6-9 miles in basal dimension. These features are often superimposed on larger structures .50-1.25 sec vertically and extending 15-25 miles in profile. Many of these large irregularities extend 100-500 fm through the sediment surface to form the large peaks which characterize the bottom topography in some of this area. This condition had been postulated by Heezen, Tharp and Ewing (1959). The PDR records from these areas are very rich in side echoes, suggesting that these basement features are even rougher than the seismic profiles would indicate and extend for some distances to either side of the ship's track. The steeper slopes of these features are 10°-20° and in some cases may be as high as 55°.

It is not known whether the characteristic basement roughness is the expression of individual peaks or of ridges. Several structural trends have been suggested from the preliminary contourings of the basement. Since the spacing of courses exceeds the average width of these features, further coverage of the area will be necessary before these trends can be positively identified. The magnetics data also failed to indicate a general trend pattern (J. R. Heirtzler, private communication). Although the average wavelength of anomalies is similar to that of the basement features, there is usually no apparent correlation between the two. A noteworthy exception to this disparity is a structural trend in the eastern section of the grid area. This trend is indicated in Figure 1 by a dashed line transecting three north-south courses.

The average basement slope to the west is of the order of 1:200 but decreases to near horizontal under the Hatteras Abyssal Plain. The basement relief shows a moderate decrease in this direction. However, it has been mentioned that the basement is poorly defined to the west. To the south toward Vema Gap the slope is approximately 1:800. The basement topography shows a marked change in this direction and is characterized by large peaks and broad sediment-filled valleys in the southern grid area.

The basement has been drawn as a single continuous reflecting surface, and it is inferred that its basic composition is everywhere the same. The four identifications of basement velocity, 5.60, 4.88, 5.11, and 5.41 km/sec obtained in the refraction profiles lie within the range of values observed in all deep-ocean areas (Officer, Ewing, and Wuenschel, 1952; M. N. Hill, 1957; Ewing and Ewing, 1959; R. Raitt, in press).

Suggested compositions of the basement material have varied from consolidated sediments, volcanics, and metamorphics to granites. In any case, the rough character of the basement structure is not peculiar to the Bermuda Rise but is observed throughout the North and South Atlantic and other oceans of the world. Thus the origin and general composition may not necessarily be unique for this area.

Conclusions

This area contains three specific types of bottom, each different from the others in shape, composition, or stratification. Each type of bottom is characteristic of large areas of the North Atlantic Ocean, and each has a different influence on the reflection of acoustic energy.

The abyssal plain is locally smooth and regionally flat. Turbidity currents have dominated deposition here and have produced a bottom composed of alternating layers of silts and clays or mixtures of the two. Reflectivity is high, owing principally to the high acoustic impedance of the silty layers. Reverberation is also high because of the many reflecting horizons near the sea floor. The effects of multi-path reflection on signal coherence is observed both at the echo sounder frequency (12 kc/sec) and at the low frequencies (100-200 cps) used by the seismic profiler. Although the echo sounder records reflections only as deep as 5-10 fm below bottom, a pulse of higher power and lower frequency might be expected to penetrate to some of the deeper horizons observed in the seismic records.

The bottom in most parts of the Bermuda Rise is locally smooth but regionally undulating. The topography has typical wavelengths of the order of 1-5 miles, amplitudes of 25-100 fm. Bottom-reflected pulses here indicate lower reflectivity and much less reverberation than in the abyssal plain. At the lower (seismic) frequencies, only a few reflections are observed within the entire sedimentary column. In general, these are separated by layers of appreciable thicknesses which, compared with the sediments of the abyssal plain, are relatively unstratified. Sediment cores show the top 15-20 meters to be slightly calcareous lutite with no silt or sand present. The echo sounder indicates reflecting horizons as deep as 20-30 fm at many locations in the Bermuda Rise traverses. The number of sub-bottom reflections visible in the echo sounder records here is seldom more than 3, whereas in typical abyssal plain records, the upper 10-20 meters of sediment contains so many reflectors that individual layers are difficult to distinguish. Specific sub-bottom reflectors in many places are clearly recorded over distances of 30 miles or more, in contrast to those in the abyssal plains which seldom persist for more than a few miles. Judging by the sediment penetration achieved by the echo sounder operating at 12 kc/sec on the Bermuda Rise, it is reasonable to assume that high energy acoustic signals in a lower frequency range will penetrate to considerable depths below the bottom. In many areas, the prominent sub-bottom horizons recorded by the seismic profiler will probably be significant reflectors at frequencies as high as a few kc/sec.

A third type of bottom is characterized by the areas where large basement outcrops occur. The basement, probably igneous rock, is very rough; and even though the outcrops are largely covered by a thin veneer of sediment, side reflections confuse the echo pattern so that signal coherence is poor - both at the echo sounder frequency and at seismic frequencies. This indicates that the basement surface is both regionally and locally rough.

The ocean bottom covered in this survey is considered to represent three basic types with respect to bottom-reflected acoustic energy.

A. The abyssal plain area is probably characteristic, to a large extent, of all the abyssal plains in the Atlantic Ocean as shown by the physiographic diagrams of Heezen and Tharp (1959). Some variation may be expected which is a function of distance from the place of origin of the turbidity currents supplying the sediments to the plains. Layers of sand, and even gravel, have been found in core samples taken from the upper (near continent) regions of the Hatteras and Sohm Plains, whereas only the finer silts are found in the outer reaches of the Nares Plain.

B. The western part of the grid area appears, from this and other reflection measurements, to be characteristic of most of the smoother regions of the Bermuda Rise, the outer ridge of the Puerto Rico Trench, and of some parts of the lower continental rise and outer flanks of the Mid-Atlantic Ridge.

C. The areas of basement outcrops are characteristic of parts of the Bermuda Rise and of the major portions of the Mid-Atlantic Ridge.

The geological implications of the grid survey are still being studied and will not be discussed in this report. Closer course spacing is required in order to determine the regional structural trends. It is planned to run additional tracks through the grid and adjacent areas. This will not only aid in the geological interpretations but will expand the study of bottom acoustics to include other types of surfaces.

Acknowledgments

This work was supported by the United States Navy under contract Nobsr 85077 with the Bureau of Ships. This publication is for technical information only and does not represent recommendations or conclusions of the sponsoring agency. Reproduction of this document in whole or in part is permitted for any purpose of the United States Government.

References

Ericson, D. B., M. Ewing, and B. C. Heezen (1952) Turbidity currents and sediments in the North Atlantic; Amer. Assoc. Pet. Geol., v. 36, no. 3, p. 489-511.

Ericson, D. B., M. Ewing, B. C. Heezen, and G. Wollin (1955) Sediment deposition in the deep Atlantic; Geol. Soc. Amer. Spec. Paper 62, p. 205-220.

Ewing, J. I., and M. Ewing (1959) Seismic refraction measurements in the Atlantic Ocean Basins, in the Mediterranean Sea, on the Mid-Atlantic Ridge, and in the Norwegian Sea; Geol. Soc. Amer., v. 70, p. 291-318.

Ewing, J. I. and J. E. Nafe (1961) The unconsolidated sediments; Lamont Geol. Obsvy. Tech. Report No. 3, CU-4-61, Nobsr 85077 Geology, 24 pp.

Ewing, J. I. and G. B. Tirey (1961) Seismic profiler; Jour. Geophys. Res., v. 66, no. 9, p. 2917-2927.

Ewing, J. I., J. L. Worzel, and M. Ewing (1962) Sediments and oceanic structural history of the Gulf of Mexico; Jour. Geophys. Res., v. 67, no. 6, p. 2505-2527.

Fry, J. C., R. W. Raitt (1961) Sound velocities at the surface of deep sea sediments; Jour. Geophys. Res., v. 66, no. 2, p. 589-597.

Heezen, B. C., M. Tharp, and M. Ewing (1959) The Floors of the Oceans. Vol. 1: The North Atlantic; Geol. Soc. Amer. Spec. Paper 65, 122 pp.

Hill, M. N. (1957) Physics and Chemistry of the Earth; vol. 2, L. H. Ahrens, et al., editors, p. 129-163.

Luskin, B., B. C. Heezen, M. Ewing, and M. Landisman (1954) Precision measurements of ocean depth; Deep-Sea Res., v.1, p. 131-140.

Luskin, B. and H. G. Israel (1956) Precision Depth Recorder MK-V; Lamont Geol. Obsvy. and Times Facsimile Corp. Tech. Report No. 12, 31 pp.

Matthews, D. J. (1939) Tables of the velocity of sound in pure water and sea water for use in echo-sounding and ranging; Hydro. Dept., British Admiralty, London.

References (continued)

Officer, C. B., M. Ewing, and P. C. Wuenschel (1952) Seismic refraction measurements in the Atlantic Ocean. Part IV: Bermuda, Bermuda Rise, and Nares Basin; Geol. Soc. Amer., v. 63, p. 777-808.

Raitt, R. W. (in press) The crustal rocks; in The Seas, Vol. 2; M. N. Hill, et al., editors, John Wiley and Son, Inc., London.

Sperry Rand Corp. (1961) Preliminary technical manual for Loran receiving sets AN/WPN-4 and AN/SPN-32; Sperry Gyroscope Div. Publication No. CA-13-0035, v. 1.

Tolstoy, I., R. S. Edwards, and M. Ewing (1953) Seismic refraction measurements in the Atlantic Ocean. Part·3; Bull. Seis. Soc. Amer., v. 43, no. 1, p. 35-48.

APPENDIX

V-18-3

Date: 9 December 1961
Lat.: 26°47'N, Long.: 66°08'W
Location: Bermuda Rise, about 340 nautical miles south southwest of Bermuda
Length: 1182 cm
Depth: 2638 fm

Description

0-87 cm	Reddish-brown foraminiferal calci-lutite.
87-168 cm	Reddish-brown foraminiferal calci-lutite mottled by whitish burrow markings.
168-548 cm	Reddish-brown foraminiferal calci-lutite.
548-553 cm	Material removed for piston entry (piston effect).
553-856 cm	Reddish-brown foraminiferal calci-lutite.
856-860 cm	Piston effect.
860-1173 cm	Reddish-brown foraminiferal calci-lutite, irregularly laminated by thin bands of dark brown calci-lutite.
1173-1182	Core catcher.

V-18-4

Date: 11 December 1961
Lat.: 24°55'N, Long.: 71°47'W
Location: Hatteras Abyssal Plain
Length: 1223 cm
Depth: 2907 fm

Description

0-120 cm	Fine, gray, slightly lutaceous silt.
120-151 cm	Light brown silty lutite mottled gray.
151-405 cm	Fine, gray, lutaceous silt mottled light brown.
405-420 cm	Tannish-brown silty lutite.
420-433 cm	Fine, gray, lutaceous silt.
433-453 cm	Tannish-brown silty lutite.
453-466 cm	Fine, gray, lutaceous silt.
466-492 cm	Tannish-brown silty lutite.
492-582 cm	Gray lutaceous silt mottled light brown.
582-613 cm	Light brown silty lutite mottled gray.
613-623 cm	Gray lutaceous silt.
623-630 cm	Material removed for piston entry; brown silty lutite.
630-678 cm	Compact brownish-gray silty lutite.
678-1223 cm	Watery uncompacted gray silt.

V-18-5

Date: 14 and 15 December 1961
Lat.: 27°08'N, Long.: 68°03'W
Location: Bermuda Rise
Length: 1201 cm
Depth: 2733 fm

Description

0-126 cm	Light brown calci-lutite mottled by reddish-brown burrow markings. Contains a band of gray silty calci-lutite at 69-71 cm.
126-319 cm	Reddish-brown calci-lutite mottled light brown by burrow markings.
319-349 cm	Light tannish-brown calci-lutite.
349-371 cm	Reddish-brown calci-lutite mottled tannish-brown by burrow markings.
371-410 cm	Light brown and tannish-brown calci-lutite.
410-557 cm	Reddish-brown calci-lutite. Mottled light brown in the lower 60 cm.
557-565 cm	Light brown calci-lutite.
565-569 cm	Material removed for piston entry; reddish-brown calci-lutite.
569-1201 cm	Reddish-brown calci-lutite.

Occasional large-sized foram tests and slightly more numerous smaller tests occur throughout the core, comprising three to five per cent of the total sediment.

Sections at 100-111 cm, 243-256 cm, 398-410 cm, 584-596 cm, and 902-915 cm were removed for heat conductivity measurements.

V-18-6

Date: 18 December 1961
Lat.: 28°00'N, Long.: 68°09'W
Location: Bermuda Rise
Length: 1200 cm
Depth: 2772 fm

Description

0-139 cm	Reddish-brown foraminiferal calci-lutite.
139-158 cm	Tannish-brown foraminiferal calci-lutite. Mottled slightly reddish-brown.
158-257 cm	Reddish-brown calci-lutite. Mottled by brownish-white burrow markings and black specks of M_nO_x or Fe_S.
257-358 cm	Gray calci-lutite. More brownish in the upper 30 cm.
358-535 cm	Grayish-brown calci-lutite. Heavily mottled by dark brown and brownish-white burrow markings.
535-890 cm	Brown to grayish-brown foraminiferal calci-lutite. Piston effect at 553-561 cm.
890-1023 cm	Reddish-brown foraminiferal calci-lutite. Mottled by light and dark burrow markings. Lower contact arbitrarily drawn.
1023-1200 cm	Brown foraminiferal calci-lutite. Piston effect at 1188-1192 cm.

Small foram tests occur throughout the core but seem to be more abundant in some layers than in others. They make up about three per cent of the sediment.

Sections at 104-117 cm, 299-312 cm, 405-418 cm, 719-731 cm, 922-936 cm, and 1080-1093 cm were removed for heat conductivity measurements.

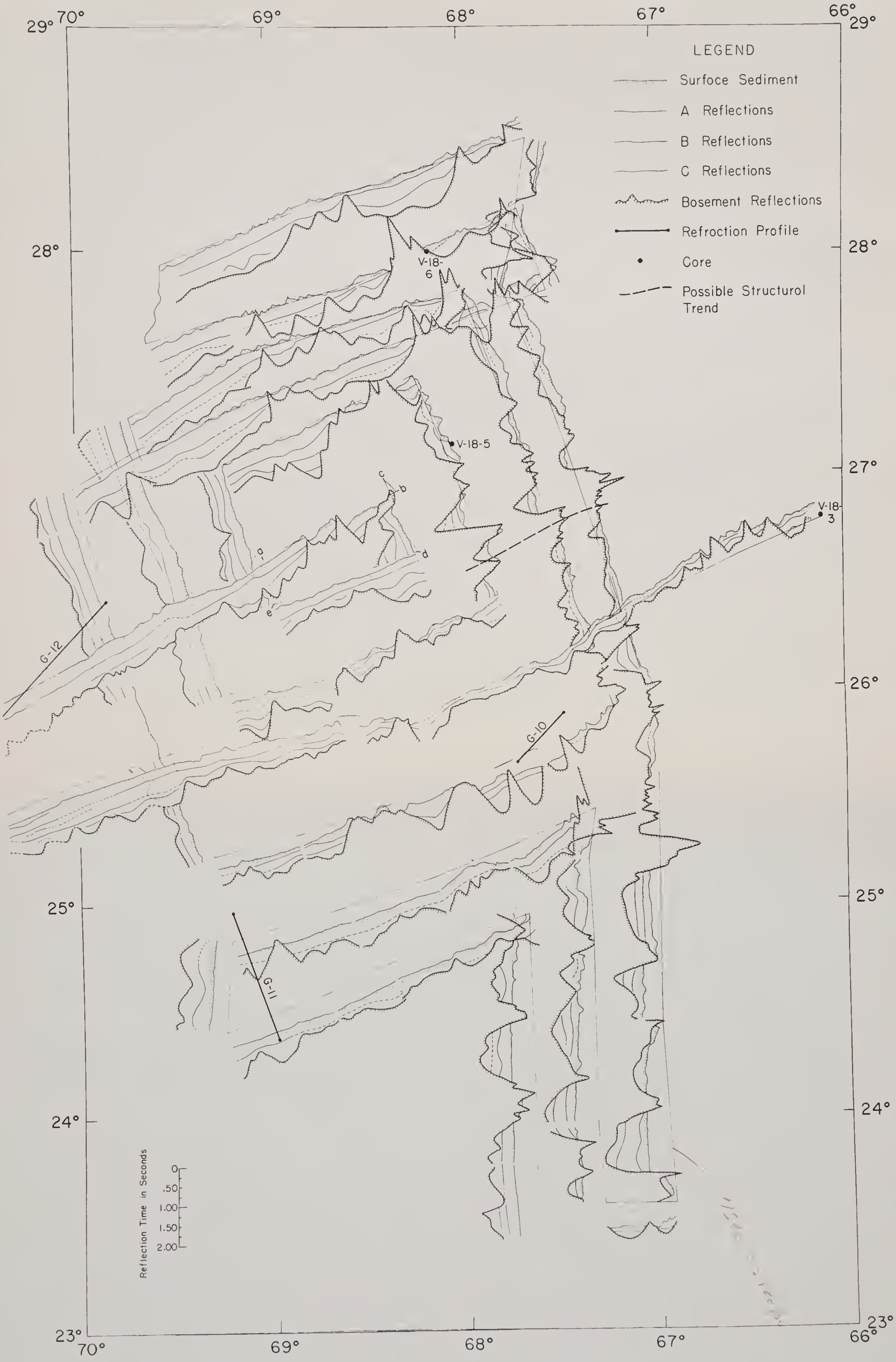

Fig. 1 Grid Survey Profiles

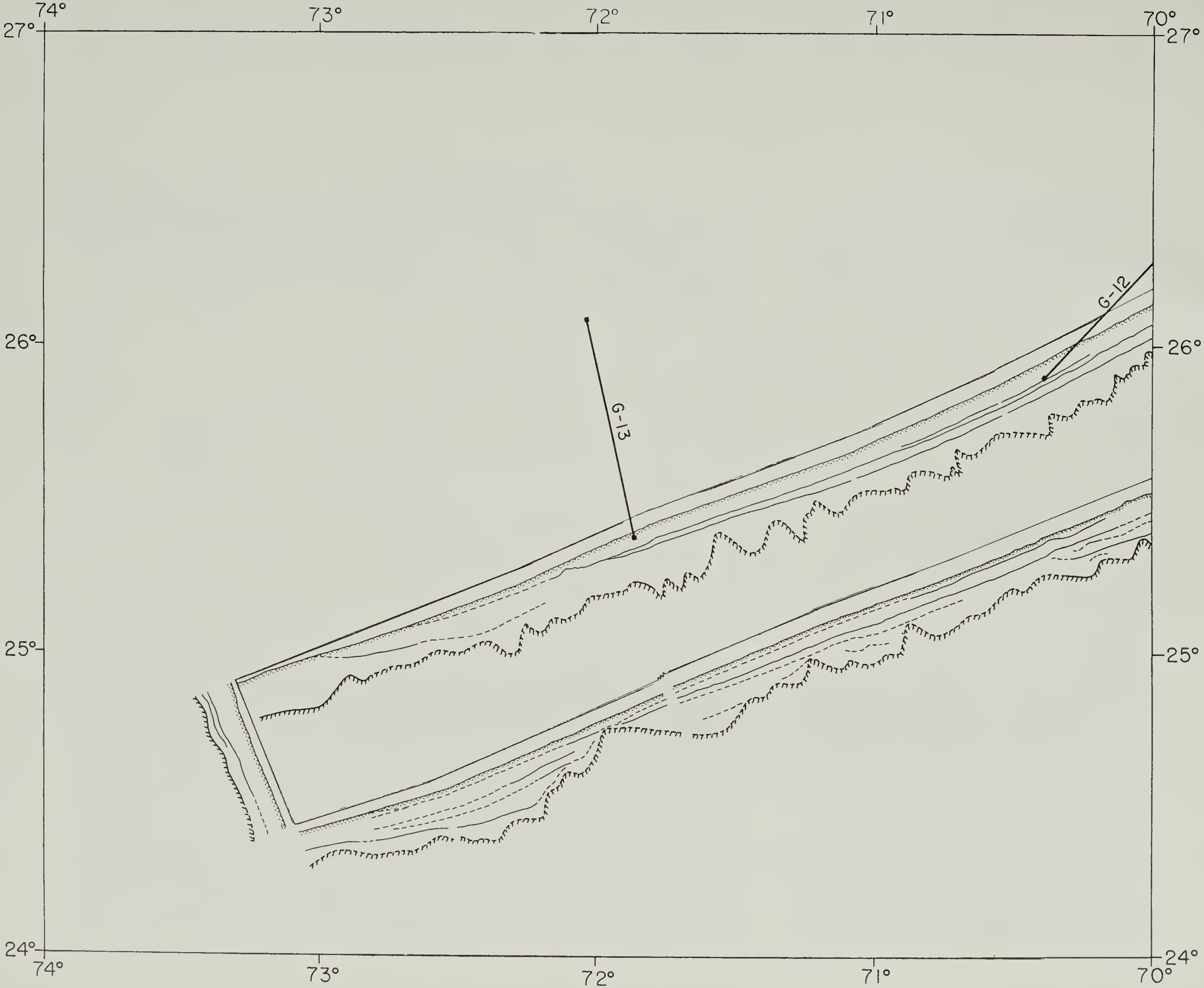

Fig. 1 (Cont'd.)

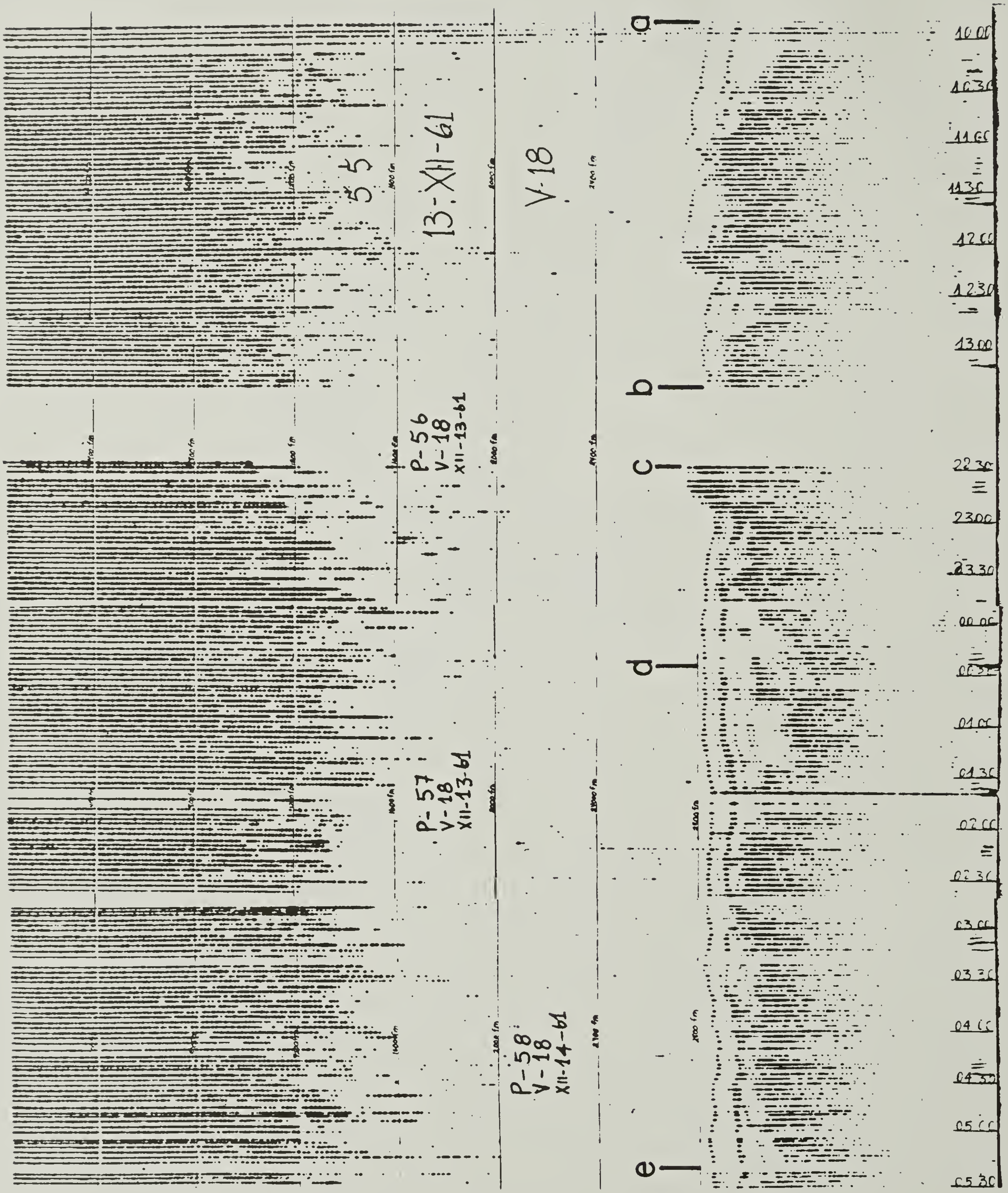

Fig. 2 Typical Seismic Reflection Profiles