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LAMONT GEOLOGICAL OBSERVATORY
(Columbia University)
Palisades, New York

CABLE FAILURES IN THE GULF OF CORINTH: A CASE HISTORY

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Bruce C. Heezen, Maurice Ewing, and G. L. Johnson

Prepared for

The Bell Telephone Laboratories
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ABSTRACT

The Gulf of Corinth is a narrow, 65 mile long, 470 fathom trench, which lies between the Peloponnesus and the mainland of Greece. The canyons of the steep southern continental slope lead from major river mouths to coalescing subsea fans. A narrow abyssal plain occupies the deepest part of the gulf.

Three telegraph cables were laid the length of the gulf and maintained for over fifty years. Two of the cables lay on the continental slope and one traversed the abyssal plain. The two cables on the continental slope were broken frequently by turbidity currents originating at the mouths of the major rivers. On the few occasions when cable repairs were made to the cable which crosses the abyssal plain, the cable was found buried.

Turbidity currents are the predominant mechanism contributing to the mechanical failure of cables in the Gulf of Corinth. The relatively high frequency of failures in the cables lying on the continental slope parallel to its trench, as compared to the virtual absence of failures in the cable laid on the abyssal plain, is of general significance when considering the layout of future cable routes, regardless of whether these routes are in deep fjords or in the deep sea.

PREFACE

Several cable failures have occurred in the past few years in the Alaskan Archipelago. Failures off the Stikine River in the Ratz Harbor to Midway section and those off the Katzehin River in the Midway Point to Skagway section of the first Alaska telephone cable have an interesting counterpart in the cable failures which have occurred in the Grecian Archipelago. The following report on the Gulf of Corinth cable failures should be of particular interest to those engaged in the maintenance or extension of the Alaska cable system.

INTRODUCTION

The Gulf of Corinth is a narrow 470-fathom-deep, 65-mile-long arm of the Mediterranean which separates the Peloponnesus Peninsula from the mainland of Greece (Fig. 1). It is connected with the Ionian Sea on its western end by a narrow one-mile-wide 30-fathom-deep strait. At the eastern end of the gulf an artificial 72-foot-wide and 26-foot-deep canal connects the Gulf of Corinth with the Aegean Sea.

Several sounding surveys were conducted by both the British and Greek hydrographic departments between the years 1840 and 1935. A submarine cable was laid the length of the gulf in 1884. Investigations relative to repairs of this and two later cables have proven valuable in understanding contemporary geologic processes occurring in the gulf (Forster 1890). A study of the cable failure data kindly supplied by Cable and Wireless Ltd. constitutes a major part of this paper. In 1910 the Danish research vessel THOR took a serial hydrographic station in the gulf (Nielson 1912). J. Y. Cousteau's ship CALYPSO ran a sounding line through the gulf and took biological samples in 1955 (Blanc 1958). The research vessel VEMA of the Lamont Geological Observatory conducted a reconnaissance survey from 22-24 July 1956. This survey (Fig. 2) included 350 miles of PDR soundings, total intensity magnetic measurements, 2 hydrographic stations, 3 bathythermograph observations, 2 large-volume water samples for radiocarbon analysis, and 7 piston cores.

Acknowledgments. The preparation of this report was supported by the Bell Telephone Laboratories. The 1956 reconnaissance survey of the Gulf of Corinth by the research vessel VEMA was supported by the Office of Naval Research and the Bureau of Ships, U. S. Navy. The cable failure data was supplied by Cable and Wireless, Ltd.

The reconnaissance survey of the gulf was conducted by Maurice Ewing with the assistance of R. S. Gerard, M. Landisman, C. Hubbard, A. Roberts and M. Talwani. VEMA was under the command of the late Capt. F. S. Usher.

During the preparation of the report the writers were aided by W. S. Broecker, R. Gerard, J. Hirshman, and Marie Tharp. David Ericson advised on the sediments and identified the foraminifera. The radiocarbon measurements were made by W. S. Broecker.

SUBMARINE TOPOGRAPHY

The bathymetric chart of the Gulf of Corinth (Fig. 3) and the physiographic province chart (Fig. 4) are based on the PDR (Precision Depth Recorder) soundings made by R. V. VEMA (Fig. 2), the spot depths shown on the U. S. Navy Hydrographic Office chart number 3963, and soundings by the cable repair ships. The VEMA PDR soundings were corrected to true depths according to the values given by Matthews (1939) [Area 50]. A graph of sound-velocity corrections for echo soundings in Area 50 is shown in Fig. 5. Selected PDR profiles are shown in Plate 1 and indexed in Fig. 6.

The Gulf of Corinth can be roughly divided on the basis of gross geography into: (1) the central basin, (2) the western arm, (3) the eastern arm, and (4) the gulfs of the northern shelf. The entire Gulf of Corinth is about 65 nautical miles long and 10 miles wide. The western arm is about 20 miles long and 5 miles wide; the eastern arm is a separate basin about 13 miles long and 8 miles wide. The two northern gulfs are roughly equilateral triangles with sides of about 6 miles.

Physiographic Provinces

The physiographic provinces delineated in Fig. 4 are based on a study of the morphology represented on the PDR echograms. The division of a small land-locked arm of the sea into provinces similar to the grand division of the major ocean basins may seem unjustified. However, the shelf of the gulf is directly connected with the continental shelf of the Gulf of Patras; the slope descending from the shelf break to the gulf floor greatly resembles the continental slope, and the rise and abyssal plain of the gulf floor also resemble ocean features. Although

Fig. 1 Geographical location of the Gulf of Corinth, index map.

Fig. 2 Track of R. V. VEMA in the Gulf of Corinth, 22 to 24 July 1956.

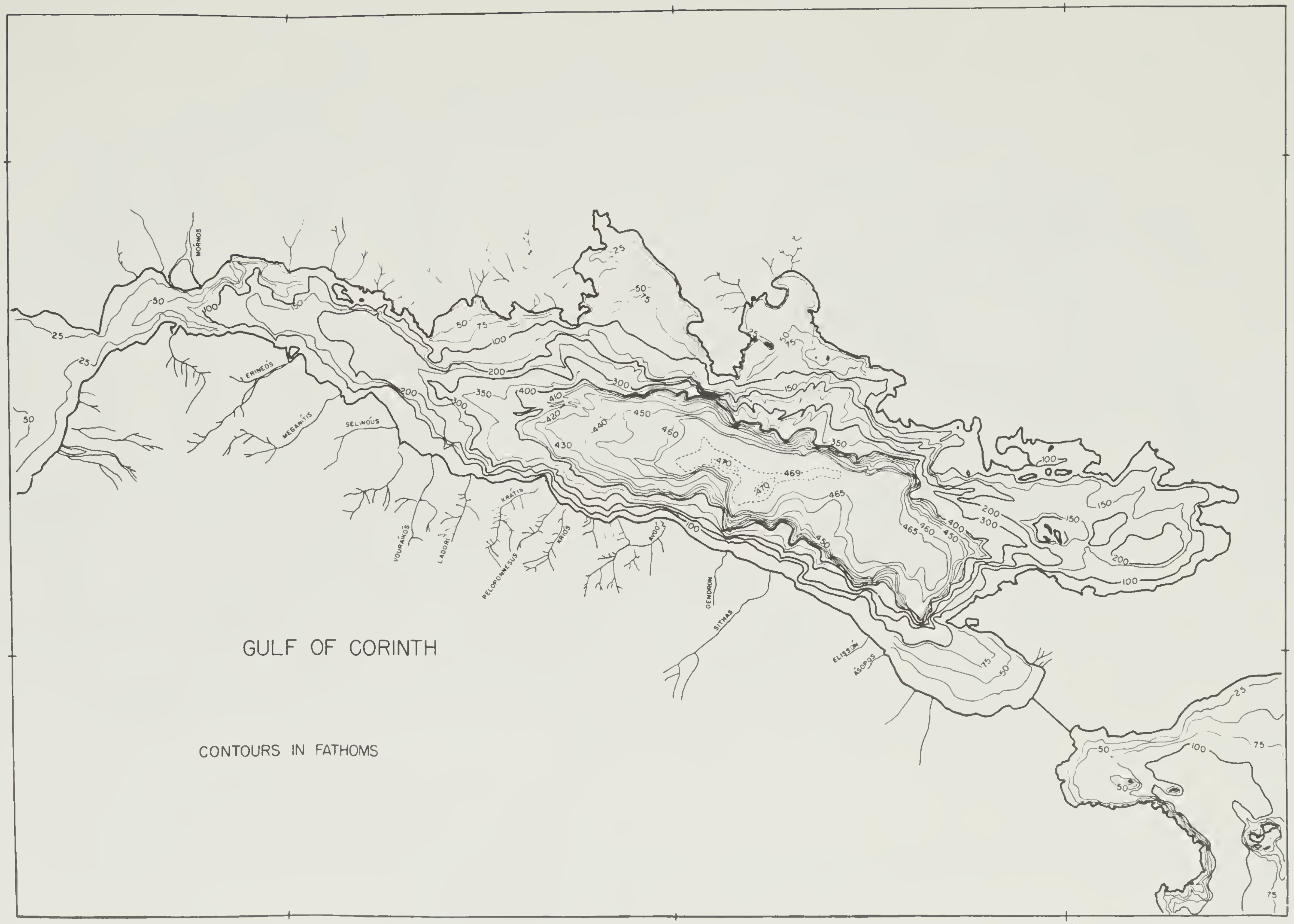


Fig. 3 Bathymetric chart of the Gulf of Corinth.

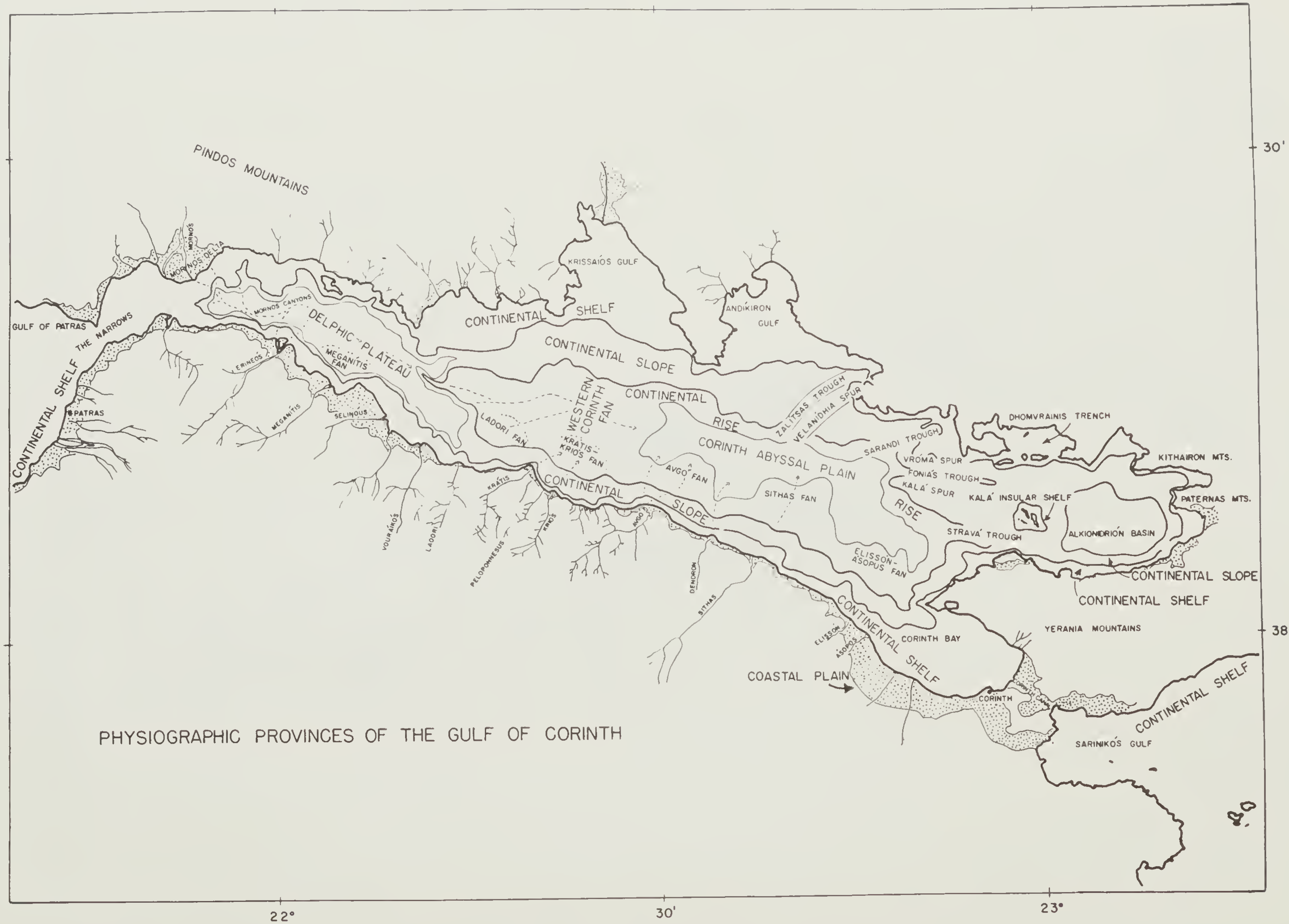


Fig. 4 Physiographic provinces of the Gulf of Corinth.

Plate 1 Selected PDR profiles in the Gulf of Corinth. Their geographical location is shown on Fig. 6. Depths are in nominal echo sounding fathoms (800 fm/sec).

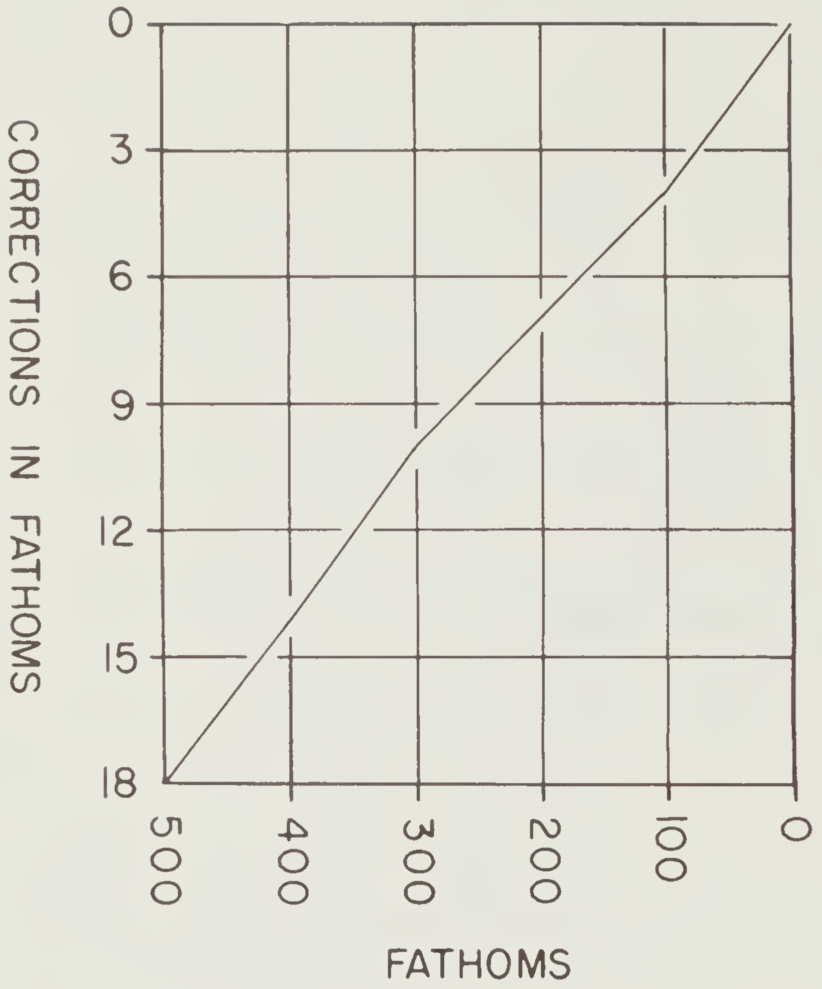


Fig. 5 Echo sounding corrections for the Gulf of Corinth. Add correction to uncorrected echo sounding to obtain the depth. Curve is based on Matthews (1939) for area 50 and is for use only where assumed sounding velocity is 800 fathoms/second.

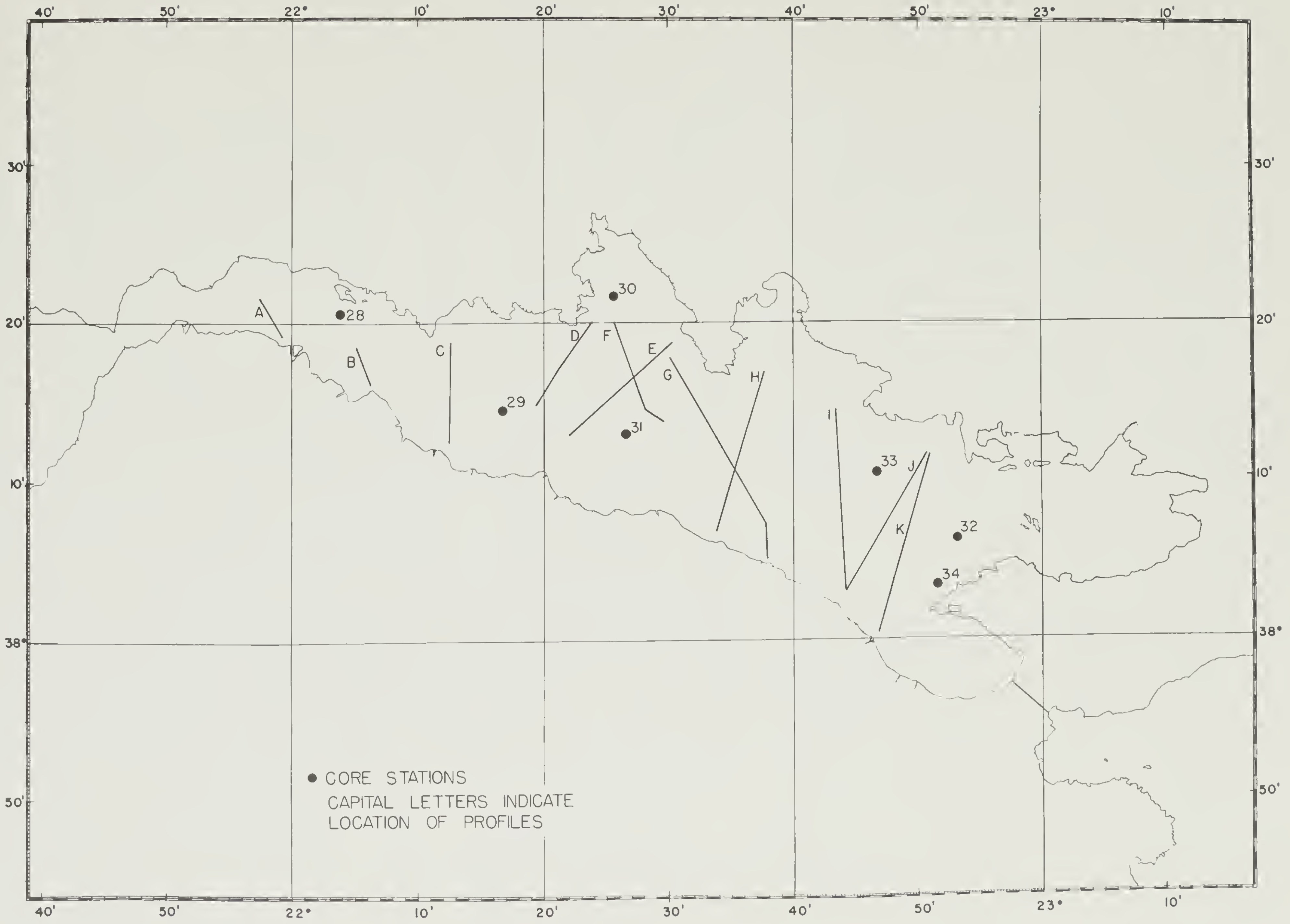


Fig. 6 Location of PDR profiles and sediment cores.
PDR profiles reproduced in Plate 1.

minute in scale when compared to the grand features of the major ocean basins, these features do greatly resemble their ocean counterparts in form and in probable origin. Thus, with some reservations, we propose a three-fold division of the gulf into continental shelf, continental slope and gulf floor.

Continental Shelf. The continental shelf of the Gulf of Corinth is generally a poorly developed feature less than a mile wide. In the center third of the gulf, along the southern shore, the shelf rarely exceeds 1/4 mile in width and comprises but a mere notch in the larger mountain slopes which drop from mountain crests over 2300 meters high to depths of over 800 meters on the gulf floor. Along the northern side of the gulf the shelf reaches its maximum development in the Gulfs of Krissaiós and Andikiron. The shelf break lies 6 miles off shore in the northern gulfs and in the Bay of Corinth. The continental shelf of the Ionian Sea extends through the narrows to the vicinity of the Mórnos Delta in the western arm of the gulf.

The shelf break ranges in depth from 15 to 120 fathoms. In general, the narrower the shelf, the shallower the shelf break. Thus the shallowest shelf break is found along the southern shore and the deepest (120 fathoms) seaward of the northern gulfs. Shelf terraces are represented in Figs. 7 and 9 (the profiles are indexed in Figs. 8 and 10). The most prominent terraces are at 19 fathoms, 23-25 fathoms, 40-41 fathoms, 42-43 fathoms and 45-47 fathoms. The capes of Vróma Island and Kalá Island are carried beneath the gulf by the subsea spurs of the same name (Figs. 4 and 11).

The weak development of the continental shelf is certainly a good indication of the gulf's comparative youth.

Continental Slope. There is a strong contrast in the form of the northern and southern continental slopes of the central basin. The southern slope is steep and straight, devoid of major benches or breaks in slope (Figs. 4 and 12-18). In contrast, the northern slope is broken by several major benches and is complexly dissected. The declinity of the southern slope ranges from 12° to 18°. The declinity on the northern slope, in contrast, varies from 5° to 15°. The western arm of the gulf is floored by a 200-fathom plateau which extends eastward as two benches along the northern and southern continental slopes of the central basin. These benches virtually disappear east of 22° 25'E. Below these benches the continental slope (or marginal escarpment) continues to the gulf floor. The eastern arm is floored by a 200-fathom Alkionidrión Basin and is separated from the central basin by a 150-fathom sill near the Kalá Islands.

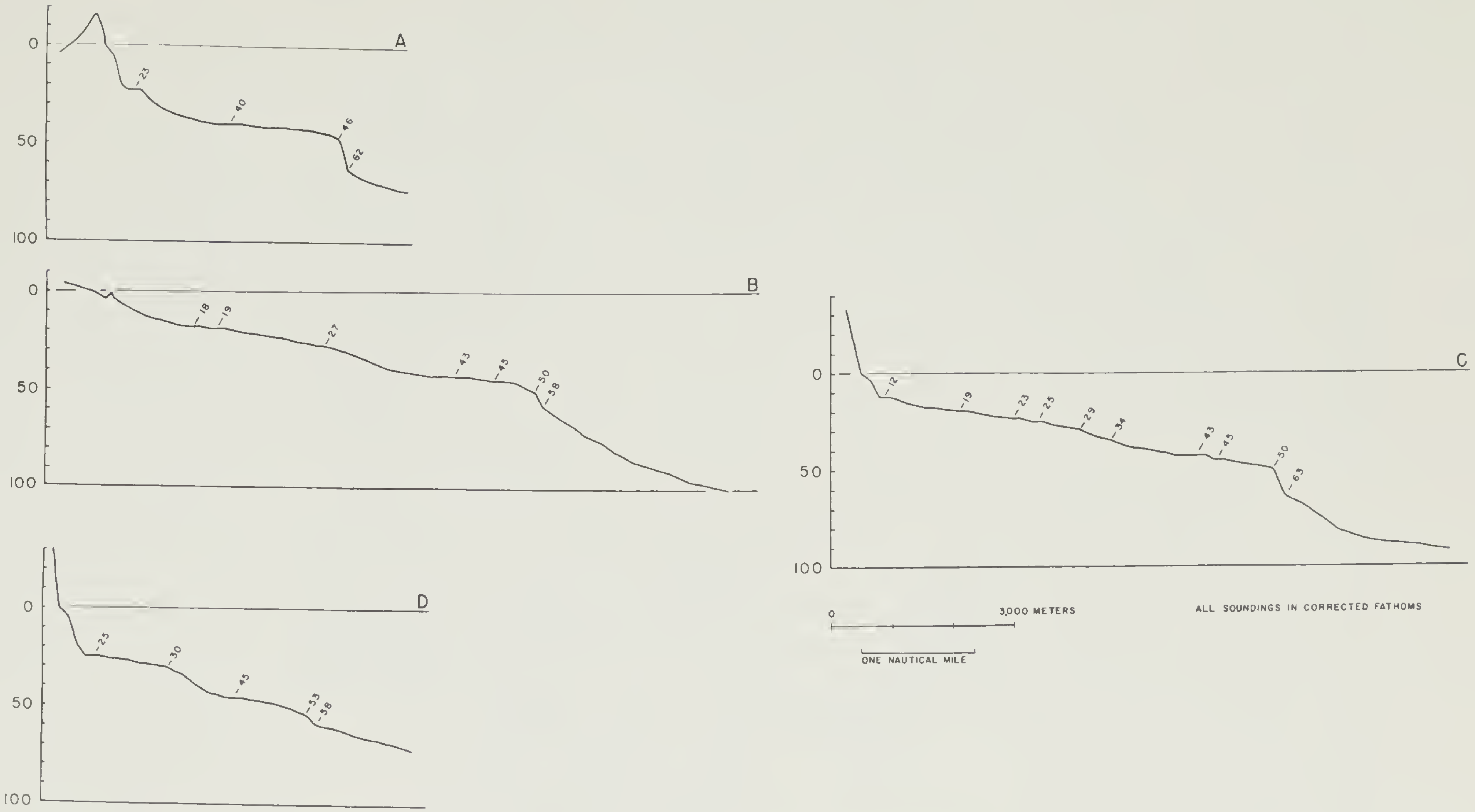


Fig. 7 Profiles in the Gulf of Krissaiós.

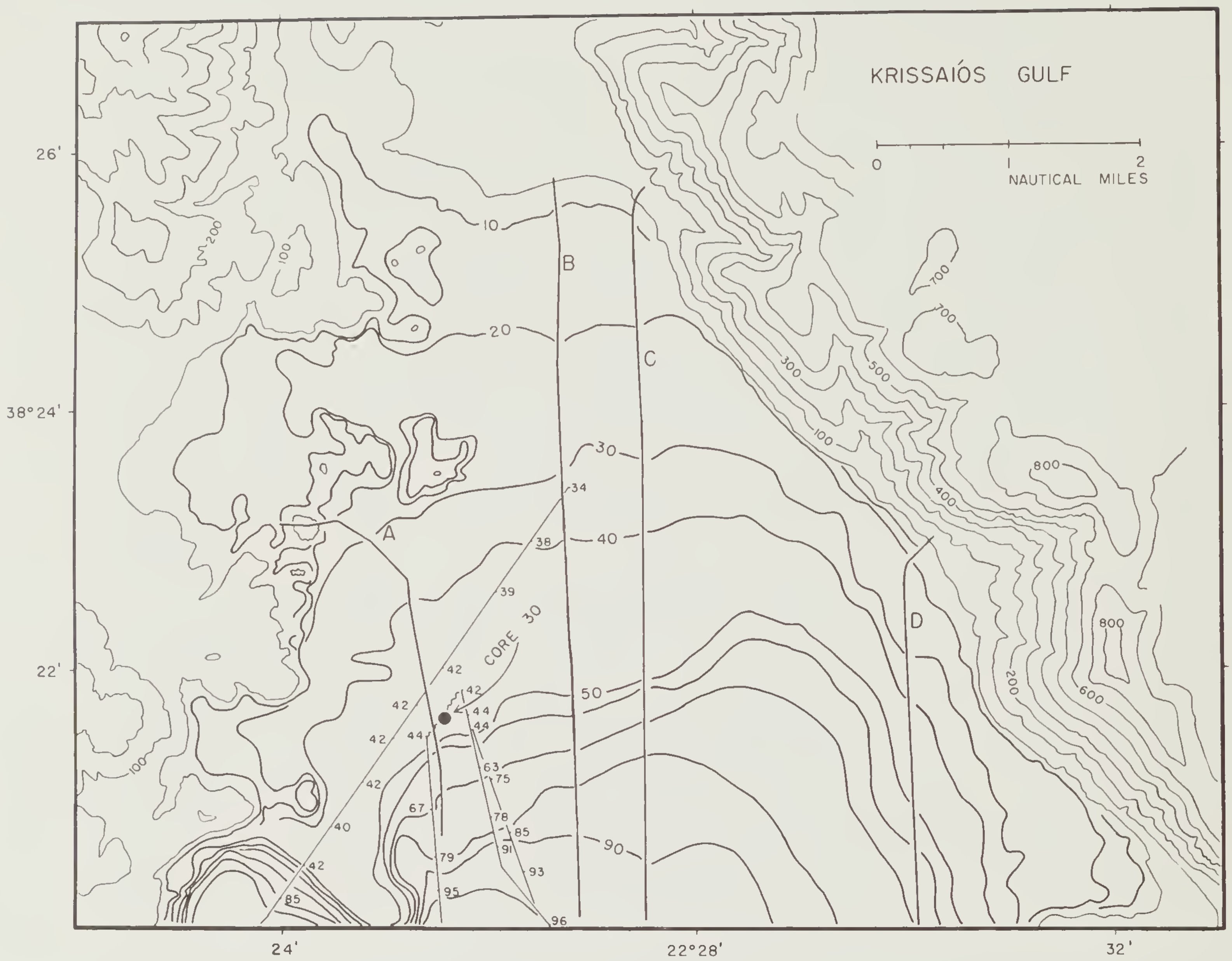


Fig. 8 Bathymetric sketch of the Krissaiós Gulf.
Krissaiós Gulf after U. S. Hydrographic Office Chart 4092.
Profiles A, B, C and D shown in Fig. 7. Contour interval
20 meters (10. 9 fathoms) on land, and 10 fathoms in
Krissaiós Gulf.

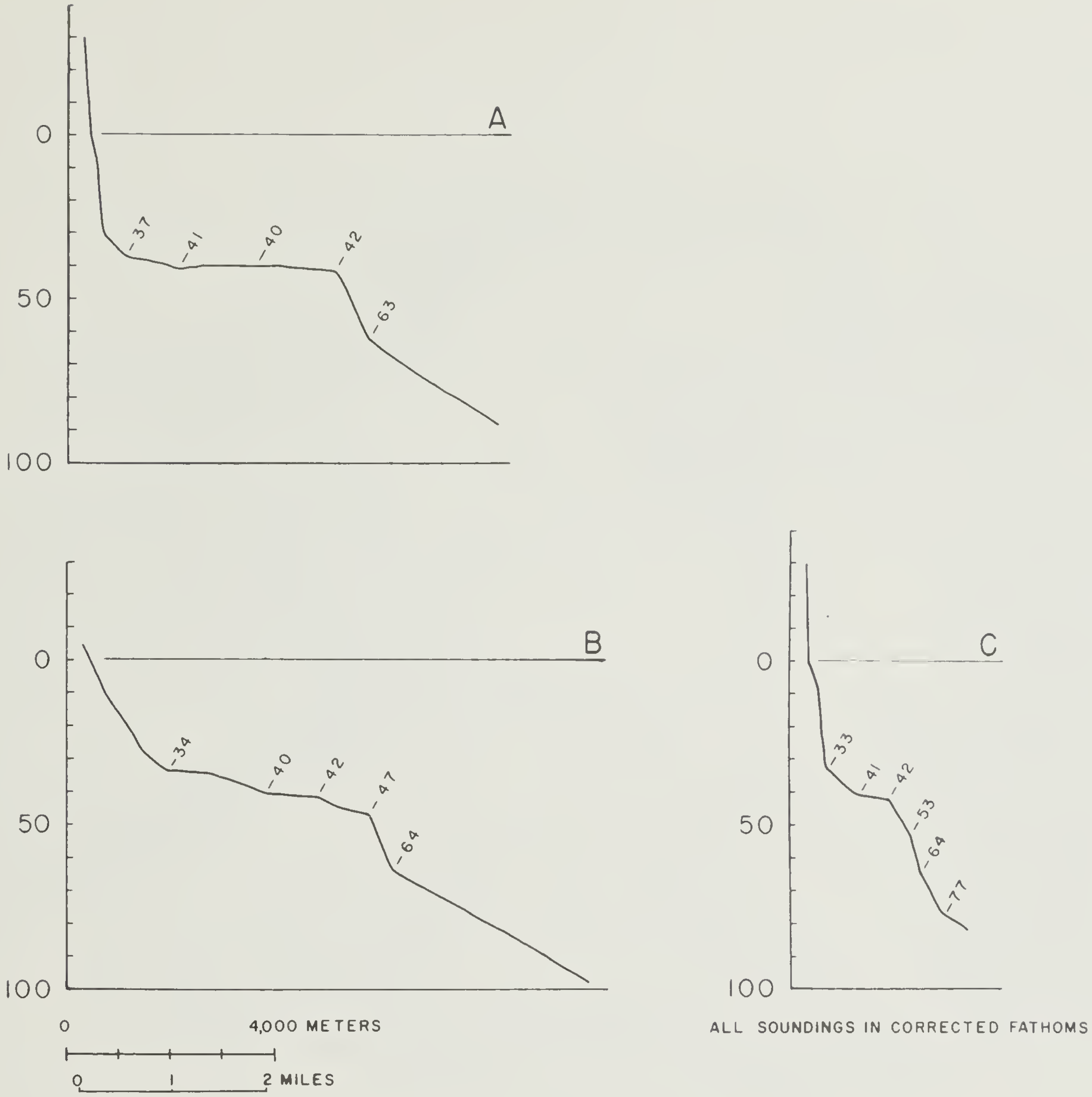


Fig. 9 Profiles in the Gulf of Andíkiron.

Fig. 10 Bathymetric sketch of the Andíkiron Gulf.
Andíkiron Gulf after U. S. Hydrographic Office Chart 4092.
Profiles A, B and C are shown in Fig. 9. Contour interval
20 meters (10.9 fathoms) on land, and 10 fathoms in
Andíkiron Gulf.

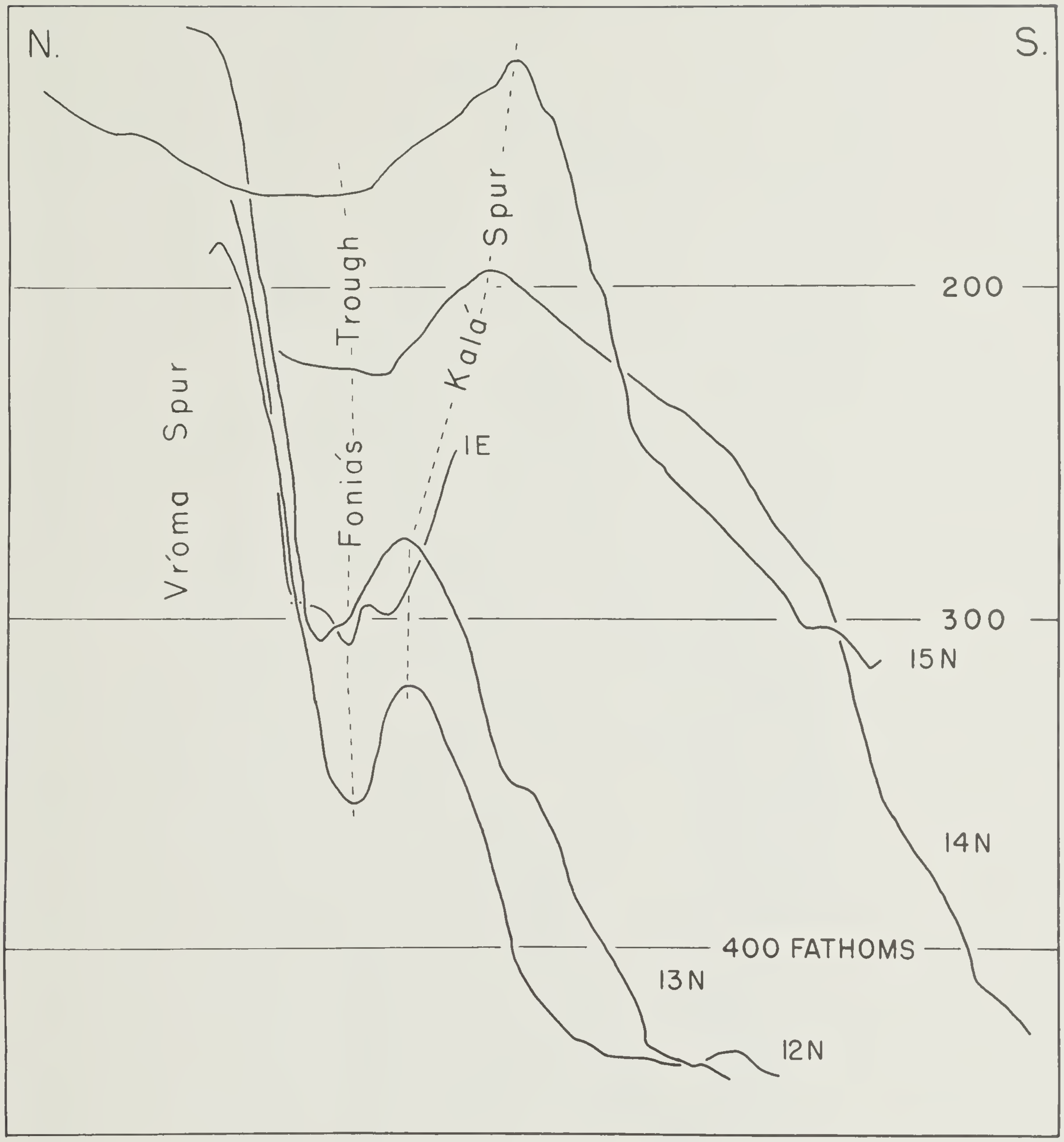


Fig. 11 Vróma Spur, Foniás Trough and Kalá Spur.
Profiles are tracings of PDR profiles indexed on Fig. 12.
Depths are in nominal echo sounding fathoms (800 fm/sec).

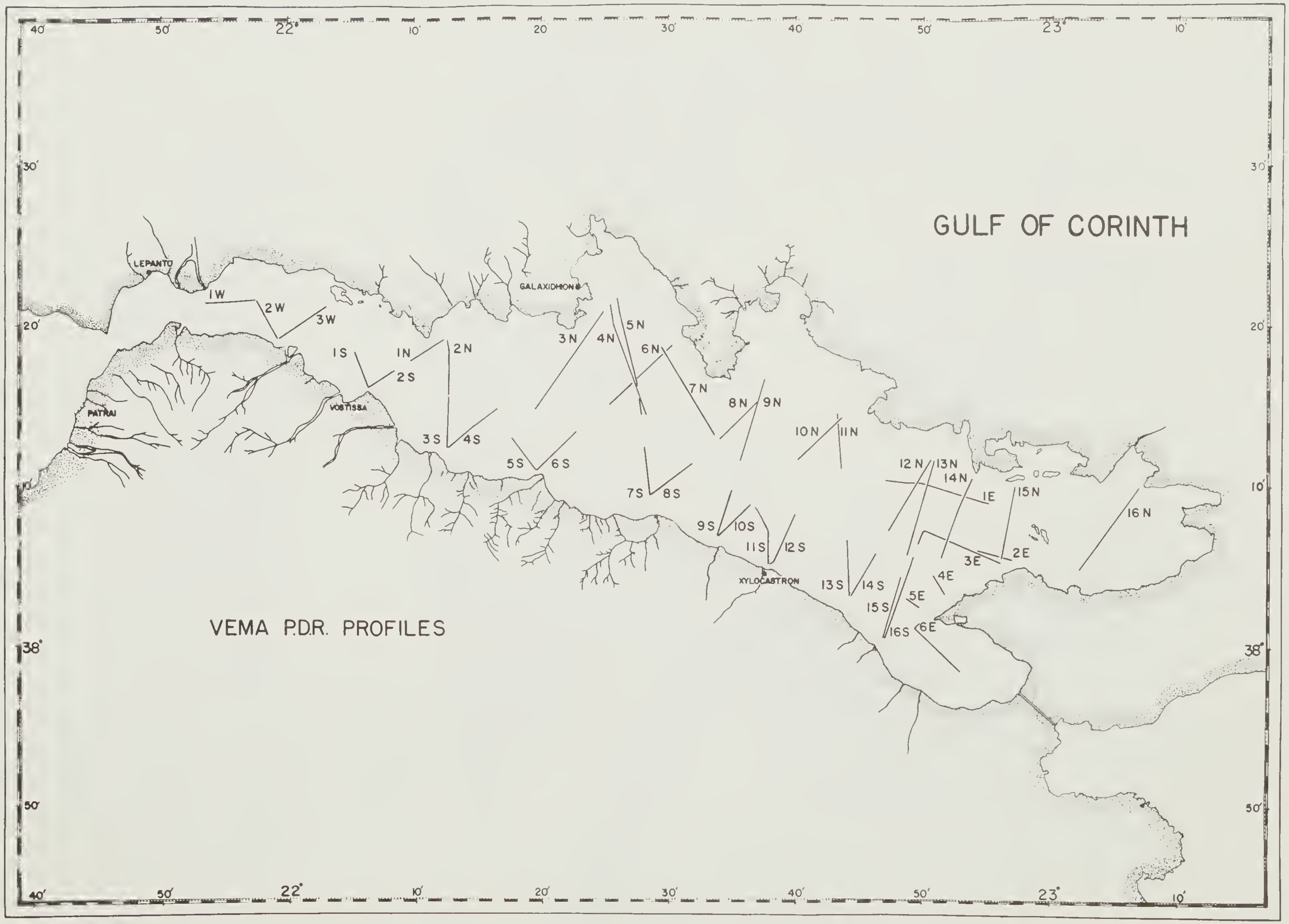


Fig. 12 Index chart for PDR tracings shown in Figs. 13-18.

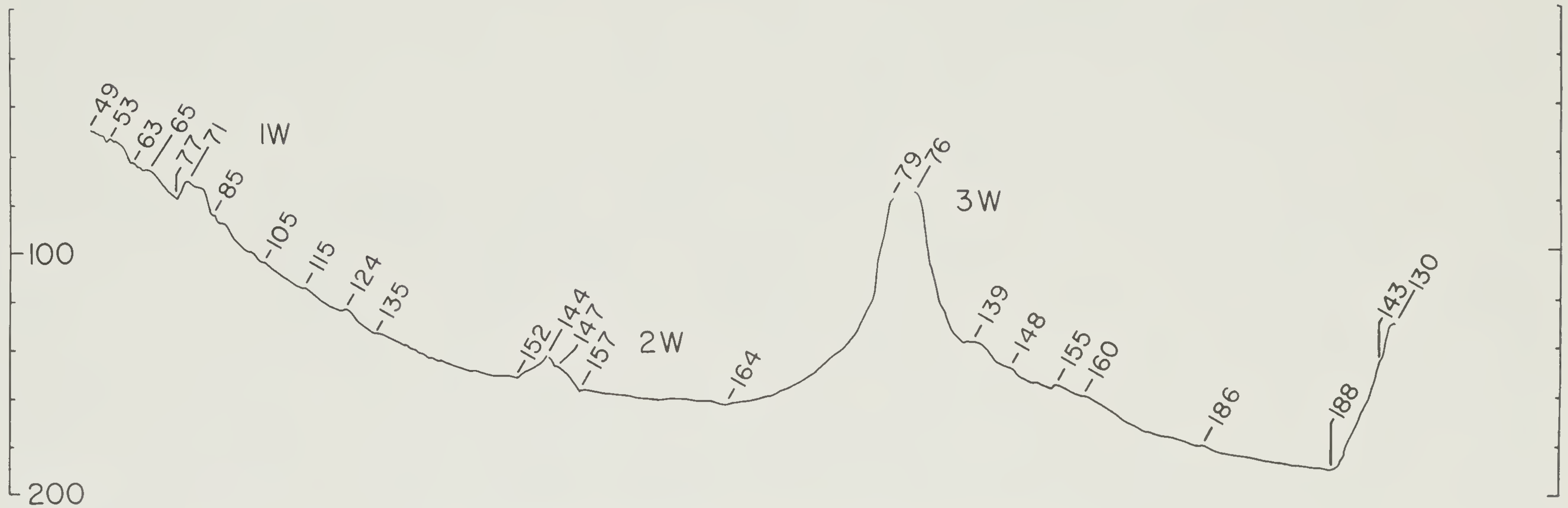


Fig. 13 PDR profiles of the western continental slope of the Gulf of Corinth. Profiles are tracings of PDR records. Their geographical location is shown on Fig. 12. Depths are in nominal echo sounding fathoms (800 fm/sec).

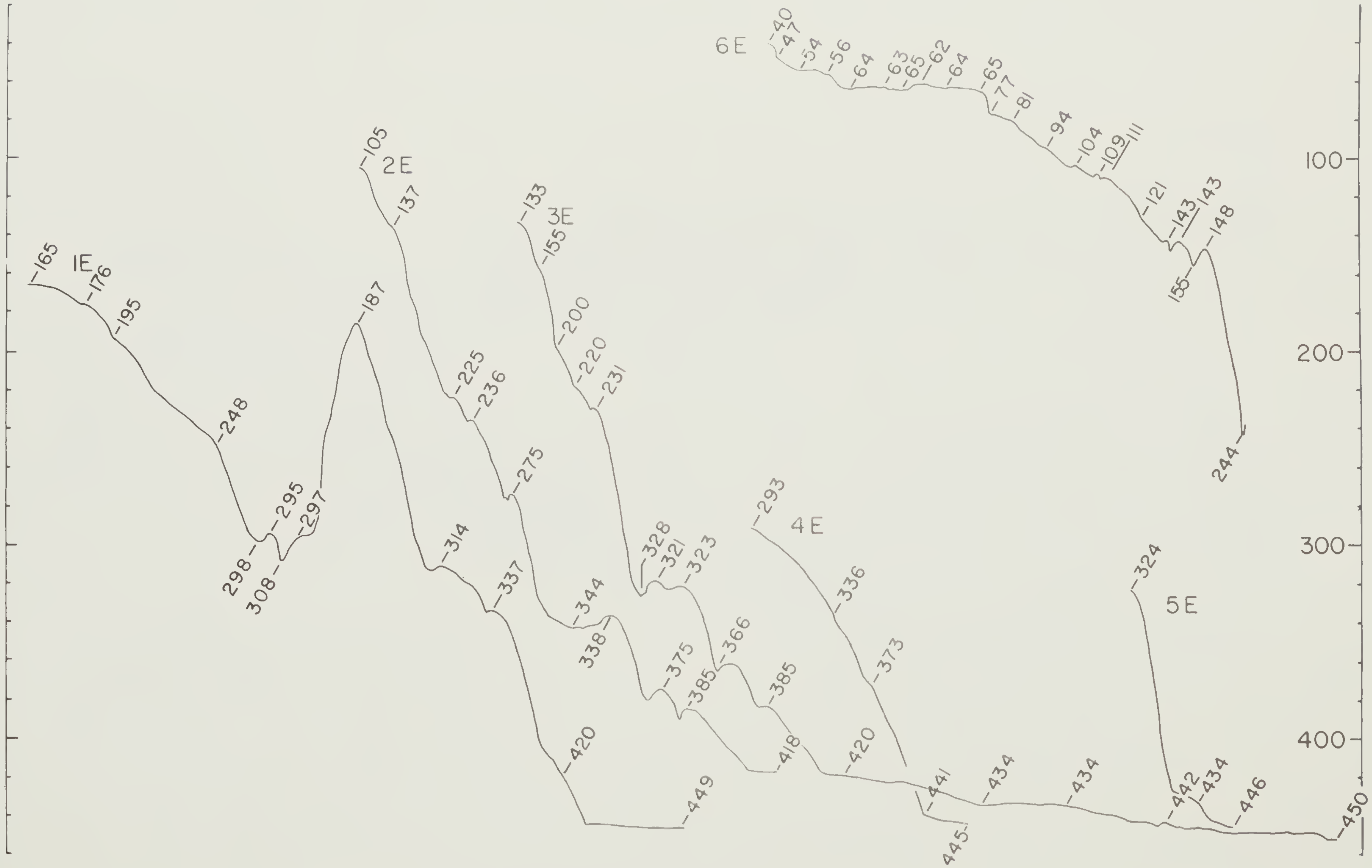


Fig. 14 PDR profiles of the eastern continental slope of the Gulf of Corinth. Profiles are tracings of PDR profiles. Their geographical location is shown on Fig. 12. Depths are in nominal echo sounding fathoms (800 fm/sec).

Fig. 15 PDR profiles of the southern continental slope of the Gulf of Corinth. Profiles are tracings of PDR profiles. Their geographical location is shown on Fig. 12. Depths are in nominal echo sounding fathoms (800 fm/sec).

Fig. 16 PDR profiles of the southern continental slope of the Gulf of Corinth. Profiles are tracings of PDR profiles. Their geographical location is shown on Fig. 12. Depths are in nominal echo sounding fathoms (800 fm/sec).

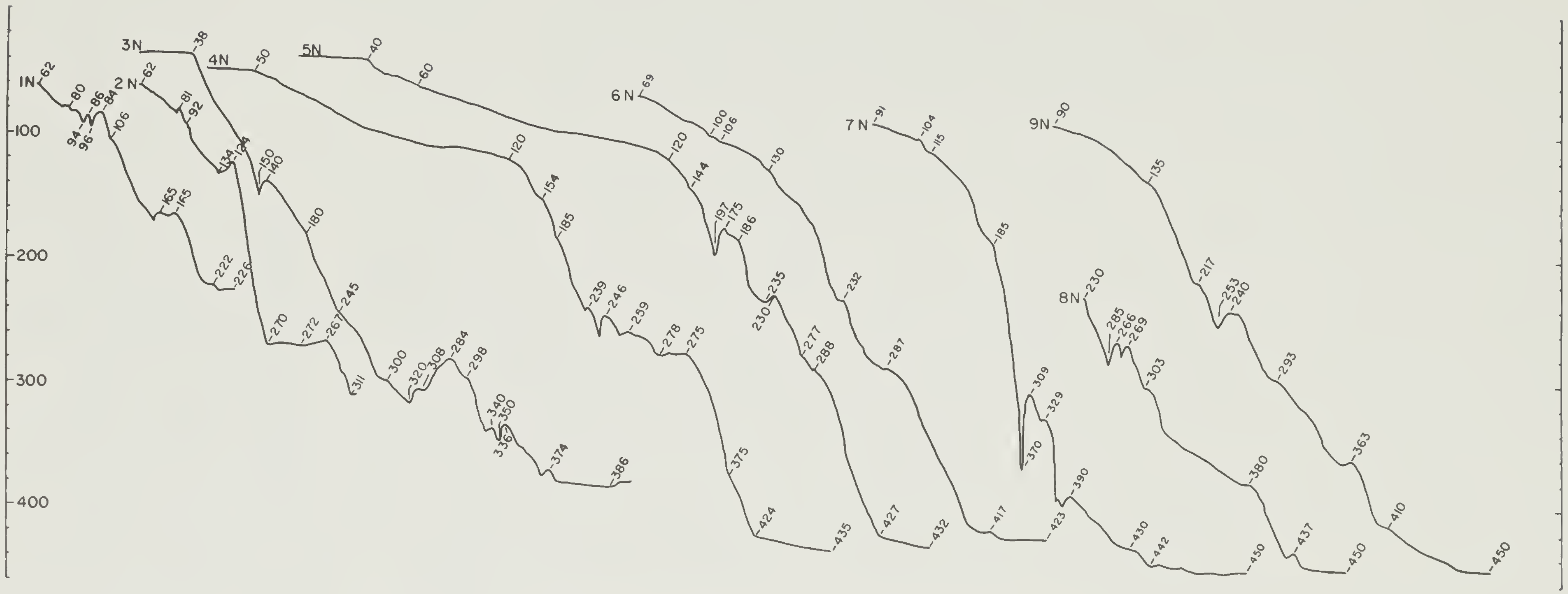


Fig. 17 PDR profiles of the northern continental slope of the Gulf of Corinth. Profiles are tracings of PDR profiles. Their geographical location is shown on Fig. 12. Depths are in nominal echo sounding fathoms (800 fm/sec).

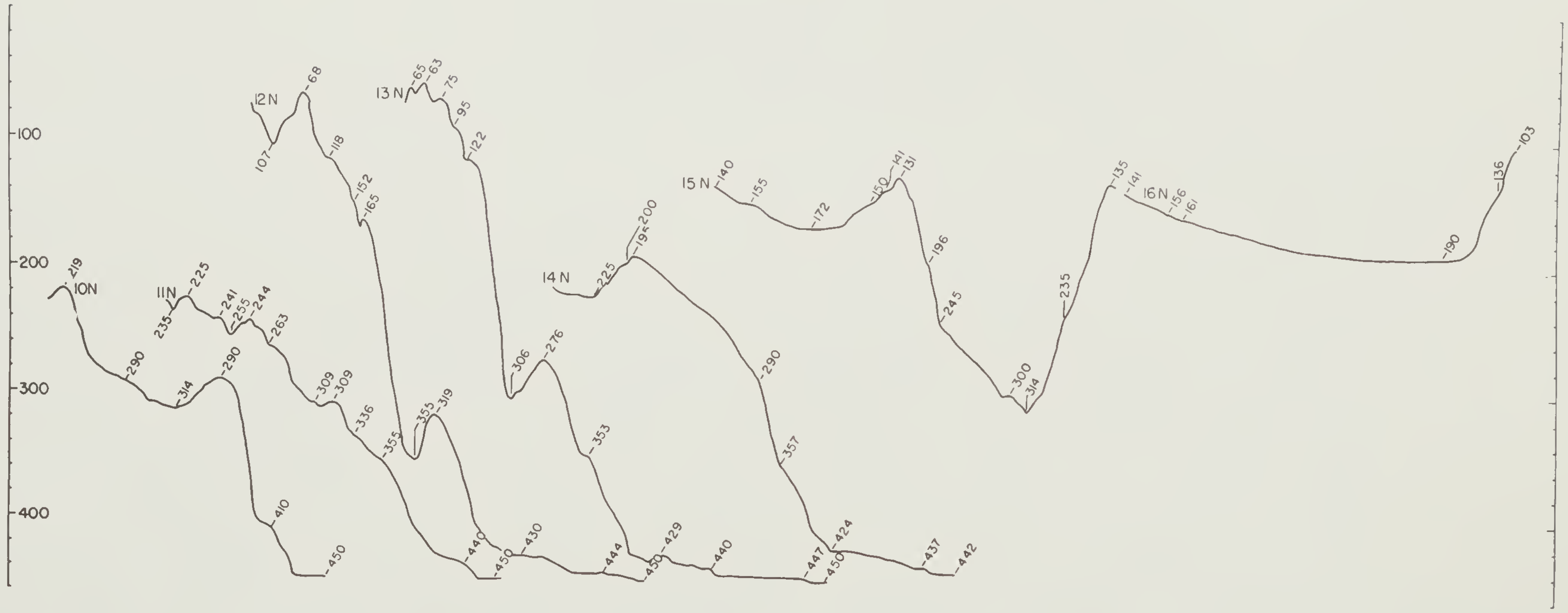


Fig. 18 PDR profiles of the northern continental slope of the Gulf of Corinth. Profiles are tracings of PDR profiles. Their geographical location is shown on Fig. 12. Depths are in nominal echo sounding fathoms (800 fm/sec).

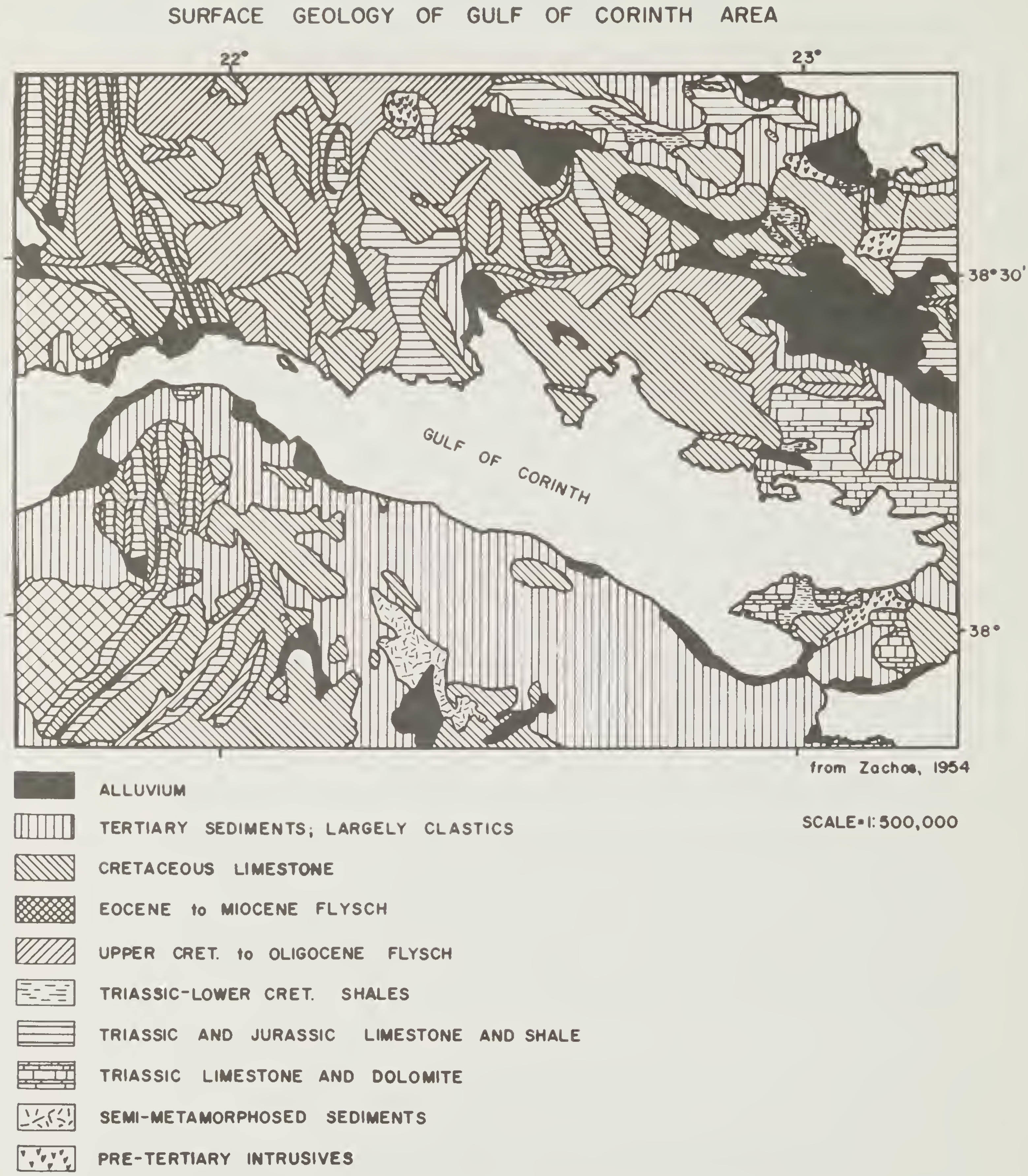
The southern continental slope is slightly indented by submarine canyons seaward of each of the major streams. The northern slope is, in contrast, dominated by small-scale tectonic relief related to the extension of the east-west faults of the mainland westward into the gulf. However, some of the dissection of the northern slope may be related to submarine canyons. The major troughs and spurs of the northern continental slope are indicated and named on the physiographic province map (Figs. 4 and 11).

Gulf Floor. The gulf floor is divided into two major provinces: (1) the rise, and (2) the Corinth Abyssal Plain. On the south the rise is dominated by the subsea fans of the major submarine canyons. On the north side the rise is narrower and of more uniform width. On the west end of the central basin the large Western Corinth Fan stretches out from the mouth of the Mórnos Canyon, which leads from the Delphic Plateau to the Corinth Abyssal Plain. The rise generally ranges from 1:35 to 1:17 in gradient, which is steeper than the normal continental rise. The rise has its greatest width about 3 miles in the region of the fans which spread out from the mouths of the submarine canyons of the southern streams. Along the base of the north slope it maintains a width of about 1 mile through the length of the central basin.

Corinth Abyssal Plain. The center of the central basin of the Gulf of Corinth is occupied by the Corinth Abyssal Plain. An abyssal plain is a broad flat area of the deepest portion of an ocean basin where the gradient of the bottom does not exceed 1:1000. The gradients of the Corinth Abyssal Plain range from about 1:1250 to 1:3000. The plain, about 2-3/4 miles wide and 27 miles long, ranges in depth from 465 to 470 fathoms. The general character of the plain is well illustrated by the profiles in Plate 1. In the western arm of the gulf an area of near-abyssal-plain flatness forms a "perched plain" on the Delphic Plateau. In the eastern arm the small Alkionidrión Basin may contain an abyssal plain about 3-1/2 miles in diameter.

REGIONAL GEOLOGY

A portion of the 1954 Geological Map of Greece (Zachos 1954) is reproduced in Fig. 19. The Pindos Mountains, which are part of the Alpine belt, form the backbone of Greece. The Pindos are composed of a hard core of granites and serpentines flanked with Cretaceous limestones.



from Zachos, 1954

Fig. 19 Regional surface geology of the Gulf of Corinth area. Based on "Geologic Map of Greece" by the Institute for Geology and Subsurface Research, Athens, 1954.

Geologists who have studied Greece believe that the folding of the Pindos began in the late Cretaceous and continued into the Miocene (Renz 1955; Brunn 1956). After the folding, they believe that the topography of Greece was greatly altered by rifting and subsidence. The steep slopes of the Gulf of Corinth suggest that the gulf originated through normal faulting. Since the Pindos range at The Narrows is not displaced either to the east or to the west, the faulting seems to have been dominantly vertical. The Gulf of Corinth is generally believed to represent an asymmetrical graben. Several other asymmetrical grabens cut across the Pindos (Brunn 1956) but are not as deep as the Gulf of Corinth. In each case the southern scarp is much steeper than the northern side.

Geomagnetic Profiles

A continuously recording total-intensity fluxgate magnetometer was towed behind the R. V. VEMA during the reconnaissance survey of the Gulf of Corinth. Three typical profiles across the Gulf of Corinth reproduced in Fig. 20 show a general lack of large magnetic anomalies. This general lack of magnetic anomalies over the steep slopes of the gulf is surprising. However, this is not the first example of apparent large faults failing to produce significant anomalies (Miller and Ewing 1956) (Davidson and Miller 1955).

Seismicity

The most severe recent earthquakes in the Gulf of Corinth area are listed in Table I. In addition, light quakes are common in the area. The distribution of epicenters in central Greece shows an alignment along the Gulf of Corinth. This alignment suggests that the major faults which bound the Gulf of Corinth are still active.

The seven cable failures in the gulf cables which occurred during or after earthquakes, were probably caused by slumps or turbidity currents triggered by the earthquake shock (Heezen and Ewing 1952, 1954).

TABLE I

Year	Day	Mo.	Time	Location	Mag.	Remarks	Source
1858	-	-	-	-	-	Town of Corinth completely destroyed	Encyclop. Brit.
1861	-	-	-	-	-	Town of Vostissa destroyed	Forster (1890)
1888	9	Sept.	1704	-	-	Nearly destroyed Vostissa and adjacent villages	Forster (1890)
1889	25	Aug.	2051	-	-	Xylokaston badly damaged	Forster (1890)
1902	9	Oct.	-	-	-	Strong quake felt at Patras	Ship's log
1909	30	May	-	-	-	Strong shock felt at Patras	Malladra (1925)
1909	28	Aug.	-	-	-	Seismic disturbance recorded	Malladra (1925)
1914	17	Oct.	-	38. 25N 23. 50E	6		Gutenberg and Richter (1954)
1918	30	Oct.	-	-	-	Seismic distrubance recorded	Malladra (1925)
1925	6	July	-	38. 25N 21. 75E	6. 5		Gutenberg and Richter (1954)
1928	25	Apr.	0-31-18	38. 00N 23. 20E	-		I. S. S.
1928	29	Apr.	9-49-12	38. 00N 23. 20E			I. S. S.
1928	20	July	18-29-45	38. 00N 23. 20E			I. S. S.

TABLE I (Cont'd.)

Year	Day	Mo.	Time	Location	Mag.	Remarks	Source
1931	4	Jan.	0-0-50	38. 00N 23. 20E		Corinth Area	I. S. S.
1938	18	Sept.	-	38. 00N 22. 50E	6. 5		Gutenberg and Richter (1954)
1953	5	Sept.	14-18-41	38. 00N 23. 00E		Corinth canal closed by caved-in earth	U. S. C. G. S.
1956	15	May	22-56-55	38. 00N 22. 00E			U. S. C. G. S.
1957	9	Nov.	23-55-50	38. 50N 22. 00E		Felt at Amphissa	U. S. C. G. S.
1958	23	Oct.	06-41-58			Felt at Arcadia Argolide-Gehie	U. S. C. G. S.
1958	15	Nov.	05-42-42	38. 00N 22. 50E			U. S. C. G. S.
1959	29	Mar.	23-07-16			Felt at Corinth and Athens	U. S. C. G. S.

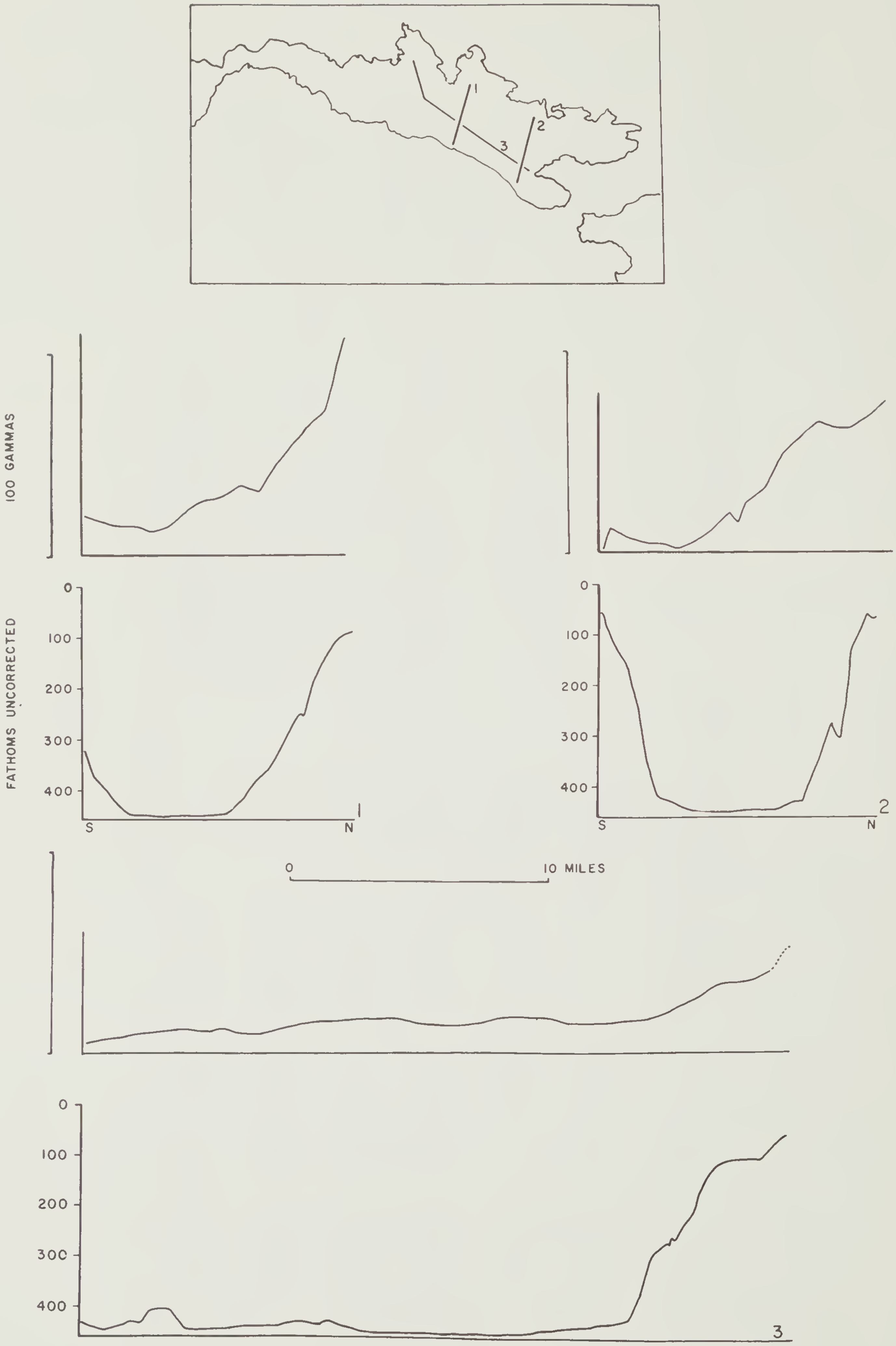


Fig. 20 Three geomagnetic profiles in the Gulf of Corinth with associated topographic profiles and index.

SEDIMENTS

Seven piston cores were obtained in the Gulf of Corinth with a 1200-pound Lamont Geological Observatory piston corer (Heezen 1953). The pertinent geographical data for the seven stations is listed in Table II. The positions of the cores are indicated in Fig. 6 and their lithologies are indicated in graphic form in Fig. 21.

Sediment Distribution and Physiographic Provinces

Continental Shelf. Bottom notations, although scarce on H. O. charts 3963 and 4092, indicate sand, mud, shell sand, and stones on the continental shelf. Such variety is characteristic of shelves throughout the world. Core V-10-30 was the only core taken by VEMA from the Gulf of Corinth continental shelf. This core, taken from the 44-fathom terrace in the center of the Krissaiós Gulf, consisted mainly of a firm white, highly-calcareous lutite throughout its length of 898 cm. Several sand pockets are found in the first 25 cm., a single one occurs at 147 cm. and one sandy silt layer occurs at 378-386 cm.

Continental Slope. Chart notations on H. O. 3963 record stones, mud, sand and rock from the continental slope. Two piston cores were obtained from the continental slope. Core V-10-34, obtained in 219 fathoms, one mile northwest of Yerania Peninsula, consists of light brown silty lutite. Pebbles of 2 cm. diameter occur near the top and bottom. The bottom 78 cm. is disturbed in a manner which suggests slumping. The shortness of the core (2. 4 m) implies that a firmer stratum was reached which limited penetration.

Core V-10-29 was obtained from near the base of the continental slope in 391 fathoms, 4-3/4 miles seaward of the Vouráikós River. It consists of a 20 cm. layer of brown silty lutite over a 6 cm. bed of gravel, which in turn overlies a 97 cm. varved sequence which extends to the base of the core.

The steepness of the slopes, the shortness of the cores and the frequent notations of rock and stones on the nautical chart support the conclusion that most of the sediment deposited on the slope is removed by gravity slides and turbidity currents. The varved sequence of core V-10-29 is certainly pre-Recent in age.

TABLE II

Sediment Cores

Core	Lat.	Long.	Depth in corr. fms	Length in cms.	Physiographic Province	Brief Description
28	38^{o}20'40"N	22^{o}03'55"E	207	612	Delphic Plateau	Alternately silt, sand and lutite
29	38^{o}15'N	22^{o}15'30"E	391	118	Slope (southwest)	Lutite over gravel over varved lutite
30	28^{o}21'40"	22^{o}25'35"E	44	895	Shelf - Gulf of Krissaiós	Firm white lutite
31	38^{o}13'N	22^{o}26'30"E	449	488	Western Corinth Fan	Thick sands, silt and lutite
32	38^{o}06'20"N	22^{o}53'45"E	436	423	Rise (southeast)	Light brown silty lutite. Slump contortions
33	38^{o}10'30"N	22^{o}46'15"E	468	483	Corinth A. P. (northeast)	Light brown silty lutite with thin sand and silt beds; some slump contortions
34	39^{o}02'N	22^{o}51'45"E	219	241	Slope (southeast)	Light brown silty lutite. Pebbles near top and bottom; slump contortions

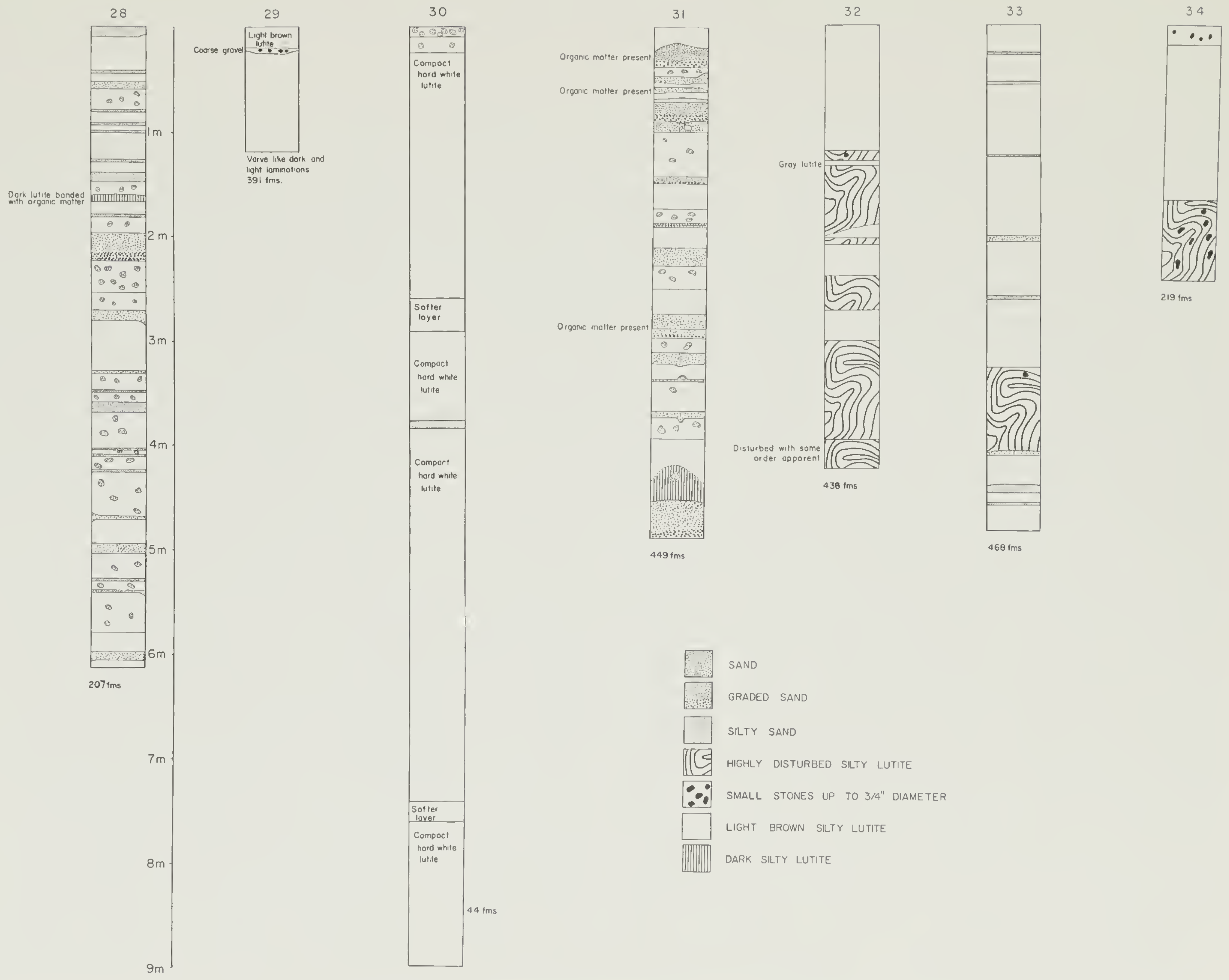


Fig. 21 Graphic logs of core lithology.
Lithology of all cores taken by R. V. VEMA 22 to 24 July 1956.

Gulf Floor. The sparse chart notations on H. O. 3963 record mud and, on two occasions, sand from the gulf floor. Four cores were obtained from the gulf floor. Core V-10-32 from the rise, 3 miles north of the continental slope, consists of 188 cm. of light brown silty lutite with one thin layer of greyish lutite. Six disturbed zones suggest that slumping from the adjacent continental slope had redeposited some of the sediments. The absence of course detrital sediments or graded beds suggests that turbidity currents were not involved. One small rounded piece of limestone about 3 cm. in diameter was found at the top of the core.

Core V-10-28, obtained from a depth of 207 fathoms on the Perched Plain of the western arm of the gulf near the Mórnos Delta, consists of sand and silt interbedded with light brown silty lutite. Grading is apparent in several beds. Pockets of sand and silt occur sporadically in the lutite. The silts and sands are certainly deposits of turbidity currents.

East of the Perched Plain a submarine canyon or trench leads to the Western Corinth Fan. Core V-10-31 taken on the Western Corinth Fan contains the thickest and coarsest sands found in any of the cores from the gulf. Nearly half the core consists of sand. The beds are consistently and obviously graded. In addition to these, there are several silt layers with sand pockets and sand layers with silt pockets. In three of the sandy layers there are bits of vegetable matter up to 0. 5 mm in diameter.

Corinth Abyssal Plain. The only core raised from the Corinth Abyssal Plain is V-10-33, obtained in 468 fathoms at the extreme northeast edge of the plain. Since the predominant source of clastics seems to be from the south and west, it is not too surprising that the sands and silts are thin and make up less than 10% of the core. The thickest of the beds of coarse sediment measures 8 cm. Much of the lutite in this core may have been deposited by arrested turbidity currents which had deposited their coarser loads nearer shore. A slump-contorted zone in this core between 325 and 407 cm. depth may have resulted from the same disturbance represented in cores V-10-32 and V-10-34. The later cores were only about 7 miles to the southeast of Core V-10-33.

Distribution of Recent Sediments. Discussion. The pattern of sediment distribution correlates well with the form of the submarine relief. Unconsolidated sediments are thin on the continental slope. Those unconsolidated sediments present are disturbed, and older sediments are reached when even slightly greater penetration is achieved. Similar results have been obtained in continental slopes throughout the world (Heezen et al, 1959).

The rise appears to represent an accumulation of slump and turbidity current deposits at the base of the continental slope. The possibility that the northern and northeastern portions of the rise were built up by slumping alone rather than deposition by turbidity currents, is supported by core V-10-33, which, while containing no silts or sands, displays slump-contorted lutites.

The somewhat speculative topographic identification in the west part of the central basin of a depositional fan (Western Corinth Fan) is supported by the thick graded sands found in Core V-10-31. Similar thick beds found in Core V-10-28 at least suggest that the Perched Plain as well as the Western Corinth Fan are fed from the west with significant contributions from the Mórnos River.

The abyssal plain core (V-10-33) supports the concept of a turbidity-current origin of this physiographic feature. The thinness of the beds in this core tentatively suggests a southwest or western source. This in turn also suggests a dominantly nonturbidity-current origin of the northern rise. Although no cores were obtained from the fans along the south side of the gulf, cable repair work, to be described in a later section of this paper, supports the dominantly turbidity-current origin of these features.

Probable Pre-Recent Sediments. One of the most interesting cores is V-10-29 from the continental slope north of Vouraikos River. The top 20 cm. is composed of silty lutite containing a fairly rich marine assemblage. Beneath is a 6 cm. layer of coarse, moderately rounded gravel up to 1 cm. in diameter. The remainder of the core consists of varve-like layers mostly 30 to 900 cm. in thickness. Foraminifera are rare and may represent reworking, since several of them are identifiable as pre-Pleistocene. Ostracods are common. Dr. L. Kornicker, who examined the Ostracods from this core, reported (personal communication) that the sample from 40 cm. depth:

> "... produced about 11 shells belonging to 6 species. All ostracods present are of benthonic types. The thin shells of these ostracods, the dominance of smooth shelled forms over ornamented forms, the lack of intricate dentition on the shells suggest fresh water environment. The assemblage does not contain species restricted to marine waters nor does it resemble a random sample of ostracods from the marine environment. This leads me to believe the ostracods in the sample are from fresh, possible brackish (very low salinity, less than say 14o/oo) water. A brief survey of fresh water literature on hand led to tentative recognition of at least one species as a form restricted to fresh or brackish water. The high diversity of specimens (6 species in 11 specimens) indicates a large body of water, but I cannot estimate depth from this sample."

The varves vary in thickness from 5 to 4090 microns, with the exception of one layer of 14, 600 microns (Fig. 22). The dark layers are almost invariably of a reddish color and considerably thinner (5 to 1640) than the light layers (30 to 4090) (Fig. 22). Pyrite is found throughout the core and in places actually forms thin layers.

Seibold (1958) studied a modern varved sequence in cores obtained from a shallow restricted marine embayment in the island of Mljet off the Yugoslavia coast, 380 miles north of the Gulf of Corinth. Seibold was able to correlate variations of the thickness of the annual varves with historical climatic cycles. In the Gulf of Corinth the dark layers are thinner than the modern varves of Mljet (30 vs. 70 microns) and the lighter varves, thicker (900 vs. 140 microns). The dark layers of the Mljet varves are described as black and the light varves as white. The Corinth varves consist of alternately reddish layers with light tan layers.

The varves at Mljet are being deposited beneath the anaerobic waters of a shallow marine embayment. Those of the Gulf of Corinth may represent a similar environment which may have existed early in the history of the gulf. The pre-Pleistocene foraminifera found in varves of Core V-10-29 may not have been displaced and may truly indicate that the varves were laid down on the anaerobic bottom of a pre-Pleistocene embayment.

It is generally believed that late Pleistocene sea level fell at least 40 to 50 fathoms below the present level. The present sill depth of the gulf is 30 fathoms and if neither tectonics or sedimentation have significantly shallowed the sill, the gulf could have been cut off from the Ionian Sea during the Pleistocene lows. The varved sequence could conceivably represent sedimentation during a Pleistocene sea level low.

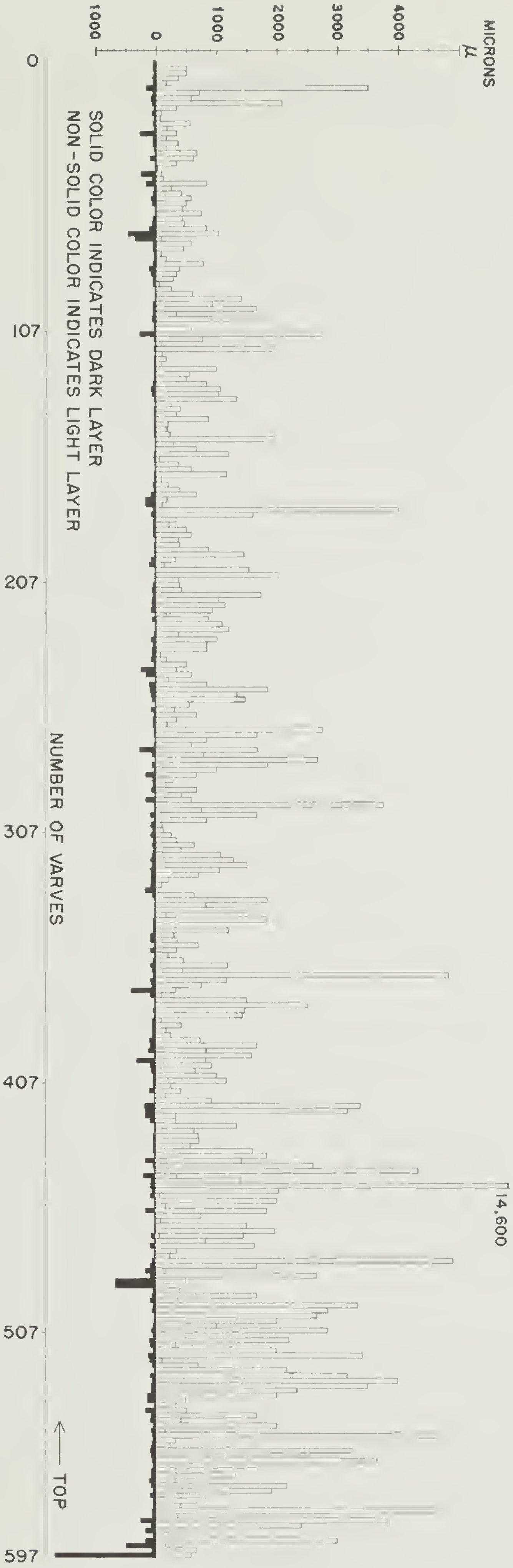


Fig. 22 Graphic log of varves in core V-10-29.
Graph of thickness in microns of varves in core V-10-29.

Regardless of the interpretation of the varves, their presence beneath only 20 cm. of recent sediments indicates that erosion has been active on the continental slope in recent times.

Core V-10-30 from the continental shelf also contains beds suggesting brackish or nonmarine conditions.

David Ericson (personal communication) reports that, "The top sample contains shells of pteropods, fairly numerous marine benthic species of foraminifera and rare planktonic species. From 50 cm. to 250 cm., only rare specimens of benthic foraminifera are present. Among these is Streblus beccarii, a species frequently found in brackish water.

"At 300 cm. the presence of Globigerina bulloides and Globigerinoides rubra as well as echinoid spines and ophiuroid ossicles indicates that conditions in the gulf were similar to those of the present.

"From 340-450 cm. planktonic foraminifera are absent, although a few marine benthic foraminifera and echinoid spines are present.

"From 500-650 cm. marine and brackish water forms are wholly absent; however, ostracods and fragments of calcareous algae are very abundant.

"From 700-850 cm. echinoid spines, marine benthic and a few planktonic species of foraminifera are present.

"In the bottom sample (896 cm.) remains of marine organisms are entirely absent."

A general interpretation assuming continuous subaqueous deposition suggests two periods preceding the present when conditions on the shelf were much as they are today. However, during deposition of most of the section, the gulf's connection with the Ionian Sea may have been more restricted than it is now. However, this core, taken in the Krissaiós Bay along the North coast of the Gulf of Corinth in 44 fathoms, may not contain a continuous unbroken record of sedimentation.

PHYSICAL OCEANOGRAPHY AND WEATHER

Weather. The following description is taken from the sailing directions. (anon. 1931):

"During the summer the winds are usually light and variable, with those from west and northwest most prevalent. Occasionally the wind from northwest blows strongly and raises a considerable sea in the eastern part of the gulf. During the night at this season, it is generally calm.

"In the western part of the gulf the prevailing wind is from the northeast. It usually commences at sunrise and increases its force as the entrance is approached, when it forms the 'Gulf Wind' of the Gulf of Patras. During the summer, when there is often a fresh breeze in the middle of the gulf, it is calm in the Gulf of Salona and Aspns Spitia Bay on the northern shore.

"In the winter, winds from east southeast are most prevalent, and are accompanied by a mild thick atmosphere and rain."

The Gulf of Corinth region is arid, the southern shore receiving only about 23 inches of rainfall per year. The northern side is more arid. Figure 23 shows the average rainfall by month at Vostissa. During the wet season from September to March, the maximum rainfall in 24 days is about 2 inches. In October up to 3 inches of rain may fall in one day. Figure 24 shows the weather data for the Patras area, and Fig. 25 shows the weather data for the Vostissa area.

There are numerous mountain streams which flow into the gulf from the surrounding mountains with steep gradients (e.g., Fig. 26). During the dry summer months these streams are reduced to hardly a trickle; however, during heavy rainfalls they become raging torrents. The spring thaws in the mountains in March and April produce destructive floods. Turbidity currents frequently triggered at the river mouths during the floods account for many of the cable failures along the continental slope.

Tides. "The tidal action in the gulf is small, but is regular and well marked. The range at spring is a little over 2 feet. In the narrows the current is tidal, turning with the time of high and low water at Trisonia Island on the north shore; setting into the gulf while the water is rising there and out when falling. At spring it attains a velocity of 2 knots in the narrows. The set and velocity both are much influenced by the previaling wind if strong. As the gulf widens east of Drepano Point, the current soon ceases to be felt, and in the middle there is no regular current, but a slight drift is frequently set up by the prevailing wind. There is often a marked setting close around the prominent capes on the northern shore, caused by the tidal current setting out of the bays." (Anon., 1931.)

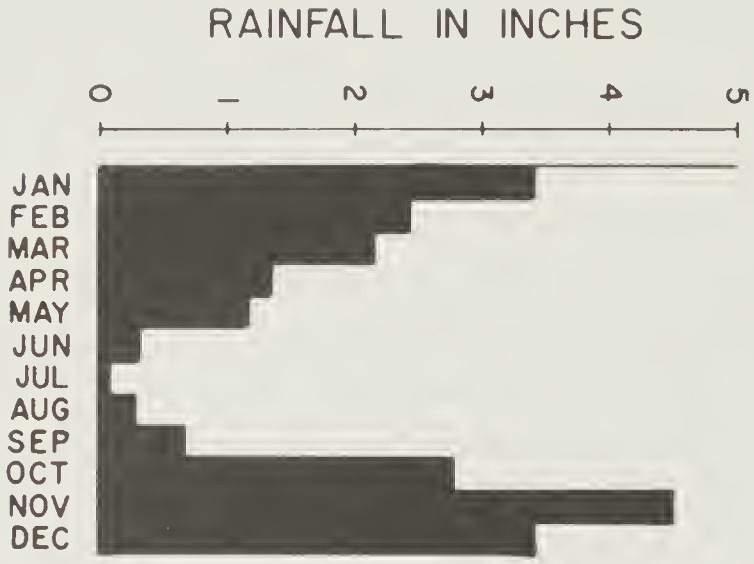


Fig. 23 Graph of annual rainfall at Vostissa. Based on (H. O. 153) (1931).

PATRAS

[Latitude 38° 15′ N., longitude 21° 44′ E. Height above Mean Sea Level, 103 feet. Meteorological Table compiled from 11-35 years observations, 1870-75; 1894-1923]

Month	Pressure at mean sea level, reduced to 32° F. and latitude 45°		Air temperature							Relative humidity	Cloud amount, scale 0 to 10	Rain			Wind										Number of days gales [3]	Number of days fogs
	Mean			Mean daily		Mean monthly		Extreme							Mean force, scale 0 to 10	Percentage of observations from—										
	For month	Daily amplitude	Average	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum			Average fall	Number of days [1]	Maximum fall in 24 hours [2]		North	Northeast	East	Southeast	South	Southwest	West	Northwest	Calm		
	Inches	*Inches*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	%		*Inches*		*Inches*												
January	30. 03	-------	51	56	44	63	35	71	27	76	5. 7	3. 98	14	1. 97	2. 7	21	19	11	11	15	8	8	4	3	0. 5	0 4
February	30. 00	-------	52	58	45	67	35	76	25	74	5. 7	3. 03	12	1. 65	2. 7	24	15	10	11	14	9	10	4	3	0. 8	0 5
March	29. 98	-------	56	62	48	73	39	82	28	72	5. 3	2. 48	10	2. 60	2. 8	21	16	10	8	14	11	13	4	3	0. 1	2
April	29. 95	-------	62	69	53	79	45	87	37	71	5. 1	2. 13	11	1. 61	2. 7	19	14	7	5	15	12	20	6	2	0. 1	1
May	29. 95	-------	69	76	59	86	52	98	44	69	4. 3	1. 42	8	1. 35	2. 5	20	8	6	5	13	13	24	7	4	0	1
June	29. 95	-------	76	84	66	92	59	99	52	66	2. 7	0. 71	6	1. 46	2. 4	13	4	4	5	16	14	34	7	3	0	0. 3
July	29. 92	-------	81	90	70	98	64	103	56	61	0. 9	0. 16	1	0. 98	2. 5	16	8	4	4	13	13	30	8	4	0. 1	0. 1
August	29. 92	-------	82	89	71	98	66	110	59	60	1. 0	0. 24	2	1. 10	2. 5	19	8	6	5	14	14	23	6	5	0. 1	0 9
September	30. 00	-------	76	84	67	92	60	101	52	64	2. 0	1. 18	5	2. 64	2. 5	21	14	10	8	11	11	17	4	4	0	0. 2
October	30. 03	-------	68	75	60	84	53	91	41	72	4. 2	3. 66	11	2. 32	2. 4	24	14	12	11	11	7	14	3	4	0. 4	0. 6
November	30. 03	-------	59	65	52	75	43	83	28	75	5. 6	4. 53	13	3. 27	2. 6	26	18	12	12	9	8	9	3	3	0. 1	0. 7
December	30. 03	-------	53	59	47	67	37	74	30	77	5. 8	4. 84	13	2. 24	2. 5	22	19	12	11	13	8	8	3	4	0. 3	1
Mean	29. 98	-------	65	72	57	[4] 100	[4] 32	----	----	70	4. 0	-------	------	-------	2. 6	21	13	9	8	13	11	17	5.	3	-----	----
Total	-------	-------	------	------	------	------	------	----	----	----	------	28. 35	106	-------	-------	----	----	----	----	----	----	----	----	----	3	9
Extreme values	-------	-------	------	------	------	------	------	110	25	----	------	-------	------	3. 27	-------	----	----	----	----	----	----	----	----	----	-----	----
Number of years' observations	29	-------	29-30	32	32	33				30	32	34	20	34	29	35									15	11

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[1] Day with trace or more rain.
[2] Maximum fall during the 24 hours from one morning observation to the next.
[3] Force 9 or over on scale 0-10.
[4] Mean of highest each year and lowest each year.

Hours of observation, 8h., 14h., 21h.

Fig. 24 Average meteorological data for the Patras area.
(H. O. 153), p. 546.

VOSTITZA (Aigion)

[Latitude 38° 14′ N., longitude 22° 00′ E., height above mean sea level, 203 feet. Meteorological table compiled from 7-18 years' observations, 1904-1921]

Month	Pressure at mean sea level, reduced to 32° F. and latitude 45°		Air temperature							Relative humidity	Cloud amount, scale 0 to 10	Rain			Wind										Number of days gales [3]	Number of days fogs
	Mean			Mean daily		Mean monthly		Extreme							Mean force, scale 0 to 10	Percentage of observations from—										
	For month	Daily amplitude	Average	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum			Average fall	Number of days [1]	Maximum fall in 24 hours [2]		North	Northeast	East	Southeast	South	Southwest	West	Northwest	Calm		
	Inches	*Inches*	°F	°F	°F	°F	°F	°F	°F	%		*Inches*		*Inches*												
January	30.06		50	55	44	64	35	69	27	70	5.8	3.39	10	1.97	2.2	7	3	6	29	10	19	10	16	0	0	0
February	30.00		50	55	44	64	35	71	25	69	5.7	2.44	10	1.97	2.3	5	2	6	28	15	17	10	17	0	0	0
March	29.98		54	60	47	70	40	77	33	70	5.2	2.24	9	1.50	2.3	10	3	7	26	13	15	9	17	0	0	0.3
April	29.92		60	66	52	76	44	82	37	66	4.7	1.34	8	1.46	2.2	16	4	4	26	8	9	9	24	0	0	0.3
May	29.95		68	75	58	85	50	91	34	63	3.9	1.26	7	1.50	2.2	20	6	4	24	10	6	5	25	0	0	0.1
June	29.92		75	83	65	93	58	105	51	61	2.4	0.31	3	0.63	2.1	28	7	3	18	5	4	5	30	0	0	0.4
July	29.89		80	90	70	98	63	104	53	58	0.8	0.08	1	0.24	2.3	29	7	4	20	5	3	3	29	0	0	0
August	29.92		81	91	71	99	66	104	63	56	1.0	0.28	2	0.83	2.2	22	9	5	24	5	6	4	25	0	0.1	0
September	29.98		75	84	67	93	59	104	53	58	2.1	0.67	3	2.09	2.2	14	6	6	28	8	9	5	24	0	0	0.1
October	30.06		66	73	60	83	52	91	47	67	4.0	2.76	8	3.03	2.1	8	3	4	29	12	20	7	17	0	0	0.3
November	30.03		58	63	52	73	42	79	34	72	5.7	4.49	12	2.91	2.2	6	2	6	25	16	20	8	17	0	0	0
December	30.03		53	59	47	66	38	78	30	73	5.7	3.39	10	2.24	2.0	8	2	6	21	16	20	9	18	0	0	0
Means	29.98		64	71	56	[4] 101	[4] 31			65	3.9				2.2	14	5	5	25	10	12	7	22	0		
Totals												22.64	83												0.1	1.5
Extreme values								105	27					77												
Number of years' observations	15		18	18	17-18							18													12-13	7

[1] Day with trace or more rain.
[2] Maximum fall during the 24 hours from one morning observation to the next.
[3] Force 9 or over on scale 0 to 10.
[4] Mean of highest each year and lowest each year.

Hours of observation, 8h., 14h., 21h.

Fig. 25 Average meteorological data for the Vostissa area.
(H. O. 153), p. 547.

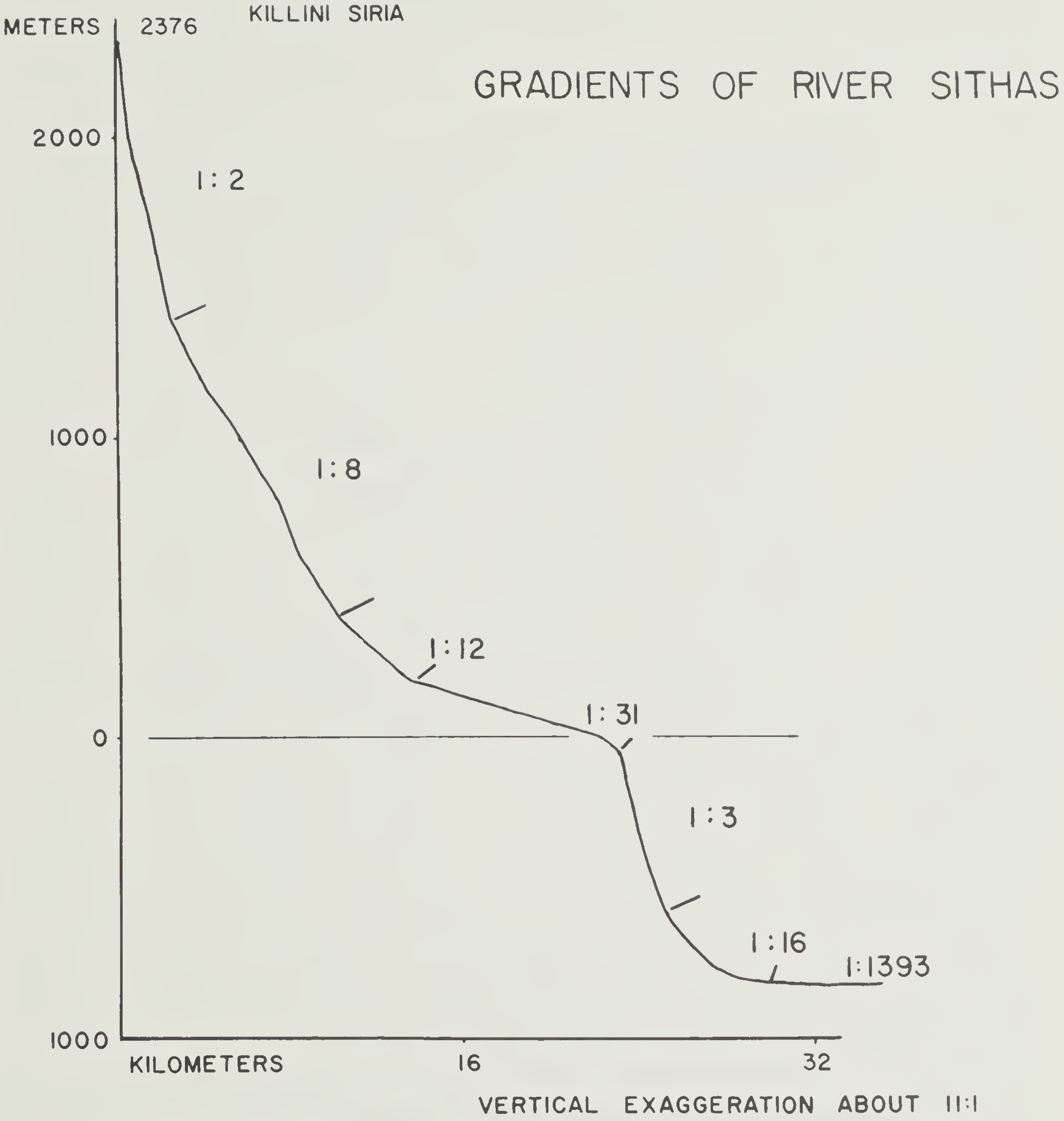


Fig. 26 Long profile of River Sithas and Sithas Submarine Canyon.

The narrows of the Gulf of Corinth are swept by tidal currents which at the surface attain a maximum velocity of two knots. Although Hydrographic Office Chart 3963 shows no bottom notations in The Narrows, the reports of two cable repairs record "mud and rocks" in the vicinity. Of the eleven cable failures in the narrows, eight occurred during the winter months. It seems likely that severe winter storms may augment the tidal currents and may thus account for this winter increase in the number of cable breaks.

Serial Oceanographic Observations. In August 1910 the Danish research vessel THOR made a serial hydrographic section consisting of 5 stations across the Ionian Sea, including one station in the Gulf of Corinth (Figs. 27 and 28). In July 1956 VEMA occupied two serial stations in the gulf and made 3 bathythermograph lowerings (Figs. 28, 29, 30, 31). It is clear that with such meager data only the most general conclusions are permissible.

Nielsen (1912), in his report on the hydrographic observations, noted that in the gulf "the hydrographic conditions below 100 meters are very different from those found in the Ionian Sea, both the temperature and salinity being much lower." He pointed out that the deep water in the gulf is formed locally by convection during winter cooling. Since each winter somewhat different minimum temperatures are reached, he predicted that wide differences would be observed from year to year, a prediction which seems fulfilled by a comparison of VEMA. and THOR data. The THOR stations of 1910 (Figs. 27 and 28) show cooler water temperatures and higher salinities in both the Gulf of Corinth and in the Ionian Sea. The oxygen content of the 1910 THOR water samples was considerably higher than those observed by VEMA in 1956. This difference in oxygen could be related to the long-term depletion of oxygen in the deep ocean noted by Worthington (1954), but more likely it merely reflects differences in the winter temperatures and intensity of convection. Pollock (1951), who found an appreciable year to year variation in the salinity of the deeper waters of the Adriatic Sea, concluded that the salinity variations likewise resulted from variations in annual convection, which in turn were related to year to year variations in the prevailing weather.

Radiocarbon. Two 100-gallon water samples were taken in the Gulf of Corinth for radiocarbon assay. The surface sample and the bottom sample had, within the limits of error, the same C^{14}/C^{12} ratios. These ratios, shown below were the lowest observed in the Mediterranean.

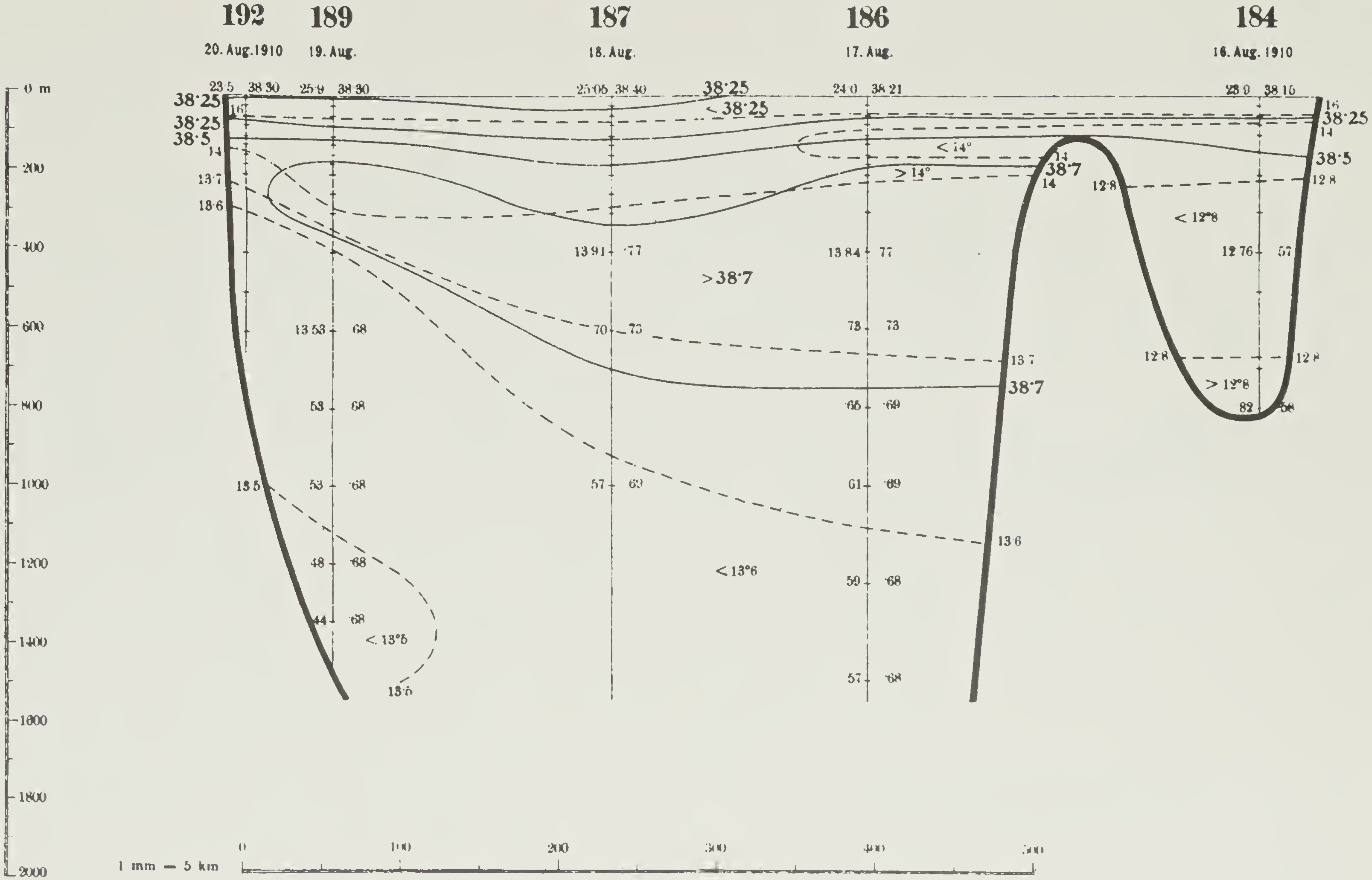


Fig. 27 THOR serial hydrographic stations in the Gulf of Corinth and Ionian Sea (Nielsen 1912). Lines of constant salinity shown solid, isotherms dotted. Figure 28 shows locations of the THOR hydrographic stations.

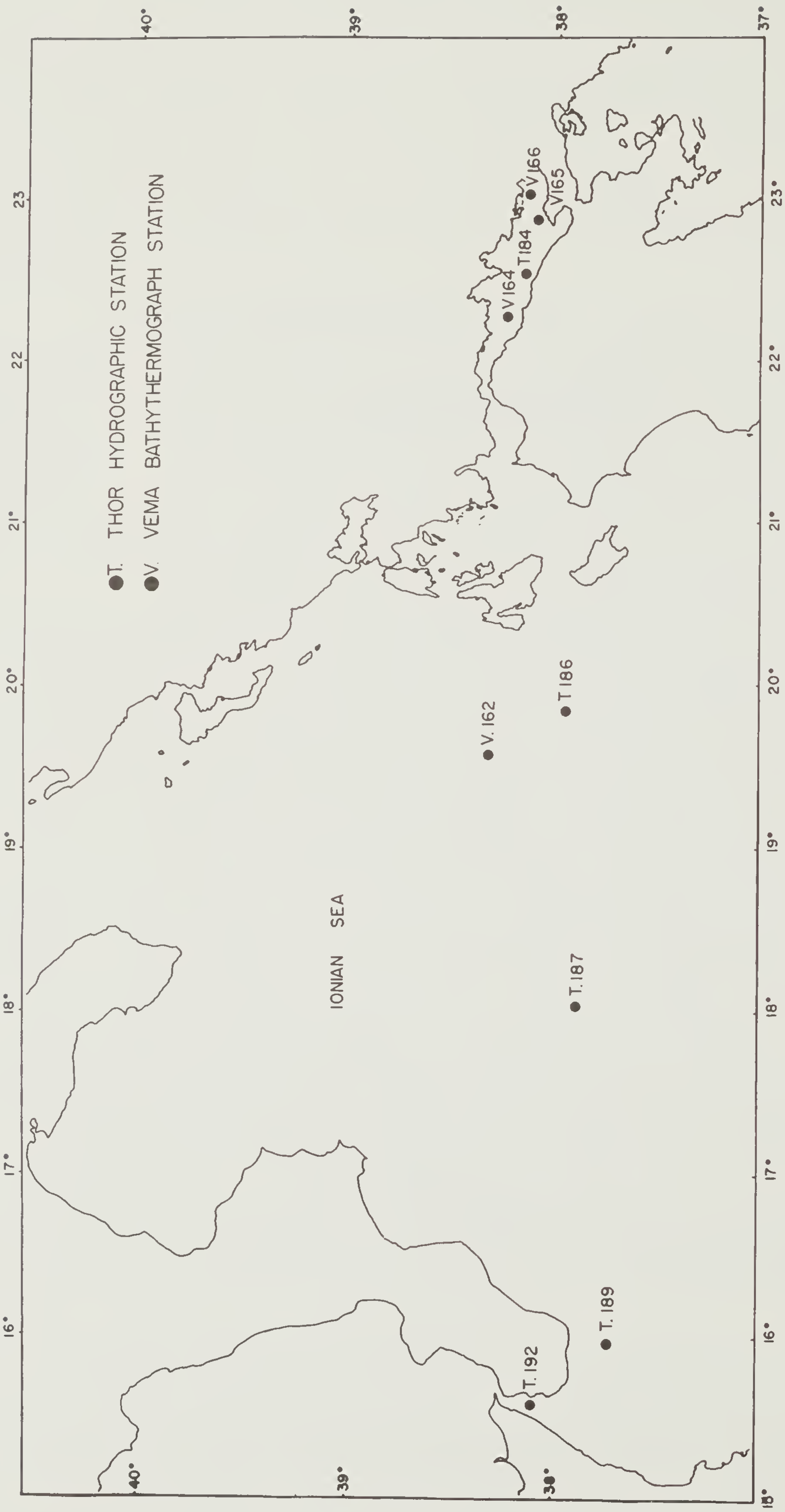


Fig. 28 Index chart showing location of THOR and VEMA hydrographic stations.

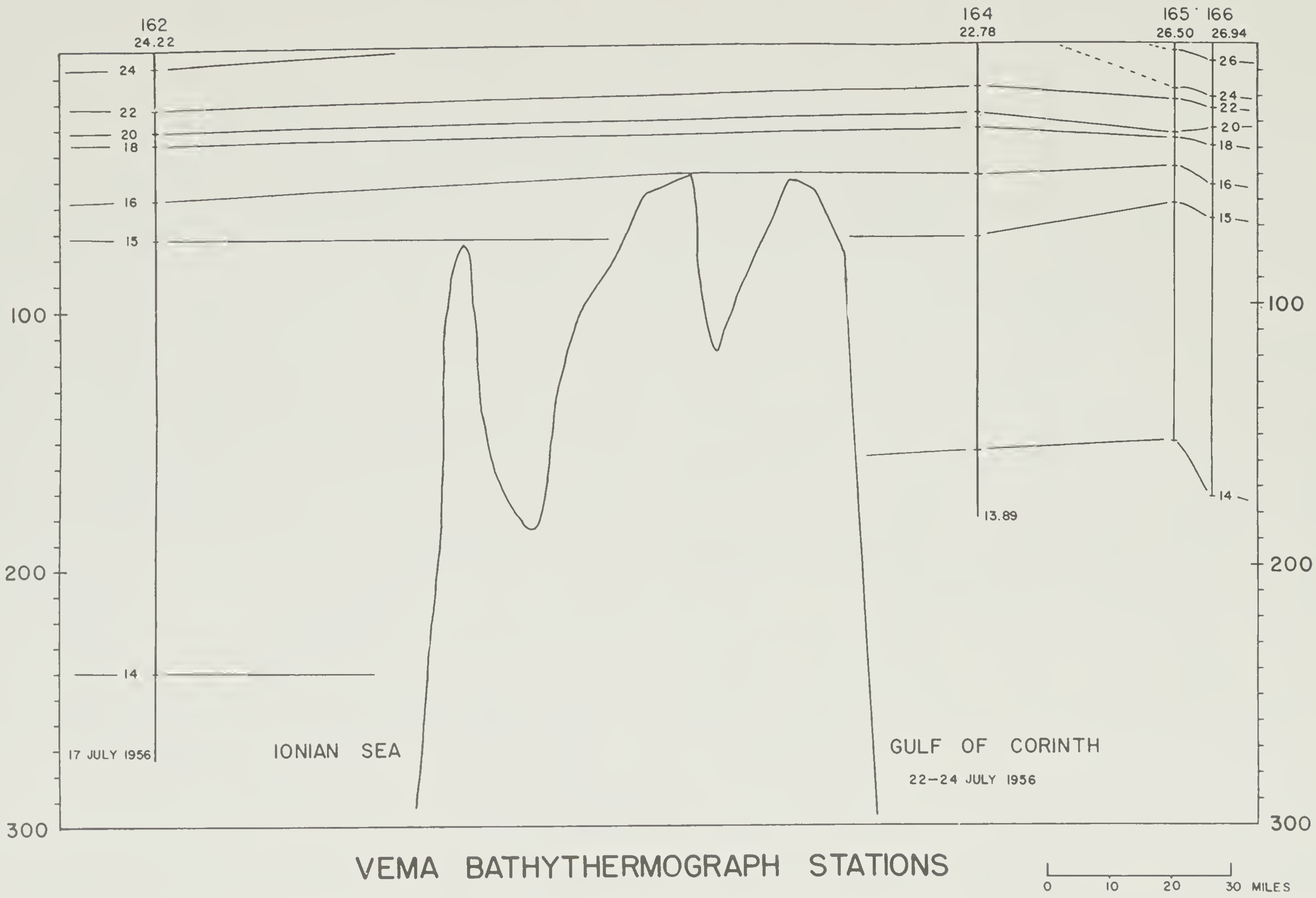


Fig. 29 Bathythermograph profile of the Gulf of Corinth and Ionian Sea. This is based solely on VEMA bathythermograph observations Location of bathythermograph stations is shown in Fig. 28.

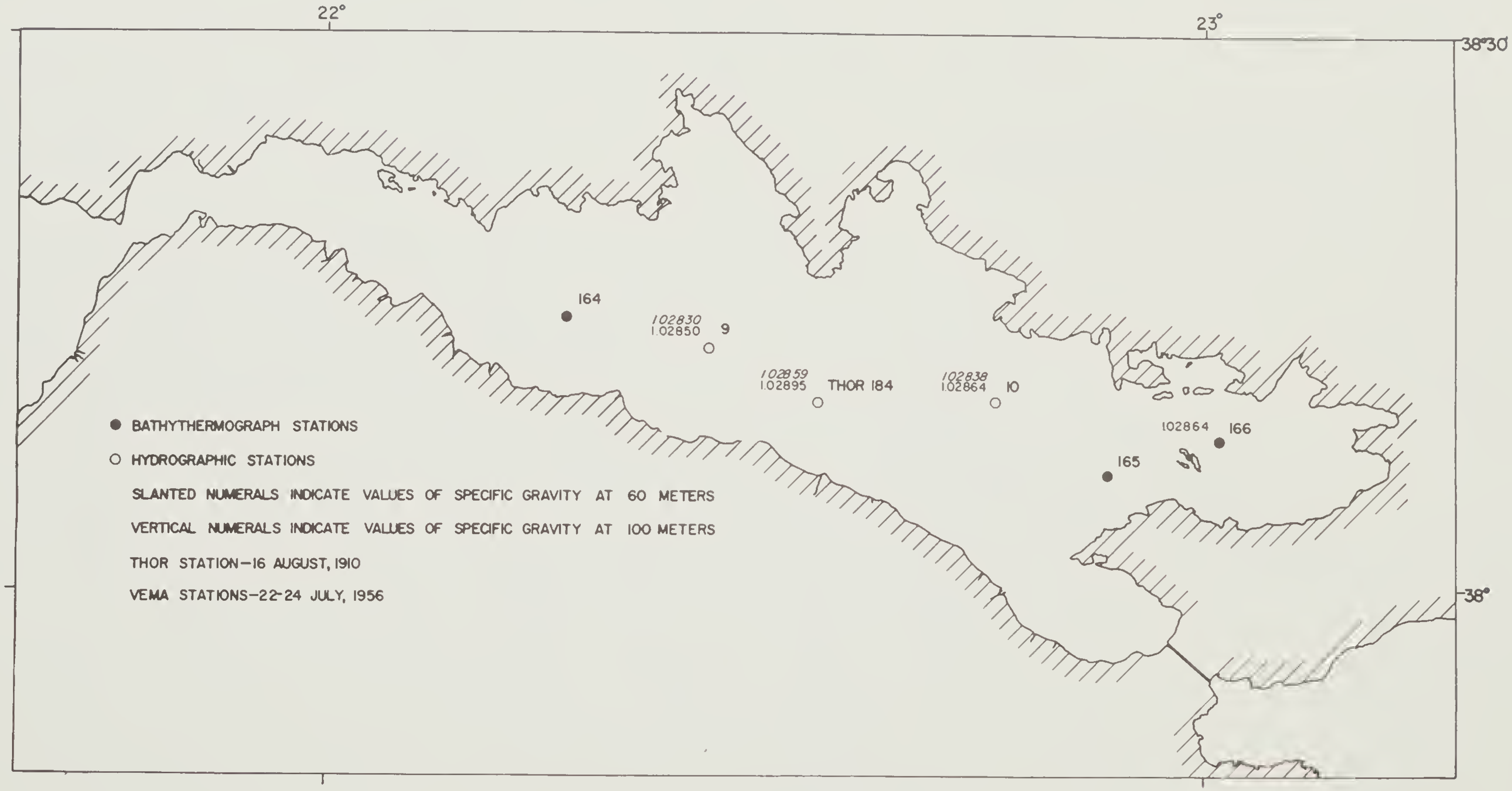


Fig. 30 Location of VEMA hydrographic stations and bathythermograph observations in the Gulf of Corinth.

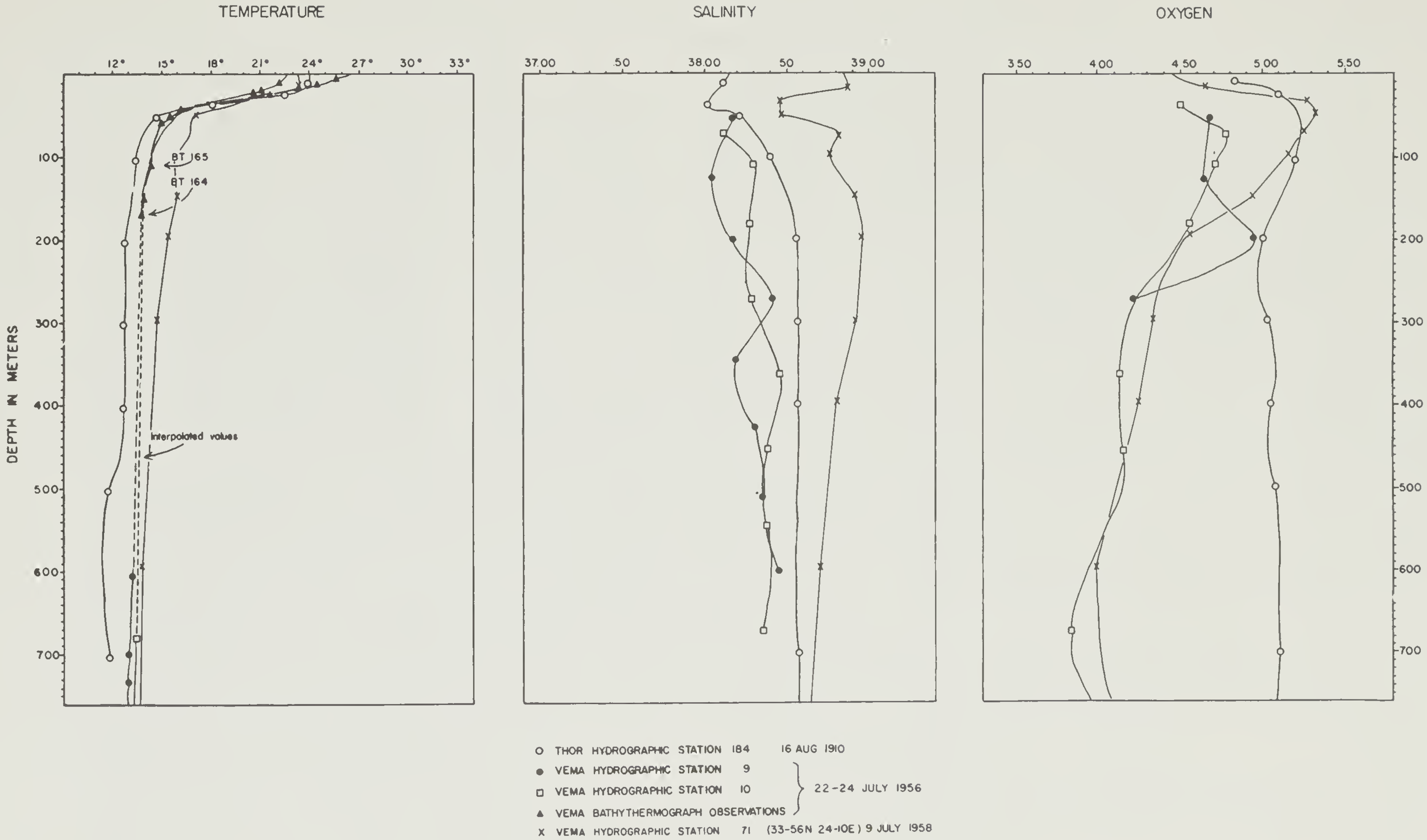


Fig. 31 Vertical distribution of temperature, salinity and oxygen in the Gulf of Corinth.
Data are based on VEMA and THOR observations.

TABLE III

Lat.	Long.	Depth	C^{14}/C^{12}*	Location
38°N	23°E	0	-4.5	Gulf of Corinth
38°N	22°E	800	-4.1	Gulf of Corinth
34°N	26°E	0	-0.5	Levant Basin
34°N	27°E	2340	-4.1	Levant Basin
37°N	21°E	4200	-3.4	Ionian Sea
37°N	19°E	3390	-1.4	Ionian Sea

*(Values expressed as % difference from average North Atlantic surface water.)

The fact that top and bottom samples give the same C^{14}/C^{12} ratios is precisely what one would expect in light of the clear evidence of local, probably annual, renewal of the bottom water. The great apparent age of the gulf waters as compared to the Mediterranean water at comparable and even greater depths is, however, surprising.

To explain this great apparent age, we might suppose that, (1) the annual overturn is so fast that the deep water has not sufficient time to become equilibrated with the atmosphere, (2) low-apparent-age water is entering the gulf from the Ionian Sea, or (3) that inert carbon from the surrounding limestone terrain is entering the gulf through the streams and is diluting the gulf water.

The first alternative is ruled out, since surface and deep water both have great apparent ages. The second suggestion is unlikely in view of the small depth and small cross section of The Narrows and the lack of any obvious source of old water in the Ionian Sea.

It is concluded that the inert carbon contained in the limestones surrounding the gulf is continually being washed into the gulf. This inert carbon lowers the C^{14}/C^{12} ratio. Annual overturn maintains this uniform apparent age from top to bottom. The limited exchange of water through The Narrows helps to preserve this great apparent age by isolating the Gulf of Corinth waters from the Ionian Sea.

The abundant evidence of frequent turbidity currents cited in relation to cable failures and sediment distribution suggests that these currents may contribute significantly to the dilution of the gulf waters with dead carbon.

SUBMARINE CABLE FAILURES

From 1884 to 1939 three cables traversing the length of the Gulf of Corinth (Fig. 32) were maintained by the Eastern Telegraph Company, now a subsidiary of Cable and Wireless, Ltd.

The northernmost cable, #2, laid in May 1884, passes along the northern side of The Narrows, directly down the continental slope, and across the abyssal plain to the Bay of Corinth. Cable #1 passed through the center of The Narrows and along the narrow continental rise and lower continental slope of the south side of the gulf. The southernmost cable, #3, laid in 1901, ran along the continental slope and shelf close to the south shore of the gulf. Of the three cables, #2 had the fewest failures and for that reason is the only one of the cables still in service. Cables #1 and #3, which failed in about equal numbers, were not renewed after World War II.

Cable Repair Data

The routine involved in repairing cables and the form of the ship report were established nearly a century ago and have remained virtually unchanged to this day. The type of data which the oceanographer or geologist finds in the cable report is nearly always the same except in those fortunate instances when an interested engineer or officer notes something which appears significant or anomalous. In shallow water the ends of a broken cable are frequently recovered. In deeper water, however, the end is more frequently abandoned than recovered. In such instances, the cause of failure is inferred from the condition of the picked up cable, which sometimes lay miles from the actual failure. To help the reader comprehend the nature of the repair data and their limitations, and to indicate the procedure of repair, the full report of a report of a routine repair is transcribed in Table IV with accompanying Figs. 33 and 34.

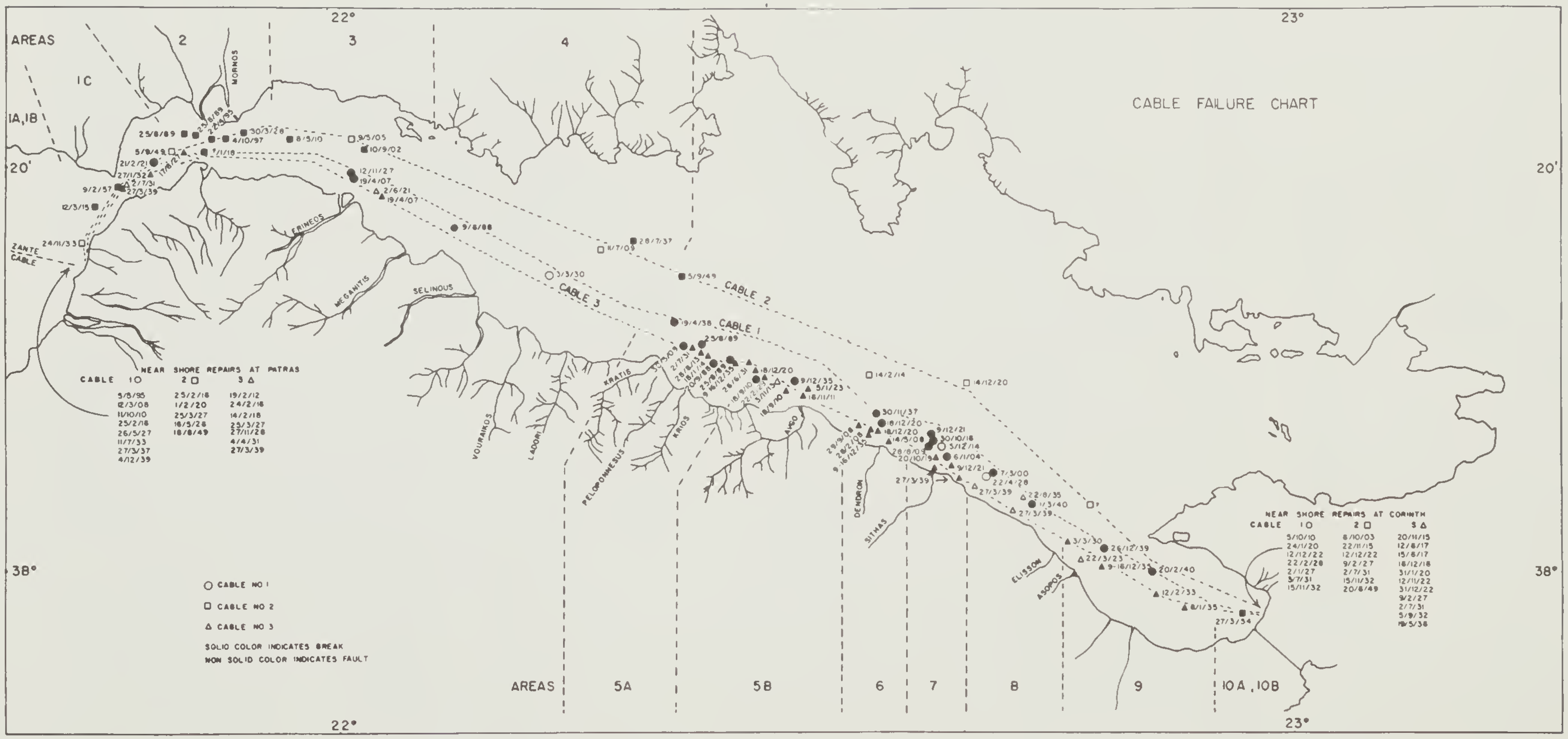


Fig. 32 Location and dates of all breaks and faults to cables 1, 2 and 3 between Corinth and Patras.

TABLE IV

SYNOPSIS OF REPAIR TO

The Eastern Telegraph Company, Ltd.	Corinth-Patras No. 1 Section C. S. "Levant"
	Diagram No. 16

Description and Cause of Defect:	Break	Submarine Landslide	
Depth of Water in Fathoms:	265	355	
Nature of Bottom:	mud & clay	mud & clay	
Distance of First Splice:	15/13-12/13t	from Corinth,	16. 331 nauts.
Distance of Final Splice:	12/13-15/13t	from Patras,	53. 414 nauts.
Present Length of Cable:	....		77. 295 nauts.

DATES

Fault Observed:		m. (local time) on	unknown	19
Ship Left Piraeus:	11:20 a. m.	" " "	9th Dec.	1921
Arrived on Cable Ground:	7:40 a. m.	" " "	10th Dec.	1921
Final Splice Slipped:	2:30 p. m.	" " "	14th Dec.	1921
Ground Cleared and Set on Course for Patras:	2: 33 p. m.	" " "	14th Dec.	1921
Arrived at Patras:	7:55 p. m.	" " "	14th Dec.	1921

SUMMARY OF CABLE LAID IN ON REPAIR

New Cable:		7. 550 nauts.
Picked up Cable out of Stock:		nil
Picked up and Relaid on Repair:		nil
	TOTAL	7. 550 nauts.

H. Finnis
Electrician

TABLE IV (Cont'd)

REPORT ON THE REPAIRS TO
PATRAS-CORINTH Nrs. 1 & 3 Secs.
by C. S. "Levant"
9/14th December 1921

Friday, 9th December/21

11:20 a. m.	Left Piraeus for Corinth cable house to localize breaks in Patras 1 & 3 sections.
4:40 p. m.	Arrived off Corinth cable house. Tests placed breaks in numbers 1 & 3 at 223 ohm and 218 ohms, respectively, from here. The ends which were not clean were apparently buried.
5:00 p. m.	Left for night's anchorage. 5:18 p. m. anchored near Corinth.

Saturday, 10th

05:80 a. m.	Left for ground.
07:40 a. m.	Arrived and down grapnel (S. P. G.[1] and Rennie[2]) to hook Patras #1 end. The northerly weather was very fresh.
09:00 a. m.	Hooked cable and continued to pick up. 9:35 a. m. cable aboard type Dt 12/13t.
09:50 a. m.	Cut and spoke to Patras. We did not delay by testing now as weather was very unfavorable.
09:55 a. m.	Buoyed Patras end. Soundings 355 mud and clay. .390 nautical miles D 12/13 was recovered to break. (Break due to landslide.) There was a lull in the weather, and advantage was now taken to grapple for Patras 3 end.
11:20 a. m.	Down grapnel (S. P. G. and Rennie) to hook Levant 1's 1st splice 24/10/19.
12:30 p. m.	Hooked cable and continued to pick up. 12:50 p. m. cable aboard type Dy 16/13.
1:05 p. m.	Cut and called Patras, but found end insulated in office. Patras had been told in the morning to cease watch, as we had intended to shelter. D. R. to Patas Office 2. 2 megs. abs.

TABLE IV (Cont'd.)

1:35 p. m.	Buoyed Patras 3 end. Soundings 95 m.
2:44 p. m.	Recovered to break 1. 207 nautical miles D 16/13, in poor and damaged state, owing to debris from torrents. The break was caused by the usual submarine landslide, originated by the heavy torrents from mountain water-courses.
4:00 p. m.	Set on for shelter at Corinth. Northerly weather very fresh.
6:55 p. m.	Arrived.
	Sunday, 11th
05:30 a. m.	Left for ground. Northerly weather very fresh. On approaching ground, weather was found quite unsuitable for operations, so ship was set on course for Gulf of Salona.
10:00 a. m.	Anchored off Itea.
	Monday, 12th
06:00 a. m.	Left for ground. Weather somewhat moderated.
7:30 a. m.	Light up cable buoy on Patras 1 end, and set on to grapple for Corinth 1 end. At this position, off Xylocastron, the position of No. 3 very uncertain. On account of this it was decided to sweep for Corinth 1 end well to the east, clear of deposit from torrents, and where the soundings are rather more uniform and the cables further apart.
7:45 a. m.	D. G.[3] (S. P. G. and Rennie).
8:02 a. m.	Cleared grapnel, which had fouled bottom.
8:05 a. m.	D. G. and commenced fresh drive further east.
10:10 a. m.	Hooked cable and continued to pick up. Strain considerable.
10:30 a. m.	Cable aboard Dt 12/13 (Chiltern's repair, May 1900) Corinth 1 end.
10:45 a. m.	Cut and tested to Corinth: D. R. 15 v. 1'Zn. .26 meg. C. .26 meg abs. C. R. 180. 8 ohms.
11:25 a. m.	Buoyed Corinth 1 end. Soundings 265 mud and clay. Original cable picked up west to break. Strain very considerable.

---

[3] Down grapnel.

TABLE IV (Cont'd.)

Monday, 12th

2:00 p. m.	Recovered 3. 877 nts. D. when cable parted at kink, . 210 nt. from break. Most of the picked up cable had been deeply silted in mud, and was jagged and ruffled, and in some parts had been suspended, as there were trees and masses of branches and weed entangled about it.
2:30 p. m.	Set on to place staff on Patras 3 end buoy.
3:00 p. m.	Set on to grapple for Corinth 3 end, after attending to Patras 3 end buoy. 3:05 p. m. D. G. (S. P. G. and Rennie).
3:55 p. m.	Picked up grapnel, having passed well over line of cable with no sign of hook.
4:00 p. m.	Left for shelter as northerly weather had become too fresh for further operations.
5:45 p. m.	Anchored near Corinth.

Tuesday, 13th

06:00 a. m.	Left for ground. Weather very unsettled.
07:50 a. m.	Arrived and stood by. Heavy rain and haze.
08:20 a. m.	D. G. (S. P. G. and Rennie) to hook Corinth 3 end.
8:40 a. m.	Grapnels foul of bottom.
9:00 a. m.	Changed grapnel for round bottom.
9:25 a. m.	D. G. (rd. btm. medium) to hook 1/2 mile further east.
10:50 a. m.	Grapnel foul of bottom.
11:00 a. m.	Cleared same and resumed drive working eastwards to get away from water-courses.
11:20 a. m.	H. C. and c. p. u. 11. 35 cable aboard. Dt $12/p^3$ original '01.
11:50 a. m.	Cut and tested to Corinth cable house. D. R. 15 v. 1'Zn. . 38 meg. C. . 28 meg abs. C. R. 196 ohms.
12:10 p. m.	Passed ends for 1st joint and spliced to Corinth 3 end.
1:30 p. m.	Completed 1st splice. 15/13-12/13t. Soundings 48 m.
1:35 p. m.	Continued to pull out and picked up.
2:40 p. m.	Recovered l. 35 nt. D. to break (due to landslide). The picked up cable was not in a good state and bore numerous signs of the effects of the torrents.

TABLE IV (Cont'd.)

Tuesday, 13th

4:20 p. m.	Reached Patras 3 end, having expended 2. 330 nts. Dt. 15/13 100/100.
	Tests to Patras: - D. R. 15 v. 1'Zn. 6. 5 megs. C. 6. 7 megs. abs. C. R. 471. 5.
	Tests to Corinth: through pulled out cable: 1
	D. R.=1 "normal" C. R.=1 221. 2 ohms.
4:30 p. m.	Passed ends for final joint and splice.
4:55 p. m.	Completed and slipped final splice 15/13-p6/13 soundings 95 m. B. T. 58. 5.
4:58 p. m.	Set on for Corinth Bay.
7:00 p. m.	Arrived and anchored.

Wednesday, 14th

5:00 a. m.	Left for ground to splice on to Corinth 1 end.
7:15 a. m.	Arrived and brought Corinth 1 end on board.
	Tests to Corinth cable house "normal."
9:25 a. m.	Passed ends for 1st joint and splice.
10:28 a. m.	Completed 1st splice 15/13-12/13t. Soundings 265 mud and clay. B. T. 58. 5.
10:30 a. m.	Continued to pick up cable.
12:50 p. m.	Reached Patras 1 end, having expended 7. 550 nts. Dt 15/15 100/100.
	Tests to Patras C. H. : -
	D. R. 15 v. 1'Zn. . 35 meg. C. 36 meg abs.
	T. C. R.=1 549. 4 approximately.
	Tests to Corinth through picked up cable:
	D. R. "normal" C. R. 263 ohms.
1:18 p. m.	Passed ends for final joint and splice.
2:30 p. m.	Completed and slipped final splice 12/13t-15/13 soundings mud and clay.
2:33 p. m.	Set on for Patras.
7:55 p. m.	Arrived.

TABLE IV (Cont'd.)

NOTE:

The number 1 section was diverted to the northward as there was space for this, but the number 3 was taken direct, as we did not feel justified in expending more cable than necessary since ship's stock D was intended for renewals to other sections.

We consider, however, that when cable is available and repairs are necessitated in this vicinity, that extensive diversions to the numbers 1 and 3 sections should be effected and thus eliminate the frequent interruptions which are invariably caused by the torrents.

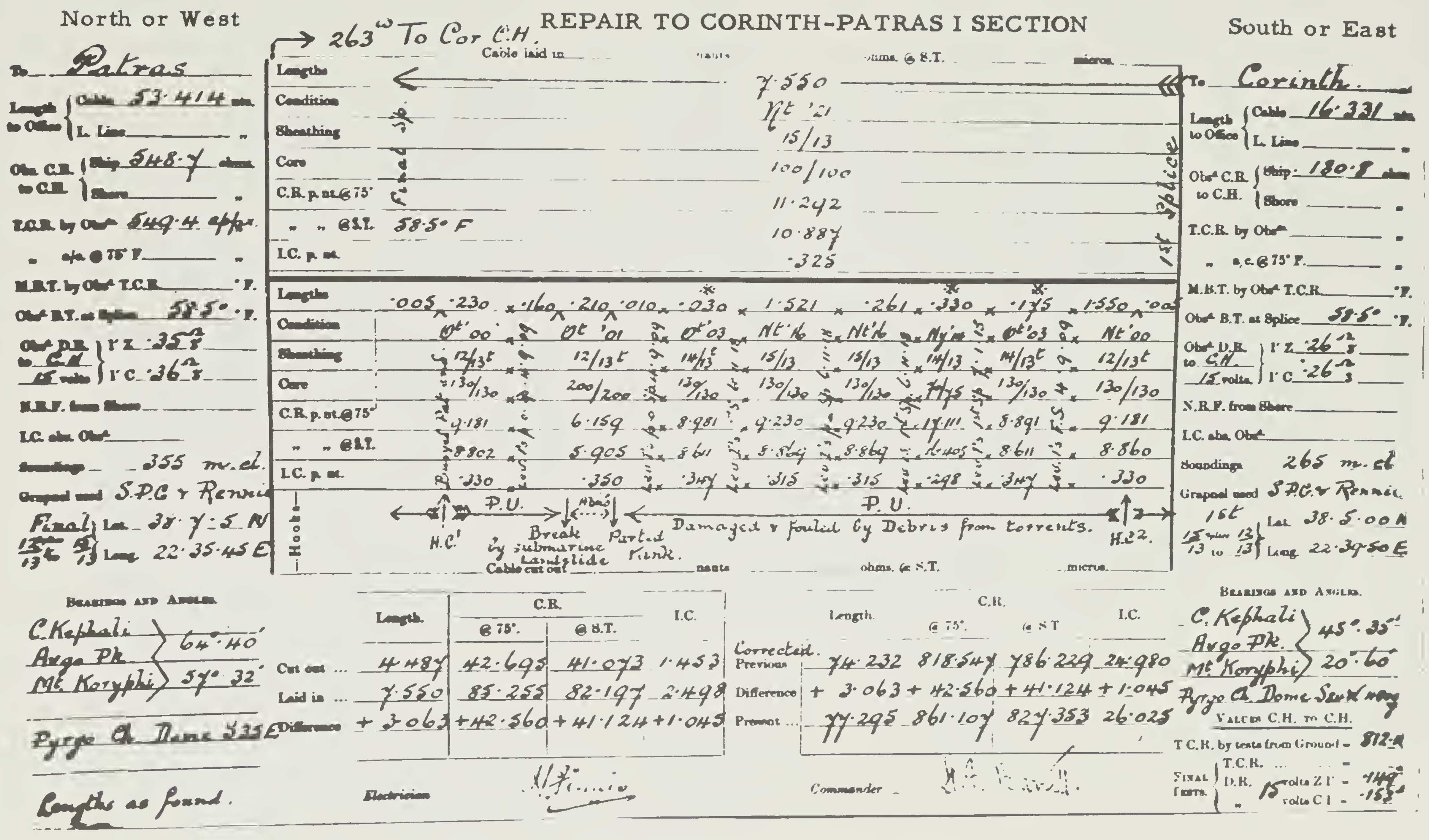
H. F. Barrett

Commander

H. Finnis

Electrician

Diagram Sheet No. 16



North or West

South or East

REPAIR TO CORINTH-PATRAS I SECTION

→ 263ω To Cor C.H.

Cable laid in ____ nauts ____ ohms. @ S.T. ____ micros.

Lengths	7·550
Condition	Nt '21
Sheathing	15/13
Core	100/100
C.R. p. nt. @ 75°	11·242
" " @ S.T. 58·5° F	10·887
I.C. p. nt.	·325

Final Sp.

1st Splice

Lengths ·005 ·230 ·160 ·210 ·010 ·030 1·521 ·261 ·330 ·175 1·550 ·005

Condition	Ot'00	Ot '01	Ot'03	Nt'16	Nt'16	Ny'[illegible]	Ot'03	Nt'00
Sheathing	12/13t	12/13t	14/13t	15/13	15/13	14/13	14/13t	12/13t
Core	130/130	200/200	130/130	130/130	130/130	[illegible]	130/130	130/130
C.R. p. nt. @ 75°	9·181	6·159	8·981	9·230	9·230	17·111	8·891	9·181
" " @ S.T.	8·802	5·905	8·611	8·869	8·869	16·405	8·611	8·860
I.C. p. nt.	·330	·350	·347	·315	·315	·298	·347	·330

Hooks

P.U. P.U.

H.C¹ Break by submarine Landslide Parted Kink. Damaged & fouled by Debris from torrents. H.C².

Cable cut out ____ nauts ____ ohms. @ S.T. ____ micros.

To Patras

Length to Office { Cable 53·414 nts. / L. Line ____ "

Obs. C.R. to C.H. { Ship 548·7 ohms / Shore ____ "

T.C.R. by Obs. 549·4 ohms

" ohms @ 75° F. ____ "

M.B.T. by Obs. T.C.R. ____ °F.

Obs. B.T. at Splice 58·5° °F.

Obs. D.R. to C.H. 15 volts } 1' Z ·35 Ω/3 / 1' C ·36 Ω/3

N.R.F. from Shore ____

I.C. abs. Obs. ____

Soundings 355 m. cl.

Grapnel used S.P.C & Rennie

Final 15/13 to 13/13 } Lat. 38·7·5 N / Long. 22·35·45 E

To Corinth.

Length to Office { Cable 16·331 nts. / L. Line ____ "

Obs. C.R. to C.H. { Ship 180·8 ohms / Shore ____ "

T.C.R. by Obs. ____ "

" a.c. @ 75° F. ____ "

M.B.T. by Obs. T.C.R. ____ °F.

Obs. B.T. at Splice 58·5° °F.

Obs. D.R. to C.H. 15 volts } 1' Z ·26 Ω/3 / 1' C ·26 Ω/3

N.R.F. from Shore ____

I.C. abs. Obs. ____

Soundings 265 m. cl.

Grapnel used S.P.C. & Rennie

1st 15/13 to 13/13 } Lat. 38·5·00 N / Long. 22·39·50 E

Bearings and Angles.

C. Kephali } 64°·40′

Argo Pk. } 57°·32′

Mt. Koryphi

Pyrgo Ch. Dome 535 E

Lengths as found.

	Length.	C.R. @ 75°.	C.R. @ S.T.	I.C.
Cut out ...	4·487	42·695	41·073	1·453
Laid in ...	7·550	85·255	82·197	2·498
Difference	+ 3·063	+ 42·560	+ 41·124	+ 1·045

Electrician

	Length.	C.R. @ 75°.	C.R. @ S.T.	I.C.
Corrected. Previous	74·232	818·547	786·229	24·980
Difference	+ 3·063	+ 42·560	+ 41·124	+ 1·045
Present ...	77·295	861·107	827·353	26·025

Commander

Bearings and Angles.

C. Kephali } 45°·35′

Argo Pk. } 20°·60′

Mt. Koryphi

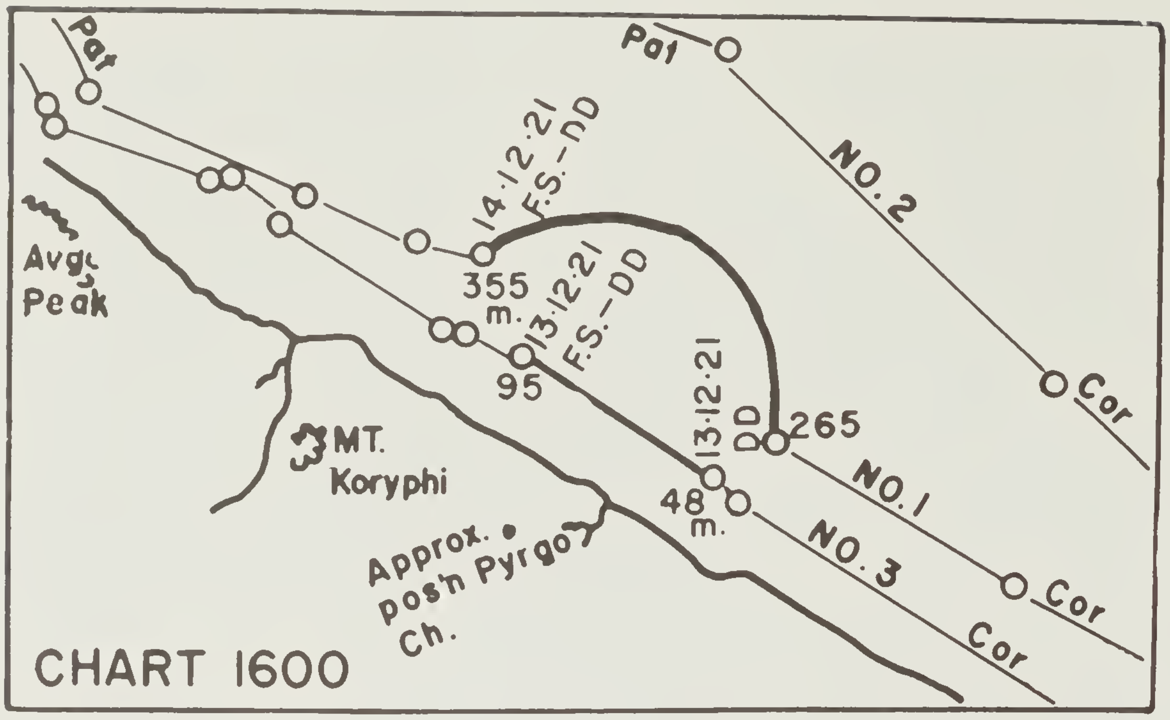
Pyrgo Ch. Dome Sec. W. [illegible]

Values C.H. to C.H.

T.C.R. by tests from Ground = 812·[illegible]

Final Tests. { T.C.R. ... = / D.R. 15 volts Z 1′ = ·149 Ω / " volts C 1′ = ·153 Ω

Fig. 33 Cable repair diagram sheet for Table IV.



REPAIRS TO PATRAS-CORINTH SECTION NOS. 1 & 3 by C. S. LEVANT

13-14. 12. 21

No. 3

1st Spl Dt - 15/13 - Dt 12/13
S77W Pyrgo Ch Dome 1700 yds
Lat. 38° 4.4'N
Long. 22° 39.5'E
Sdg 48 m. cl.
Laid in 2.330 Dt 15/13

F. S. Dy 16/13 - Dt 15/13
C. Kepheli
Avgo Pk 53° 50
Mr Koryphi 42° 40
Pyrgo Ch Dome S38E 2900 yds
Lat. 38° 6.0'N
Long. 22° 36.25'E
Sdg 95 m. cl.

Cut out
D:2.564 P.U.
Lev I's laid in spl 24.10.19
Lev I's F.S. 24.10.19
Grapnels used -
S. Pr H Rennie at F.S.
Large R.B. at 1st spl

No. 1

1st spl Dt - 15/13 - Dt 12/13
C. Kephali
Avgo Peak 45° 35
Mt. Koryphi 20° 00
Lat. 38° 5.0'N
Long. 22° 39.5'E
Sdg 265 m. cl.
Pyrgo Church Dome S 84W 4800 yds
Laid in 7.550 Dt 15/13
Used large R.B., SP & Rennie grapnels

F.S. Dt 12/13 - Dt 15/13
C. Kephali
Avgo Peak 64° 40
Mr. Koryphi 57° 32
Lat. 38° 7.5'N
Long. 22° 35.45'E
Sdg 355 m. cl.
Pyrgo Church Dome S 35 E

Cut out
D. 4.277 P.U.
D. .210 abd.
4.487 Total
All splices between and including Lev. I laid in spl 4.9.09 and Lev. I F.S. 4.9.09

H. J. Barrett
Commander

Fig. 34 Chart of repairs to cables 1 and 3, 10 to 14 December 1921.

When trouble develops in a submarine cable, it is usually possible to locate the fault or break by determining the electrical resistance or capacitance of the cable between the testing point ashore and the point of failure at sea. The navigator of the repair ship can then proceed to the vicinity of the trouble and mark the area with a buoy. The cable ship then commences to grapple for the cable (Fig. 35). When the cable has been raised to the surface, test leads are attached and the fault is localized. When it is determined that the cable is electrically sound to one of the shore stations, that end is buoyed. The ship then proceeds to recover the cable on the other side of the fault or break (Fig. 36). This end is picked up until the tests indicate continuity and satisfactory insulation to the cable house. The faulty cable is cut out and new cable from the ship's tanks is spliced on. The cable ship then commences paying out the new cable toward the buoyed end, which, when it is reached, it is taken aboard (Fig. 37). Final tests are taken in both directions. If these tests are satisfactory, the final splice is completed. The cable is then eased over the bow and drops to the ocean bottom.

The cause of failure reported in repair reports is generally not more than a word or two based on the engineer's experience, and unfortunately depends to a large degree on conventional clichés. We must try to analyze the ship report and the reported cause in order to reconstruct the evidence which led the engineer or ship captain to his conclusion. From this uneasy point we can reinterpret his evidence in the light of available oceanographic data and present theory.

Cable failures are divided into faults and breaks. A break is a complete interruption of the electrical circuit. A fault is short to ground without complete interruption of the circuit. Often, faults are left in the cable for some time before the cable is repaired if they are not too serious. Breaks are almost always accredited to "tension." If the writer of the report does not believe in submarine landslides, he may ascribe a tension break to "suspension" of the cable across a chasm. Suspension can, of course, cause failure, but the correct identification of suspension failures is not easy. If the depth is less than 500 fathoms and fishermen are known to frequent the area, the break is ascribed to "trawlers." Generally there are other telltale indications of trawlers' damage such as "mauling," "saw cuts" and "axe cuts." If an earthquake was observed preceding a cable break, "seismic disturbance" is generally entered in the report.

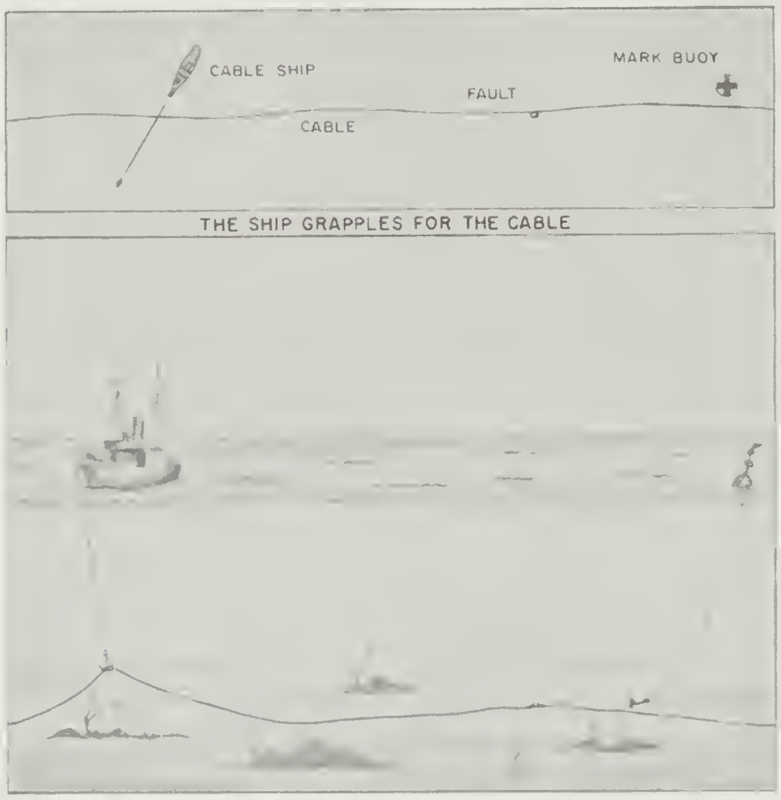


Fig. 35 Cable ship grappling for cable.

Fig. 36 Cable ship hauling in a fault.

Fig. 37 Cable ship paying out new cable to final splice.

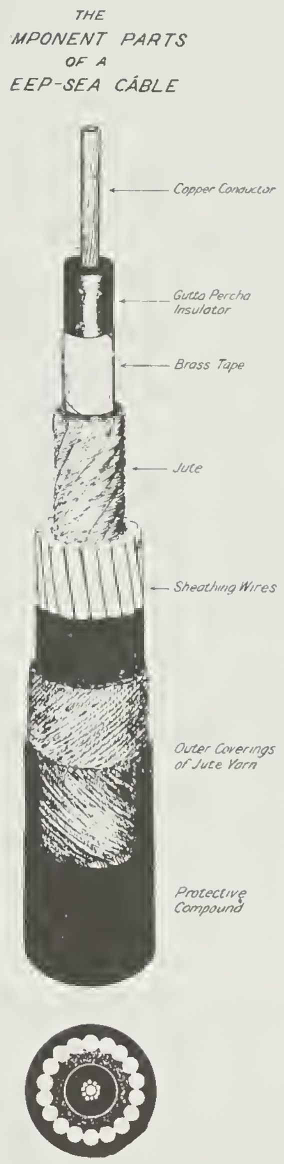


Fig. 38 Component parts of a typical deep sea telegraph cable.

Faults are generally ascribed to "chafe," "corrosion," "chafe and corrosion," "kink," "deterioration," "perished core," "teredo," or "trawler maul." If the armor wires are worn or bright, the failure is ascribed to "chafe." If the cable armor is corroded and not particularly polished, the failure is ascribed to "corrosion." If corrosion and abrasion of the cable are observed in the picked up cable, "chafe and corrosion" are reported. "Kink" or "tightened kink" is probably indicative of tension insufficient to break the cable. However, it is often thought that corrosion of a kink left in the original cable is involved and that no additional tension is indicated. Frequently it is supposed that suspension of an original kink over a long period of time has led to a particular failure. "Deterioration" and "perished core" are probably indications of bacterial action and "teredo," of course, refers to damage by this boring isopod. Considering that the fault or broken end is frequently not recovered and that the men writing the reports are generally not trained in biology or geology, one realizes that he cannot take the brief one-or-two-word reported cause in any specific report as more than an indication of the condition of the picked up cable.

Frequently, however, exceptional observations are reported more fully in the cable report and give us firmer ground. Some cable engineers and captains, endowed with an exceptional interest in the cause of failure and with a flair for writing, have furnished lights to guide us through the fog. Figure 38 shows the component parts of a deep sea cable.

Geographical Distribution of Cable Failures

The breaks and faults in the three Patras-Corinth cables are summarized in Tables V-XIV from the data of laying to about 1957. At that time only cable #2 was operating, #1 and #3 having been abandoned during World War II.

	Year Laid	Year Records Cease
Cable #1	1884	1939
Cable #2	May 1889	1957
Cable #3	1901	1939

The data are grouped into ten areas and the failures are listed chronologically for each area.

Trench line repairs at Patras, Area 1A. (See Table V and Fig. 32.) All repairs listed for Area 1A are routine land renewals and are of no oceanographic interest.

Repairs near the beach at Patras, Area 1B. (See Table V and Fig. 32.) Five of the seven repairs were due to natural causes, two were due to anchor damage. The failures are too few in number to allow the determination of significant patterns.

The Narrows and Western Entrance of the Gulf of Corinth, Area 1C. (See Table VI and Fig. 32) Of the 14 failures, three can be excluded as not being caused by the forces of nature. The cable repairs made 66 to 72 nautical miles from Corinth lie in the western entrance, and those 66 to 63 nautical miles are in The Narrows. Except for one failure which was repaired 2/7/31 (date of failure unknown) and one which occurred in August 1927, the remaining five failures occurred during the normally stormy autumn and winter months.

The failures at the entrance show a similar pattern with one repair in July (date of failure unknown) and 3 in the winter months.

These failures can be ascribed to chafe due to bottom currents flowing through The Narrows. The specific times of failure may have been determined by the occurrence of a particularly violent intensification of the current which snapped the already chafed and weakened cable. The high frequency of failures in the winter and autumn months may be due to storm-augmented tidal current. It could also indicate a particularly high westward flow of water along the bottom of the straits. This may correspond with the formation of bottom waters by the cooling and sinking of surface waters during the winter months. The inward flow of surface water at the straits could at that time be balanced by an outward flow along the floor of The Narrows. There are small streams emptying into The Narrows which could occasionally cause turbidity-current damage. The break on 21/2/21 has the appearance of a turbidity-current failure, although it is impossible to be sure. The Mornos River might also occasionally create a turbidity current in a westward direction.

TABLE V

TRENCH LINE REPAIRS AT PATRAS - AREA 1A (see Fig. 32)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
-	3	BB*	-	-	24/2/16	Renewal	Trench line renewal
-	2	BB*	-	-	25/2/16	"	" " "
-	1	BB*	-	-	25/2/16	"	" " "
-	3	BB*	-	-	25/3/27	"	" " "
-	2	BB*	-	-	25/3/27	"	" " "
-	3	BB*	-	-	27/3/39	"	" " "

*N. B. Cable used was BB (10/6) or 10/2.

APPROACHES TO PATRAS CABLE LANDING - AREA 1B (see Fig. 32)

70	1	A	3	-	6/6/95	Fault	Perished core
71	1	BB*	2-1/2	-	12/3/08	Fault	" "
72	1	BB*	3-1/2	-	11/10/10	Fault	" "
73	2	BB*	2/3	16/5/28	17/5/28	Break	Anchor
72	3	BB*	18	27/11/28	14/12/28	Break	Strain at kink due to ship's anchor
72	3	BB*	-	4/4/31	26/6/31	Break	End pulled out of Patras cable house
72	2	BB*	10	24/11/33	23/12/33	Break	Corrosion

*N. B. Cable used was BB (10/6), B or 10/2. 1895 repair type A failed and was replaced by B.

TABLE VI

CABLE REPAIRS IN AND NEAR THE NARROWS - AREA 1C (see Fig. 32)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
68	3	BB	40	19/2/12	24/2/12	Break	Chafe and corrosion
68	2	BB	25	12/3/15	14/3/15	Break	Chafe and corrosion
68	3	BB-Dt	38	14/2/18	1/5/18	Fault	Boom defense
72	2	Dy-BB	22	-	1/2/20	Fault	Unrecovered
65	1	Dt	31	21/2/21	2/3/21	Break	Chafe and corrosion (strain evident)
68	1	BB-15/3	44	26/3/27	27/3/27	Fault	Boom defense mooring
63	3	Dt	46	17/8/27	18/8/27	Break	Corrosion
66	3	-	27	-	2/7/31	?	?
65	3	16/11-18/13	29	27/1/32	9/9/32	Break	Chafe and corrosion
70	1	-	-	-	11/7/33	Fault	Perished core
66	3	B	30	27/3/39	5/12/39	Break	Chafe and corrosion
66	2	Dy	-	18/8/49	21/8/49	Cable cut by robbers	
63	2	Dy	47	-	5/9/49	Fault	Perished core; teredoed
66	2	-	47	9/2/57	-	Break	Corrosion

TABLE VII

CABLE REPAIRS IN THE WESTERN GULF - AREA 2 (see Fig. 32)

Naut. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Causes of Failure
62	2	-	37	25/8/89		Break	Submarine landslide caused by strong earthquake. One mile unrecovered ... "indicating a mechanical force sweeping down over the cable from the point on the northern shore due east of Lepanto and in a southwest direction." (Forster 1890)
61	2	B	51	22/4/95	2/5/95	Break	Chafe.
60	2	D	46	4/10/97	12/10/97	Break	Submarine landslide.
61	2	Dy	43	?/1/18	21/2/18	Break	Corrosion ... "but the cable was silted in place and could not be reached."
59	2	Dy-Dt	55	30/3/28	4/4/28	Break	Original break due to effects of submarine river ... "the cable was deeply buried in patches the picking up strain at times rising to 60 cwt from normal - about 3 cwt. Heavy entanglements of dead shore scrub and brush occurred at frequent intervals indicating a submarine freshwater stream from the surrounding snow-clad mountains. The break was probably due to the collapse of a gully which had been formed in the sea bed and the heavy weight of brush entanglements in the bottom depth currents."

TABLE VII (Cont'd.)

AXIAL CANYON - WESTERN GULF OF CORINTH - AREA 3A

Naut. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Causes of Failure
53	2	D	104	10/9/02	-	Break	Strong quake at Patras. #2 cable went dead.
54	2	D	202	9/5/05	9/12/05	Fault	Bad kink.
57	2	Dt	164	8/5/10	10/5/10	Break	Corrosion.

Seaward of Mórnos River, Area 2. (See Table VII and Fig. 32.) Five of the six failures off the Mórnos River were probably caused by turbidity currents. The first break on 25/8/89 followed an earthquake and was probably caused by a seismically triggered turbidity current. (The same earthquake also caused a break in Area 5A.) The fact that cables 1 and 3 which lie along the south shore of the strait did not break in Area 2 supports the conclusion that all five breaks were due to turbidity currents flowing down slope from near the mouth of the Mórnos River.

Just conceivably, the breaks in Area 2 may be due to the outflow of deep gulf water along the bottom. A westward flow would be deflected to the right, thus explaining the distribution of failures on the right side only. However, the evidence seems to favor turbidity currents from the Mórnos River. Of course there may be a relation between the frequency of turbidity currents off the Mórnos River and the quantity of sediment transported through the straits by the bottom current. The rains in January-March may provide "teeth" to the bottom currents in the form of detrital sediment, and the increased transport of sediment might then cause the failures in The Narrows. Needless to say, this relationship is extremely speculative.

Axial Canyon - Western Gulf of Corinth, Area 3A. (See Table VII and Fig. 32.) Three failures have occurred in cable 2 where it crosses the Mórnos submarine canyon, which runs from the vicinity of the Mórnos River mouth to the abyssal plain of the Eastern Gulf. The failure in 1902 was probably caused by a turbidity current triggered by a strong earthquake. This turbidity current probably originated near the Mórnos River and flowed down the canyon to the abyssal plain. Only cable 2 was disturbed in this area because the other two cables do not cross the Mórnos Canyon. The canyon can be clearly seen in Fig. 3.

Continental Slope Seaward of Erineóus River, Area 3B. (See Table VIII and Fig. 32.) Four failures have occurred in this area. In 1907 cables #1 and #3 failed on the same day. Both cables showed evidence of violent strain. The two 1907 breaks could have been caused by two currents, one flowing northwest and the other southeast, each of which broke one cable without breaking the other. The concept of a single large flow is, however, favored. Of the other failures, two were in April and one in November, which corresponds generally to the time of maximum precipitation, and are therefore probably the result of turbidity currents generated by the Erineóus River.

Continental Slope and Plain Seaward of the Meganitís River, Area 4. (See Table VIII and Fig. 32.) The break on 9/11/1888 is unrelated to the other three failures in this area. This break occurred following the earthquake at 1704 L.S.T. 9/11/1888. The town of Vostissa was destroyed and a moderate tsunami was observed on the opposite side of the gulf. The town had been previously damaged in 1861 by an earthquake. It is presumed that most of the unstable sediment was dislodged by these two earthquakes and for this reason, failures have subsequently ceased in this area. There is some suggestion that the 20/11/88 failure in Area 5A may have actually occurred on the ninth, having been triggered by the same earthquake. Of the remaining three breaks in Area 4, two are on the abyssal plain of the gulf. Two were faults and one was unrecovered.

Continental Slope Seaward of Kratís and Kriós Rivers, Area 5A. (See Table IX and Figs. 32 and 39.) There have been 12 failures in this area of which 7 can be definitely attributed to turbidity currents and slumps. As can be seen from Fig. 3 there is a suggestion of submarine canyons in this region, but unfortunately we have no echograms in this area. It is difficult to ascertain if these breaks occurred in one large canyon fed by the Kratís, in several smaller individual ones, or in several small canyons which join at the base of the slope to form one larger canyon. It seems most likely that the Kratís, Peloponnesus, and Kriós have formed individual canyons which may join at the base of the slope.

During the 1935 repair a jumble of debris was found tangled in the cable. This break occurred along with several others during the severe gales of December 1935. Of the four nontension breaks, it is interesting to note that in two cases the cable was deeply buried, probably by deposits of alluvium laid down turbidity currents and slumps.

TABLE VIII

CABLE REPAIRS OFF THE ERINEOUS AND MEGANITIS RIVERS -

Continental Slope Seaward of Erineous River - Area 3B

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cuase of Failure
53	1	-	150	19/4/07	24/4/07	Break	"The break in this and #3 section seemed both caused by some violent tension, but there is nothing to show the cause, although it is suspected to be due to earthquake.
51	3	-	158	19/4/07	24/11/07	Break	As above.
52	3	Dt	140	-	2/6/21	Fault	Intermittent fault - deeply buried .
53	1	Dt	164	12/11/27	14/11/27	Break	(Unrecovered) 'Probably due to a form of submarine landslide, brought about by torrents . . . a portion recovered deeply silted. "

TABLE VIII (Cont'd.)

Continental Slope Plain Seaward of the Meganitis River - Area 4

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Causes of Failure
49	1	-	300	9/9/88	-	Break	"Completely fractured . . . both ends were frayed out . . . the break was caused by the cable being suddenly tauted by a mass of clay and mud sweeping down from the 100 fathom band towards the 300 fathom bottom . . . the ends of the cable for some length were covered up more or less firmly by what appeared when brought to the surface as fresh clay or mud." Strong earthquake destroyed the city of Vostissa two miles to the south. Cable interruped at 1704 LST. (Forster 1890)
40	2	Dy	360	-	11/7/09	Fault	Badly perished core (unrecovered) cable was deeply buried as it kept parting and part had to be abandoned.
45	1	-	222	-	3/3/30	Fault	Teredo.
40	2	D	350	28/7/37	5/8/37	Break	(Not recovered) probably due to corrosion.

TABLE IX

CABLE REPAIRS OFF THE KRATIS AND KRIOS RIVERS - AREA 5A (see Figs. 32 and 39)

Nauts. from Corinth	Cable No.	Type of Cable	Depth of Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
28	1	-	200	20/9/88	25/9/88	Break	Cable snapped by heavy strain.
29-27	1	-	400	25/8/89	-	Breaks	Caused by slump generated by earthquake at 2051 LST.
30	1	Dt	400	30/5/09	11/6/09	Break	Probably earthquake (unrecovered).
29	3	Dt	398	28/8/13	30/8/13	Break	"It was evident now that 3 nauts. of cable to the east were deeply embedded in masses of mud, which were apparently shifted on to cable by the terrific force of the river Kratis which runs into the sea at this point. This is proved by the fact that as soon as we grappled a little to the west of this river the cable was hooked.
28	3	Dt	413	18/1/14	13/2/14	Break	Submarine landslide. "Break was due to a heavy body falling on the cable which was found badly flattened and twisted." "Cable was run north in order to get it out of reach of the destructive torrents from the Peloponnesus."
27	3	Dt-Dy	443	26/6/31	30/6/31	Break	Corrosion, cable was deeply buried. "The cable was apparently buried by silt from the mountain torrent . . . only the long prong grapnel could reach it."

TABLE IX (Cont'd.)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
28	3	D	419	9/12/35 16/12/35	20/12/35	Break	"Chafe and tension caused by accumulation of alluvium-coincided with a bad gale in the Gulf of Corinth. It was due primarily to chafe, probably at the point of suspension, but final rupture was without a doubt accelerated by the stress of alluvium deposits which, including roots and branches of shrubs and a jumble of brushwood, were found foul of the cable near the original break." "A jumble of some 50 fathoms of abandoned cable was wrapped securely around the section under repair. Twigs and leaves of bushes were caught in the maze." "Sheathings were polished with slow chafe probably caused by the action of alluvium through the 15 years the cable had been laid. Roots or bushes and their branches, together with a jumble of brushwood, were recovered near the original break." "There were only minor signs of strain within 100 fms of each end of this tension break, but about 180 fathoms on its Corinth side. The section was fouled by a jumble of approximately 50 fathoms of abandoned cable. Twigs and leaves of bushes were caught in the jumble. It is thought this abandoned cable may have offered obstruction to a growing accumulation of river mud, etc., which finally exerted sufficient pressures over a long length of working cable to cause rupture. Several torrents and one mountain river debouch in the gulf in the immediate vicinity, carrying - especially during the winter gales of rain and hail - a vast quantity of alluvium into the sea."
31	1	Dt	420	19/4/39	20/11/38	Break	Due to corrosion.
32	2	-	412	5/9/49	-	Break	Not recovered probably due to corrosion.

Fig. 39 Location of all cable failures and cable repairs in areas 5A, 5B and 6.

Continental Slope Seaward of the Avgó River, Area 5B. (See Table X and Figs. 32 and 39.) There have been eight failures in this area. Seven are clearly due to turbidity currents or slumping. The fault repaired on 3/11/13 is most likely related in cause to the other seven. All these failures occurred from September to February, which corresponds well with the maximum precipitation (Fig. 23). The failures are aligned in a NW and SW pattern along one large canyon. At 1630 L. M. T. on the 18th of September 1910, both cables 1 and 3 were broken. They must have been broken by one large flow down the axis of the canyon. On all other occasions, however, only one of the two cables broke. Cable #3, which lay closer to the mouth of the Avgó, failed five more times, but cable #1 failed only once again, during the December 1935 storms. Cable #3 possibly escaped injury in 1935 because it was newer and therefore stronger than the #1 cable, but it may have been buried; or lacking obstructions or brush entanglements, the flow could have swept over it without breaking it.

Continental Slope Seaward of the Dendron River, Area 6. (See Table XI and Figs. 32 and 39.) The eight failures in this area were all the result of slumps or turbidity currents originating at the mouth of the Dendron River. Cable #3 crosses the submarine canyon on the continental slope, cable #1 lies at the base of the continental slope on the narrow continental rise, and cable #2 lies on the abyssal plain. In 1908 three failures occurred in cable #3. In 1914 a fault developed in cable #2. When repairing this fault, the repair ship found #2 deeply buried. They parted the cable 18 times and finally had to abandon 12 nautical miles, since they were unable to pick it up. It appears that the flows from 1884 until 1914 had deposited sufficient sediment over #2 to cause this difficulty. These flows were either the ones which broke cable #3 in 1908, or else smaller flows which did not have sufficient power to break any of the cables. #1 was unaffected during this period, probably because it had been buried by earlier flows. At 0430 L. M. T. 18 December 1920, both #1 and #3 were broken. This was most likely the result of a single large flow which had sufficient force to uncover and break #1 in addition to #3. In 1935 #3 broke during the severe gale, which resulted in several other failures. #1 was not affected in 1935 but in 1938 it was broken by a turbidity current which deposited twigs and foliage in the area.

TABLE X

CABLE REPAIRS OFF THE AVGO RIVER - AREA 5B (see Figs. 32 and 39)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
26	1	Dt	398	19/9/10	6/10/10	Break	Submarine landslide. "There had been a considerable strain on cable while it was being recovered, which proved it had been deeply buried."
25	3	Dt	422	18/9/10	27/9/10	Break	Unrecovered; probably due to submarine landslide. "Cable flattened, probably due to submarine landslide . . . it was evident now that 3 naut. of cable to the east were deeply embedded in masses of mud which were apparently shifted onto cable by the terrific force of the Kratis which runs into the sea at this point. This is proved by the fact that as soon as we grappled a little to the west of this river, cable was hooked."
25	3	Dt	200	18/11/11	23/11/11	Fault	Fault jag caused by submarine landslide. "Cable buried by heavy masses of mud and silt." "It was seen that the cables contain some twists and small jags as well as the main jag which had been the cause of the fault. These marks were evidently due to the submarine landslide, the bottom at this position

TABLE X (Cont'd.)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
							across the mouth of the large torrent, close to Avgo Peak being extremely anomalous. The recovered cable had been for the greater part deeply buried but in one place it had been suspended, for when recovering the fault, a large mass of driftweed and wood which had accumulated round the cable in a very entangled manner was brought to bows."
26	3	Dt-Dy	400	-	3/11/13	Fault	At kink.
27	3	-	410	18/12/20	27/12/20	Break	"Buried by deposits from torrents; unable to hook."
25	3	-	210	5/1/23	-	Break	Cable damaged by landslide.
26	3	Dt	400	22/2/29	27/2/29	Break	"Buried by deposits from torrents; unable to hook."
25	1	16/10?	352	9/12/35	23/12/35	Break	(See Sect. 5.) "The break was caused by tension at a point of corrosion, the former probably being due to increasing accumulation of alluvium augmented by heavy winter gales of rain and hail which persisted throughout the 9 December and subsequent days. During the same period breaks similarly caused had occurred in Patras-Corinth #3. The grapnel was caked with heavy black mud."

TABLE XI

CABLE REPAIRS OFF THE DENDRON RIVER - AREA 6 (see Figs. 32 and 39)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
21	3	Dt	105	28/2/08	9/3/08	Fault	"Jammed core."
20	3	Dy	50	14/5/08	15/6/08	Break	"Submarine displacement."
22	3	Dt	100	29/9/08	7/10/08	Break	"Break was due to damage caused evidently by submarine landslide. This piece was badly jagged and flattened, and contained many kinks."
23	2	Dt 11/13-10/13	420	14/2/14	15/3/14	Fault	Unrecovered; cable probably deeply buried as had trouble pulling it up.
21	3	Dy	100	18/12/20	23/12/20	Break	"Buried by deposit from torrents; unable to hook."
21	3	Dy	400	18/12/20	23/12/20	Break	Submarine landslide.
21	3	D	90	9/12/35-16/12/35	19/12/35	Break	"Slides triggered by strong gales, "See also further remarks under Sect. 5.
21	1	Dt	360	30/11/37	25/4/38	Break	Due to corrosion at twist. "The cable was obviously buried by alluvium, the grapnel being chocked with tree roots and decayed foliage."

Continental Slope Seaward of the Sithas River, Area 7. (See Table XII and Figs. 32 and 40.) The nine failures in this area all resulted from turbidity currents or slumps originating from the mouth of the River Sithas (Fig. 40). The failures in cables #1 and #3 all occurred in the submarine canyon of the River Sithas. In Fig. 16 canyons are visible in profile 12S at shallow depth and again in profiles 11S and 12S at the base of the slope. The one fault in #2 occurred in the abyssal plain. The failures must have been caused by small turbidity currents because in only one case (1921) did the #1 and #3 cables fail simultaneously. Although #1 failed in 1904, 1909, 1914 and 1918 during the same interval, cable #3 did not fail once. The failures are probably to be attributed to small turbidity currents which had enough force to break cables only on the steepest slopes when they were traveling at their maximum velocity and carried their maximum loads. The frequent reports of brush and tree trunks suggests that only when they are carrying such debris, or when enough is caught in the cables to present a sufficient obstacle, can the currents exert enough pressure on the cables to cause failure.

This pattern is understandable if we consider the steep slopes involved (Fig. 26), the frequency of trigger effects (earthquakes and floods), and the consequently relatively small quantity of sediment available for each flow. All the failures occurred in the autumn to winter months, again possibly indicating a correlation between river discharge and failures.

Continental Shelf and Slope East of Sithas River, Area 8. (See Table XIII and Fig. 32.) Of the five repairs reported for this area, three are faults. Two repairs were made to cable #3, which lies near the edge of the continental shelf in this area. The three repairs to cable #1, which lies on the continental slope, may be due to slumps or weak turbidity currents. Three of the failures occurred in March and one in August. This suggests a possible correlation with the late winter gales which may trigger displacements from the shore. The one failure in April was due to a landslide triggered by an earthquake.

TABLE XII

CABLE REPAIRS OFF THE SITHAS RIVER - AREA 7 (see Figs. 32 and 40)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
19	1	D	275	6/1/04	9/1/04	Break	"The break in this cable was caused by heavy brushwood and tree trunks from mountain torrents having been swept down and encircling the cables which must have been suspended between rocks for the circumference of the brushwood was 5 fathoms."
18	1	Dt	300	28/8/09	5/9/09	Break	Damage due to falling mass. Unable to grapple. "It seemed very evident that the cable in this vicinity was considerably embedded, for its true position was known and yet our long prong grapnel could not reach it." "Recovered .455 naut. to fresh break, the last 0.66 naut. of which was very badly damaged and flattened - the core having been forced out between the sheathing wires. By this it was concluded that either a heavy mass of hard clay had been a submarine displacement and the displaced mass had lodged upon the cable."
17	1	Dt	300	5/12/14	7/1/15	Fault	Due to a jag apparently caused by submarine landslide "cable being embedded very deeply in mud."
18	1	Dt-Dy	340	30/10/18	6/11/18	Break	Due to submarine landslide. "While picking up, cable was so deeply buried that at times our gear was unable to clear it." "In paying out cable it was taken into deeper water to get it as far as possible from the influence of the torrents as was reasonable in this instance when the gap was small."

TABLE XII (Cont'd.)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
17	3	Dt	220	20/10/19	24/10/19	Break	"Cable fouled and could not be cleared. Evidently a submarine landslide had broken cable and buried it."
18	2	Dy	450	-	14/12/20	Fault	Corrosion (renewal). Two faults due to corrosion. Cable was deeply buried as positions had to be abandoned.
17	3	Dt	50	9/12/21	13/12/21	Break	Damaged and fouled by debris from torrents.
18	1	Dt	370	9/12/21	14/12/21	Break	"The break was caused by the usual submarine landslide, originated by the heavy torrents from mountain water courses. Cable recovered in poor and damaged state, owing to debris from torrent. Most of the picked up cable had been badly silted in mud, and jagged and ruffled, and in some parts had been suspended, as there were trees and masses of branches and weed entangled about it. We consider, however, that when cable is available and repairs are necessitated in this vicinity, that extensive diversions to the #1 and #3 sections should be affected and thus eliminate the frequent interruptions which are invariably caused by the torrents.
17-16	3	D	100 50	27/3/39	8/12/39	Breaks	Chafe and corrosion.

TABLE XIII

CABLE REPAIRS - SITHAS RIVER TO CORINTH BAY

Continental Slope and Shelf East of Sithas River - Area 8 (see Fig. 32)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
14	1	Dt	271	7/3/00	8/3/00	Break	Corrosion and splice slipping.
14	1	Dt	220	22/4/28	30/5/28	Fault	Due to tightly drawn kink; "Evidently cable was buried as at this part submarine landslides occur from time to time, and in this instance the fault appeared at the time of the big earthquake in Corinth."
11	3	D	300	-	22/8/35	Fault	Teredo.
14 & 11	3	D	75-50	27/3/39	6/12/39	Faults	Perished core.
11	1	Dt	300	1/3/40		Break	Corrosion; sheathing was needle-pointed.

TABLE XIII (Cont'd.)

Continental Shelf in Corinth Bay - Area 9 (see Fig. 32)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
8	3	D	40	22/3/23	12/4/23	Fault	At joint, due to teredo.
10	3	D	60	3/3/30	21/7/30	Break	Corrosion.
5	3	Dt-Dy	60	12/2/33	26/2/33	Break	Chafe and corrosion.
8	3	D	43	9/12/35-16/12/35	17/12/35	Break	Corrosion, see earlier remarks - Sect. 5.
4	3	D	40	6/1/35	6/4/35	Break	Corrosion.
8	1	Dy	105	26/12/39	20/2/40	Break	Due to needle-point corrosion.
6	1	-	66	20/2/40	-	Break	Corrosion (?).

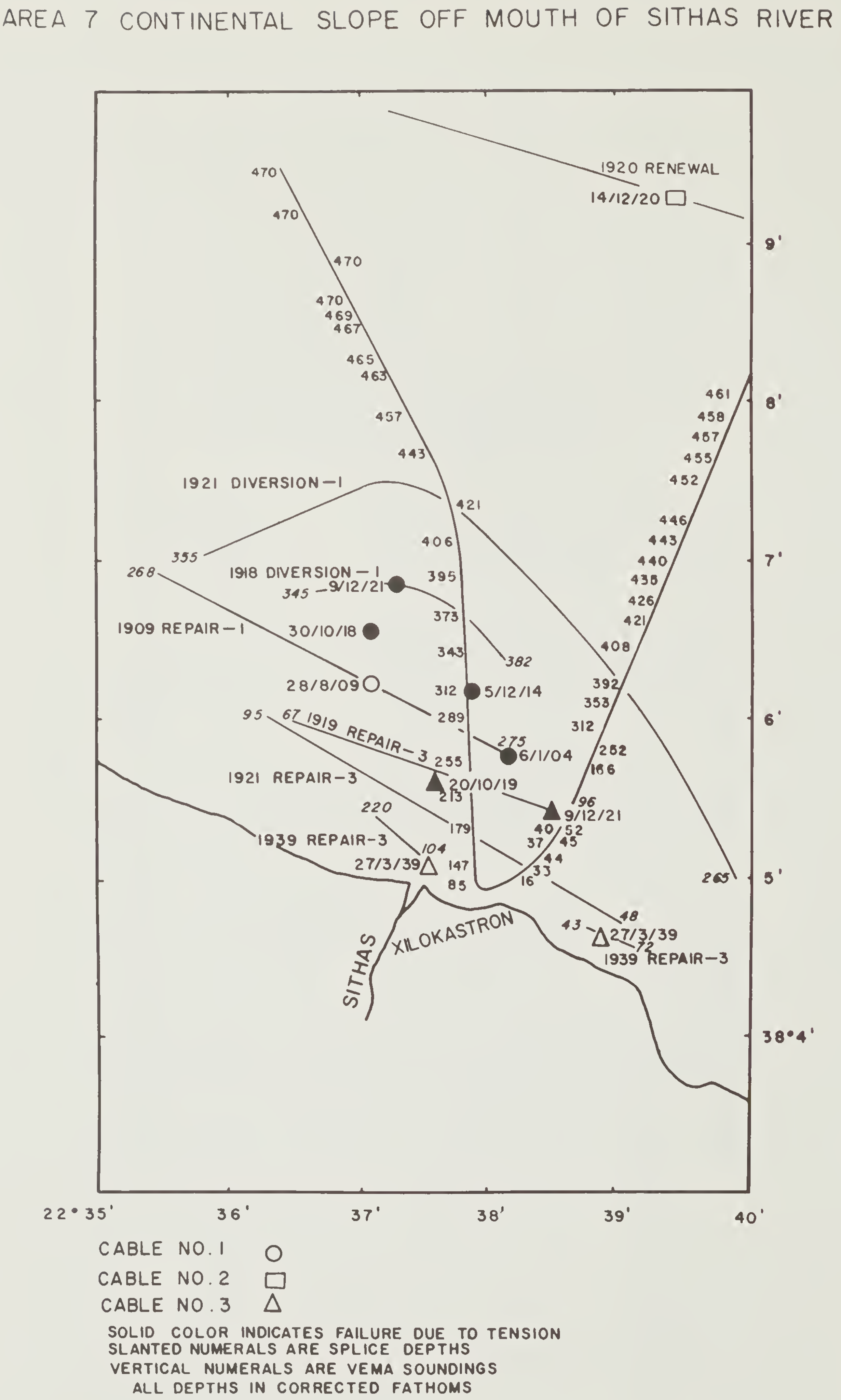


Fig. 40 Location of all cable failures and cable repairs at the mouth of the Sithas River.

Continental Shelf in Corinth Bay, Area 9. (See Table XIII and Fig. 32.) The seven failures in Corinth Bay all occurred between late December and mid March. They are all (except possibly 26/12/39) probably due to chafe, and their times of failure probably are determined by the occurrence of heavy winter gales. Six of the seven failures were breaks, which suggests that a strong current or slide caused the failures. Since six of the failures were on the broad shelf of the Bay of Corinth, the failures were probably due to the action of bottom currents on the cables weakened by chafe rather than by slumps or turbidity currents.

Approaches to the Corinth Cable Landing, Area 10A. (See Table XIV and Fig. 32.) Of the 22 failures near the beach at the Corinth landing, all can probably either be attributed to anchors or other human damage. The large number of ships that have hooked the cable while waiting to clear the canal have necessitated such frequent repairs to the cable that the wearing action of waves and currents have never had time to chafe through any of the cables.

Trench Line Repairs, Corinth, Area 10B. (See Table XIV and Fig. 32.) Trench line repairs due to deterioration have been less frequent at Corinth than at Patras, since on several occasions ships have pulled the cable out from the cable hut, requiring the replacement of the entire shore end and trench line. The trench line cables and the cable used in approach to the cable landings are usually B type. The remainder of the cable length was almost invariably a form of D cable. This makes it difficult to say that one cable broke and the other was unaffected because it was a stronger type. It is most likely that if a type B or C cable had been used to traverse the length of the Gulf of Corinth, the number of failures would have been reduced significantly.

Discussion of Gulf of Corinth Cable Failures

Damage by Human Activity. Twenty-five failures have occurred due to anchor damage. The great majority of these failures occurred off Corinth, presumably inflicted by ships waiting to enter the canal. In two cases the cable was stolen by robbers, and was once broken by fishermen's dynamite. There are also two instances in The Narrows when boom defense moorings damaged the cable. These failures have no geologic interest except insofar as they make impossible a study of chafe due to breakers and surf.

TABLE XIV

CABLE REPAIRS AT CORINTH

Approaches to Corinth Cable Landing - Area 10A (see Fig. 32)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
.1	1	-	10	5/10/10	25/10/10	Break	Puncture.
1	3	-	10	20/11/15	3/12/15	Breaks	Two due to ship's anchor; third due to strain.
.8	2	-	3	22/11/15	1/12/15	Break	Anchor.
.4	3	-	6	12/6/17	15/6/17	Break	Parted by strain at chopped place; cable hooked by anchor.
.1	3	-	-	15/6/17	16/6/17	Break	Anchor.
.8	3	-	14	16/12/18	22/12/18	Break	Anchor.
.7	1	-	15	28/1/20	28/;/20	Break	Cable end dragged out of cable house by ship's anchor.
1.6	3	-	20	31/1/20	2/2/20	Break	Cable end dragged out of cable house by ship's anchor.
.5	3	-	10	12/11/22	1/1/23	Break	Anchor and axe break inshore.
.6	1	-	10	12/12/22	16/12/22	Break	Cable strained, twisted and core spewed; anchor hook.
.2	2	-	-	12/12/22	17/12/22	Break	Badly corroded; end damaged by ship's anchor hooking cable seaward.
-	3	-	-	31/12/22	31/12/22	Break	Pulled out of trench by ship's anchor.

TABLE XIV (Cont'd.)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
.3	1	-	4	22/2/26	23/2/26	Break	Cable hooked by ship's anchor and drawn away from Corinth cable house.
.1	1	-	-	2/1/27	3/1/27	Break	Cable hooked and pulled out of cable house by some ship.
-	2	-	-	9/2/27	20/2/27	Break	Cable hooked by ship and drawn a short way from cable house.
.6	3	-	15	9/2/27	19/2/27	Fault	Anchor damage.
.1	2	-	-	2/7/31	3/7/31		Core exposed for two fathoms; sheathing stripped by fisherman's dynamite.
.5	1	-	15	15/11/32	25/2/33	Break	Anchor hook.
.2	2	-	4	15/11/32	23/2/33	Break	"Corroded kink "... due to #1 having been dragged across #2.
.2	3	-	1/2	5/9/32	10/9/32	Break	Dynamite used by fisherman.
1	2	-	20	20/8/49	27/8/49	-	Replacement of missing (believed stolen) shore end at Corinth and repair of two old breaks, one unrecovered, probably due to anchor; other due to trawler or mine sweeper.
1	2	-	15	27/3/54	18/5/54	Break	In conductor; ship's anchor.

TABLE XIV (Cont'd.)

Nauts. from Corinth	Cable No.	Type of Cable	Depth in Fathoms	Date of Failure	Date of Repair	Type of Failure	Reported Cause of Failure
-	2	-	-	-	16/10/03	Renewal	Trench line repair.
-	1	-	-	-	3/7/31	Renewal	Cable house end badly perished and cracked.
-	3	-	-	-	2/7/31	Renewal	Fault at Corinth cable house.
-	3	-	-	-	19/5/36	Renewal	Corinth trench end repair.

Shelf Failures. The 21 cable failures (excluding Area 2) on the shelves ranging from 25-100 fathoms depth testifies that sufficient abrasion occurs in those depths that the light (D) and intermediate (B) type armoring is gradually worn through. The failures on the shelves cannot, in general, be ascribed to gravitational movements, since the slopes are too low to initiate movements and also too low to sustain them.

Failures in The Narrows. The cables pass through the narrow straits known as The Narrows. Strong tidal currents flow in and out through these straits at the surface. The depth of the sill is 30 fathoms. The cables through The Narrows have broken seven times, generally in the stormy autumn and winter months when gales might be expected to augment the tidal action.

Gravitational Movements. The cables have been broken by slumps and turbidity currents which originated off the mouths of rivers emptying into the gulf. A minimum of 47 breaks have occurred which are related to at least 10 different streams.

A most important conclusion of this study is that a turbidity current may cross a cable without snapping it. The basis for this conclusion is that on only four occasions have both cables crossing a canyon been broken simultaneously. On all other occasions either #1 or #3 failed and the other one remained intact. Cable #2, which lies in the abyssal plain, was found deeply buried during the very few times it was recovered. The frequent reports of entanglements of brush and trees in the cables indicates that the turbidity currents in the gulf generally do not break the cables unless sufficient resistance is offered due to entanglements of brush which increased the cable's effective cross section.

Turbidity currents and slumps; breakage of cables. There are many mountain streams which empty into the Gulf of Corinth, and during times of flood these streams carry a heavy load of sediment and debris. As one can see from examining Tables V-XIV, there are many cases in which branches, twigs and brushwood of various kind have been found wrapped around the broken cable. As can be seen from Fig. 41, there is a tendency for cable failures due to turbidity currents or slumps to occur during the winter months, with November, December, and January as the peak months. The high incidence of winter breaks corresponds to the season of maximum precipitation for the area (Fig. 23). The December 1935 breaks occurred during the first heavy winter gales. The repair ship log also notes: "Several torrents and one mountain river debouch in the gulf in the immediate vicinity carrying, especially

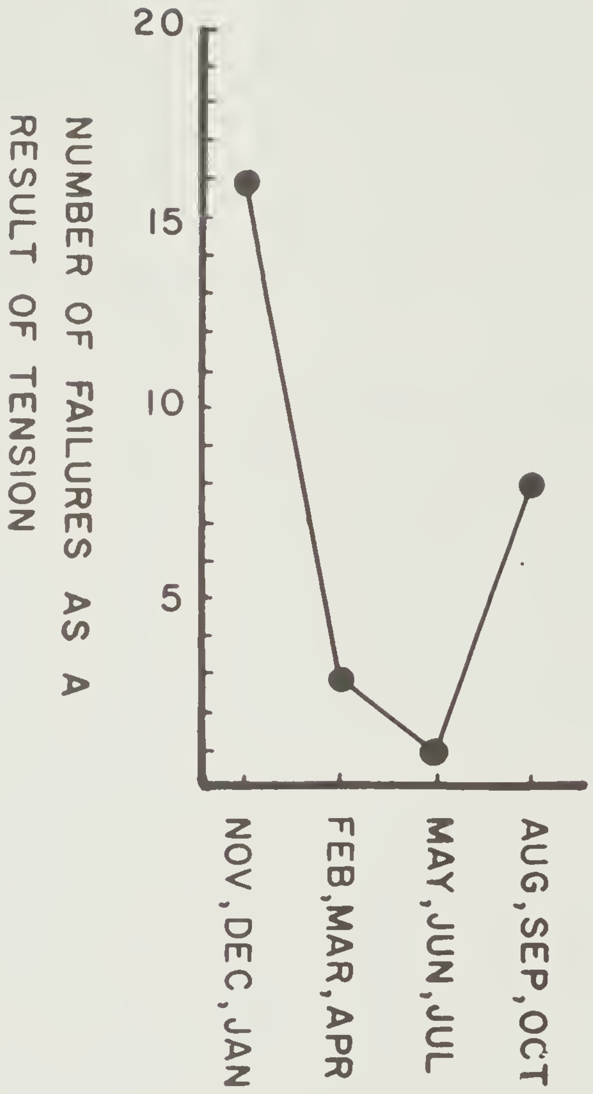


Fig. 41 Seasonal distribution of tension breaks.

during the winter gales of rain and hail, a vast quantity of alluvium into the sea." In all, the cable ship repair logs list a total of 28 breaks as due to submarine displacement or tension.

Turbidity currents and slumps; burial of cables. In the few times that cable #2 developed faults, it was found to be buried. The fault in Area 5A (Fig. 32) 5/19/49 could not be recovered, indicating deep burial. Again in Area 6 - on 14/2/14 - the fault was unrecovered. The repair ship had trouble raising the cable - a fact indicative of deep burial. The cable was hooked and parted 18 times. The 7/4/09 break also showed indications of burial.

Cable diversions. The cable company soon began to detour its repairs in a loop around the areas where breakage was most frequent. In Fig. 39 the 1935, 1937, and 1938 repairs on cable #1 represent successful detours around the river mouths. The 1911 diversion for cable #3 in Area 5B around Avgó River was not sufficiently far out and the cable broke again in 1923. The 1914 diversion of cable #3 in Area 5A was successful.

Earthquakes. There are at least 6 breaks which are definitely associated with earthquakes. The earthquakes trigger slumps along the slopes, which deeply bury and break cables in their path. Following the 1889 August 25 earthquake which damaged Xilokastrom, both #1 and #2 cables broke at widely separate areas.

Cable failures off the Sithas River - an example. The group of cable failures located off the town of Xilokastron on the south shore of the Gulf of Corinth is particularly interesting and will be discussed in more detail (Fig. 40). In this immediate vicinity the River Sithas empties into the gulf from the mountain Killini Seria, 2376 m. in altitude (see Fig. 26). There have been nine cable failures here since 1904, six of which are definitely attributable to turbidity currents generated at the mouth of the Sithas. With the exception of the break on 28 August 1909 (which probably was related to an earthquake), all the breaks occurred during the autumn-winter season, which corresponds to the time of maximum precipitation for this area. It seems probable that the Sithas during times of flood, while swollen with silt and debris, triggered the turbidity currents which caused the breaks.

We will examine the breaks in chronological order:

The first failure in this area occurred on 6 January 1904. There is not much information in the repair ship's log book as to the difficulties encountered in recovery. There is, however, one very significant paragraph:

"The break in the cable was caused by heavy brushwood and tree trunks from mountain torrents having been swept down and encircling the cables, which must have been suspended between rocks, for the circumference of the brushwood was five fathoms."

The brushwood was almost certainly carried down the slope by a turbidity current. It would appear in this case that the cable crossed a submarine canyon scoured by turbidity currents. During the periodic flooding of the river, material was swept down the submarine canyon with some of it entangling in the cable. Eventually the mass of debris increased to a point where its cross section offered such an obstruction to turbidity currents that the cable snapped. Alternatively, the debris could all have been carried by one large flow. In any case, a tangle of brushwood thirty feet in circumference would no doubt offer sufficient resistance to a turbidity current to break the cable.

The next break occurred 28 August 1909. This break was probably related to an earthquake. Malladra (1925) lists this break as "Seismic disturbances probably caused by landslide of a heavy mass of hard clay on cable." Obviously the landslide did not cause the earthquake, but rather it seems likely that a small earthquake jarred loose some alluvial sediment from the shelf. Since only cable #1 was broken, the slump was either fairly small or originated seaward of cable #3 on the continental slope, or else it passed over cable #3 without breaking it. It would be expected that a slump would deeply bury that cable. The following quotation from the ship's log will indicate the difficulties caused by this deep burial:

"Grappled until 2 P.M. having made nine steady and long sweeps over line of cable with no signs of having hooked it. Occasionally the hard patches of clay were encountered and these 'brought up' the ship, but the greater part of grappling ground appeared to be muddy and of a viscous nature."

(Next day) "Down grapnel. Ship made 7 drives, sweeping carefully across line each time, and working gradually eastward 0.75 naut. of cable had been covered but no signs whatever of having hooked or touched it. It seemed very evident that the cable in this vicinity was considrably embedded, for its true position was known and yet our long prong grapnel could not reach it."

(Following day) "After nine drives and when ship had gradually worked eastwards to .45 nauts. east of Levant #1 (first splice March 04), the cable was hooked. Commenced to pick up cable bight.

"A very heavy strain was soon observed, however, and when the cable had been raised about 150 fathoms from bottom, the picking up of gear could not overcome the strain. Occasionally the strain would give way for a moment, and a few fathoms of rope could be snatched. But this state of affairs did not last long, for at 2 P. M. the strain fell suddenly, indicating the cable had parted to the westward.

"Hooked cable after seven drives at . 748 naut. west of final splice. While raising cable, a similar strain as that on the Corinth end was encountered and it was thought the cable would part; fortunately this did not occur.

"... endeavoured to recover as much as possible of the fouled eastern end, but the end could not be brought more than a few fathoms inboard, so cable had to be cut and abandoned."

The following quotation indicates how badly crushed the cable was:

"Recovered . 455 naut. to fresh break, the last . 066 naut. of which was very badly damaged and flattened, the core having been forced out between the sheathing wires. By this it was concluded that either a heavy mass of hard clay had accumulated as the result of the deposit from mountain torrents and settled down upon the cable, or that there had been a submarine displacement and the displaced mass had lodged upon the cable."

The next fault occurred 5 December 1914. Evidently the cable had been buried by a mass of alluvium carried down by a turbidity current. A very heavy strain was observed while picking up the cable. During burial the cable was damaged, since the repair ship's log lists the fault as caused by a "jag caused by a submarine landslide."

On 30 October 1918, #1 cable was again broken. The cause of the break is similar to that for the 1914 repair. A quotation from the repair ship's log indicates the similarity, and also their awareness of the cause:

"While picking up, cable was so deeply buried that at times our gear was unable to clear it. Recovered cable badly damaged and jagged owing to heavy body falling on cable. In paying out cable it was taken into deeper water to get it as far as possible from the influence of the torrents as was reasonable in this instance where the gap was small."

On 20 October 1919, #3 cable broke in this area for the first time. It was a typical turbidity current burial and break. The cable was fouled and could not be cleared by the ship. This is the first instance in this area of rupture due to turbidity current in #3. It is assumed that #3 lay near enough the land to escape the destructive force of a turbidity current as it swept down the slope, although it must have been subjected to considerable chafe. Since #1 cable was not broken at this time, the current must have been relatively weak. Another contributing factor could be the fact that #3 cable was 18 years old and probably fairly weak due to chafe and corrosion by this time.

On December 14, 1920, #2 cable was renewed because a fault had developed. This cable lies in the basin and well away from destructive turbidity currents and slumps. However, #2 might be buried by fine material carried down by turbidity currents and deposited in the basin. The repair log makes no mention of the cable being deeply buried. However, in 1914 #2 cable developed a fault five miles west of the 1920 fault. During this recovery the log is more specific and we discover it was indeed buried. Two quotations from the log show how deeply it was buried:

"... very heavy strain observed while picking up."
"... hooked and parted 18 times."

On 9 December 1921 both #1 and #3 cables broke. (See Table IV for full report.) Unfortunately the log does not record the exact times of the breaks. They are typical turbidity current breaks as is evidenced from the following ship log quotations:

"The break was caused by the usual submarine landslide, originated by the heavy torrents from mountain water courses."
"Cable in poor and damaged state, owing to debris from torrent. Most of picked up cable had been deeply silted in the mud, and jagged and ruffled, and in some parts had been (apparently) suspended, as there were trees and masses of branches and weed entangled about it."

"We consider, however, that when cable is available and repairs are necessitated in this vicinity that extensive diversions of #1 and #3 sections should be effected and thus eliminate the frequent interruptions which are invariably caused by the torrents."

Note that these two breaks fall in line perfectly with the NNW-SSE trend of breaks. The break in #3 cable is in an area cut by canyons as shown in Fig. 16, profile 12S. Refer to Table IV (a routine repair report) and Figs. 33 and 34.

On 9 December 1939, #3 cable was renewed in two places because of faults. The faults occurred during a heavy gale which also caused a break in the Bay of Corinth.

In 1921 the detour of cable #1 was successful in placing the cable beyond the reach of the turbidity currents from the Sithas. The 1921 repair of #3 cable moved it further inshore. While this repair moved the cable off the slope, it left the cable subject to chafe and corrosion on the shelf.

CONCLUSIONS

The Gulf of Corinth serves as a good example to illustrate some of the salient oceanographic principles which should be observed in cable route layout.

First, let us examine the cable failures for the Gulf of Corinth proper, ignoring The Narrows and Area #2. In this entire area cable #2 never failed due to a tension break, whereas #1 and #3 broke 32 times. There is a very definite reason for this. Cable #2 was laid directly down the slope, along the middle of the basin, and directly up the slope on the eastern end. Cables #1 and #3 run parallel along the continental slope. These two cables are therefore subjected to sudden strains by turbidity currents and slumps sweeping down the slope. This type of trouble is especially common near river mouths, as can be seen from Fig. 32. In Figs. 39 and 40 it is apparent that cable detours around the river mouths have been moderately successful in preventing further breaks due to turbidity currents. There were 20 cases of faults due to chafe, corrosion, and teredo attack on cables #1 and #3, whereas only eight faults occurred in cable #2. The cables running along the continental slope parallel to the shelf edge are subject to chafe and abrasion by slumps and turbidity currents originating off the many rivers debouching in the gulf.

The breaks in the Alaska communication system cables which occurred off the mouth of the Katzehin and Stikine Rivers are remarkably similar to those in the Gulf of Corinth in relative location and cause. Terzaghi (1957) described similar cable failures in Norwegian fjords which he attributed to spontaneous liquefaction of the bottom sediments without horizontal transport. He suggested that the cables sank through the sediment and broke of their own weight when the bearing strength of the sediment was diminished by spontaneous liquefaction. However, the evidence he presented seems to be much more satisfactorily explained in terms of turbidity currents.

It is evident that when possible, cables should be run perpendicular to the strike of the continental slope. Any cable crossing a continental slope will be subject in some degree to the same hazards as the cables traversing the continental slope in the Gulf of Corinth.

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