THE MARINE GEOPHYSICAL SURVEY IN THE MEDITERRANEAN

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ABSTRACT

The analysis of 13 000 mi of continuously recorded bathymetric and seismic data in the Mediterranean Sea indicates a considerably different physiography and sediment distribution in the western and eastern segments.

Seismic reflection profiling reveals much thicker accumulations of sediment in the Western Mediterranean than in the tectonically active Eastern Mediterranean. In the Balearic Sea, abyssal hills previously interpreted as salt domes have been identified over a large region in the subsurface. Bottom photographs taken on the Mediterranean Ridge show outcrops of an indurated or consolidated sediment, indicating either tectonic activity of the ridge or lack of accumulation of sediments.

INTRODUCTION

In response to Naval requirements for ocean wide environmental measurements, the U.S. Naval Oceanographic Office, Marine Geophysical Survey Project (MGS) is now surveying extensive areas in the North Atlantic and Pacific Oceans (Figure 1). In addition to providing data of value to the U.S. Navy, these surveys have a secondary objective of increasing the global knowledge and understanding of the physical and geological nature of the oceans and the sea floor.

In order to obtain a broad sampling of the ocean with a minimum of ship's time, the MGS Project departed from the conventional survey grid. Rather, a statistical sampling of various physiographic provinces of the

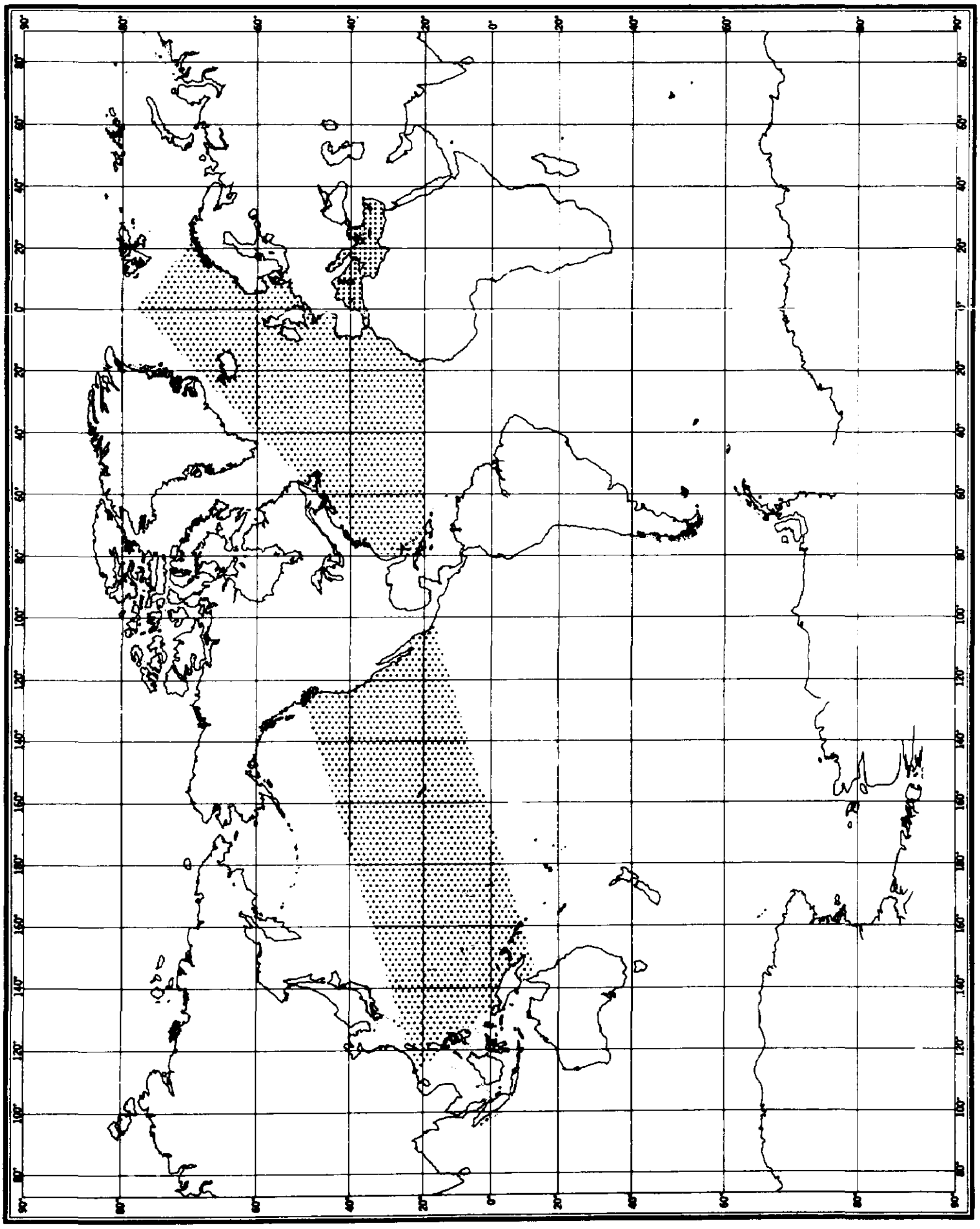


FIG. 1. — Oceanic areas which have been, or will be in the future, surveyed by the Marine Geophysical Survey Project.

efficient mode of attack. The basic hypothesis in this type of survey is that the ocean is divisible into physiographic provinces so that a limited number of samples within each province boundary will be sufficient to define the characteristics of the province as a whole.

Operations

The oceanic areas to be surveyed are illustrated in Figure 1. The sea floor (Heezen, Tharp and Ewing [1]) was deemed to be the most Marine Geophysical Survey Program is being conducted by contractors under the direction of the U.S. Naval Oceanographic Office. To initiate the survey program, contracts totaling $ 11.5 million were awarded by the Naval Oceanographic Office on 24 March 1965 to Texas Instruments Incorporated of Dallas, Texas and Alpine Geophysical Associates of Norwood, New Jersey. A sizable portion of the areas off the east coast of the United States, north and west of Iberia and in the vicinity of Hawaii have now been completed.

Presurvey planning for any particular subdivision of the area includes :
- Assembling all of the available historical data;
- Plotting of this data on charts;
- Planning a reconnaissance survey so as to most economically sample the known provinces and water masses and to best explore those regions where historical data is either scarce or lacking.

Charts prepared for the vessels included bottom contour charts, ocean currents and structures, sound velocity, bottom sediments and magnetic total intensity.

A reconnaissance survey is first accomplished by two ships collecting continuous sea surface temperature, total magnetic intensity, sea floor depths and subbottom data. Each vessel covers approximately 3 000 mi. The geophysical data are worked up aboard ship during the survey so that modifications in the proposed track are possible to better define any anomalous area that may develop.

The second phase of the survey plan includes approximately 100 stations which are located on the basis of information obtained during the reconnaissance survey as well as historical data. At each station seismic reflections are measured utilizing two ships and explosive sound sources. In addition, a surface to bottom sound velocity profile is taken with a sound velocimeter. At ten selected stations, bottom cores, bottom photographs and Nansen casts are taken. While steaming between stations the precision echo sounder, magnetometer and seismic "sparker" systems are operated to further assist in determination of the provinces. Figure 2 illustrates the reconnaissance and detail survey track lines of the Texas Instruments Incorporated ships R/V *Arctic Seal* and R/V *Atlantic Seal* in the Mediterranean.

Parameters Measured

The information currently being collected by the Marine Geophysical Survey includes some classified data for Navy programs and as listed in Table 1 a number of unclassified measurements.

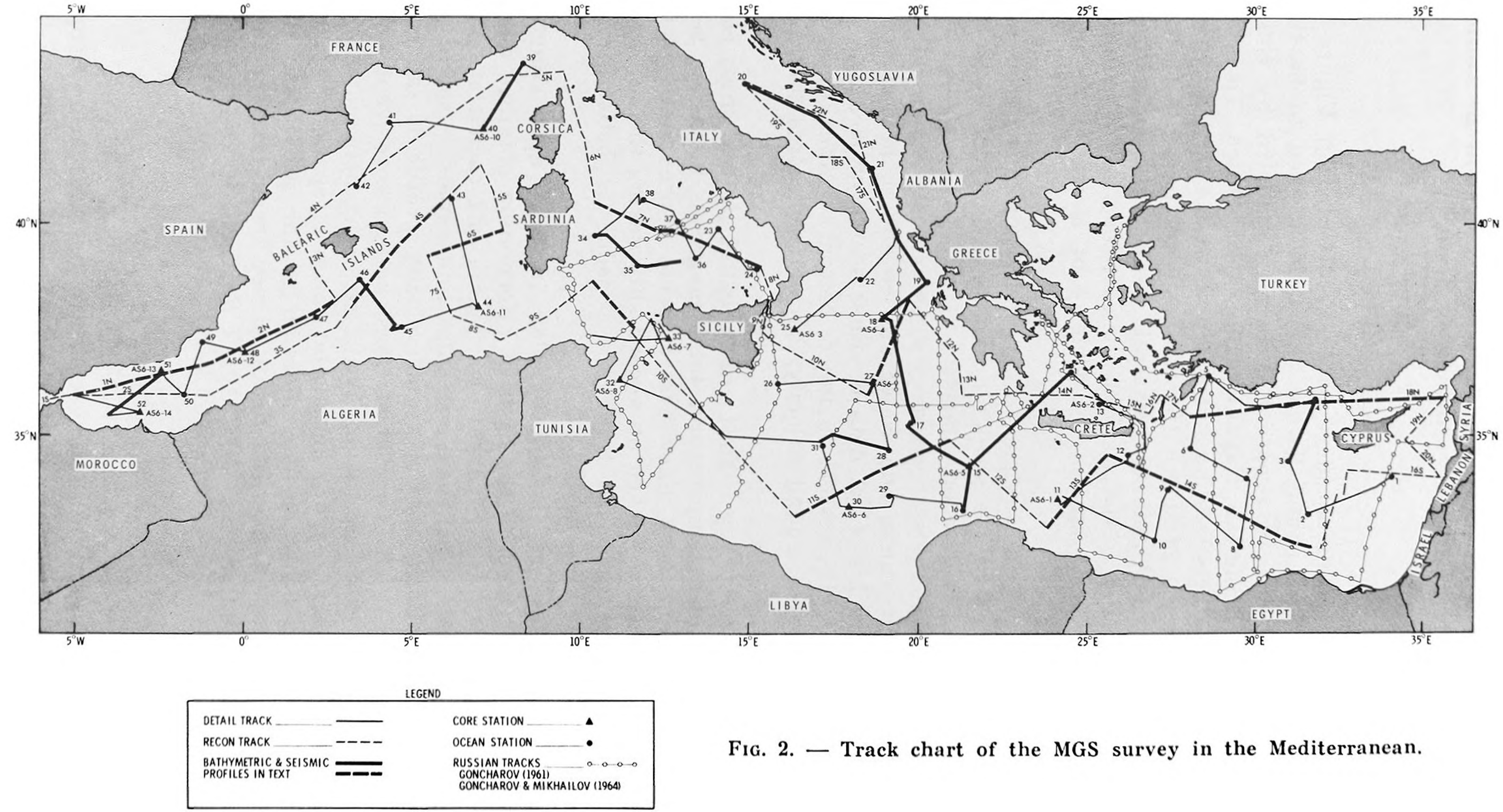


FIG. 2. — Track chart of the MGS survey in the Mediterranean.

TABLE 1

Oceanic Property	*Measurement*	*Accuracy*
Water depth	Precision echo sounder	± 1 in 3000
Bottom slope	Precision echo sounder	± 0.5°
Micro-topography	Bottom photographs	0.05 ft resolution
Bottom composition	Piston cores	
Bottom structure	Seismic profiler (sparker) Short pulse echo sounder Magnetic profiles	± 30 ft resolution 6 ft resolution ± 2 gamma
Sea-surface temperature	Thermistor	± 0.1°C
Temperature and salinity vs depth	Nansen casts	± 0.02°C ± 0.003‰
Sound velocity vs depth		± 3 ft/sec

Reduction Techniques

Depth records were obtained with a Gifft Depth Recorder and visually displayed on a 19-in. precision depth recorder. The depth records are recorded on magnetic tape at the laboratory, and a computer program plots the profiles at a standard vertical exaggeration of 100/1.

A Varian Proton Precession Magnetometer was used to measure total field intensity. Magnetic data are displayed on a strip chart recorder and also digitized for later analysis.

The seismic reflection profiles were obtained with a 10 000-joule "sparker" sound source used in conjunction with receiving and recording equipment manufactured by Texas Instruments as part of the U.S. Naval Oceanographic Office's shipboard survey system (BRANHAM, [2]). The sparker produces acoustic energy by discharging a capacitor bank through multiple electrodes, vaporizing the water near each electrode, and creating an acoustic pulse similar to that of a small underwater explosion. Two graphic recorders — one with a fixed 8-sec sweep, the other a selectable 1-sec sweep for maximum resolution — were utilized. A 21-element hydrophone streamer, 70 m long, picks up the reflected signals.

Availability of Data

At the completion of each survey area, the contractor prepares a final report of the data. Copies of unclassified reports are available from :

Defense Documentation Center
Defense Supply Agency
Cameron Station
Alexandria, Virginia

A reproduction cost of $ 3.00 (U.S.) per volume is charged.

Temperature and salinity data, sound velocity profiles, and copies of core analyses will be forwarded to the National Oceanographic Data Center for inclusion in their holdings and subsequent release through their system. Copies of the magnetic data will be retained by the Magnetic Division of the U.S. Naval Oceanographic Office which has been assigned the responsibility for maintaining the centralized library for Department of Defense magnetic data. Sounding and seismic reflection data can be obtained from Acoustic Data Facility, Code 9320, U.S. Naval Oceanographic Office.

GEOLOGICAL/GEOPHYSICAL OBSERVATIONS IN THE MEDITERRANEAN

The Mediterranean Sea has been studied in detail during the past few years by groups at Woods Hole Oceanographic Institute and Lamont Geological Observatory (HERSEY [3]; EMERY, HEEZEN and ALLAN [4]; RYAN and HEEZEN [5]; and RYAN, WORKUM and HERSEY [6]). Interpretation of MGS data was affected by and drew heavily from publications by these groups. Bathymetric profiles taken in the Levant and Tyrrhenian Seas in connection with the International Geophysical Year (GONCHAROV [7] and GONCHAROV and MIKHAILOV [8]) have also been useful.

The physiography of the Mediterranean (Figure 3) may be divided logically into western and eastern segments by a line between Italy, Sicily, and Tunisia. The western segment primarily consists of continental margins descending to abyssal plains. The eastern segment is more structurally and physiographically complex, and in many respects, is atypical of the usual oceanic divisions. An example of this is a series of basins paralleling and abutting the Mediterranean Ridge. Tectonic activity in this region apparently has prevented development of extensive abyssal plains such as those occurring in the Western Mediterranean. In this text, basins are those enclosed basinal areas which are only partially smoothed. Although "basin" is somewhat unorthodox as a physiographic province term, we believe it to be valid in the case of the Eastern Mediterranean and have followed RYAN and HEEZEN's [5] use of the term.

WESTERN MEDITERRANEAN

Alboran Sea

The Alboran Sea is situated at the western margin of the Mediterranean, adjacent to the Balearic Sea. The narrow continental shelf (less than 5 mi) bordering the basin is bounded seaward by a steep continental slope having an average gradient of 1/25 (Figure 4, Leg 1N). Two large structural terraces interrupt the continental slope off Morocco. The Alboran Abyssal Plain lies at a depth of 750 fm; however, a narrow topographic depression cuts through the eastern slope.

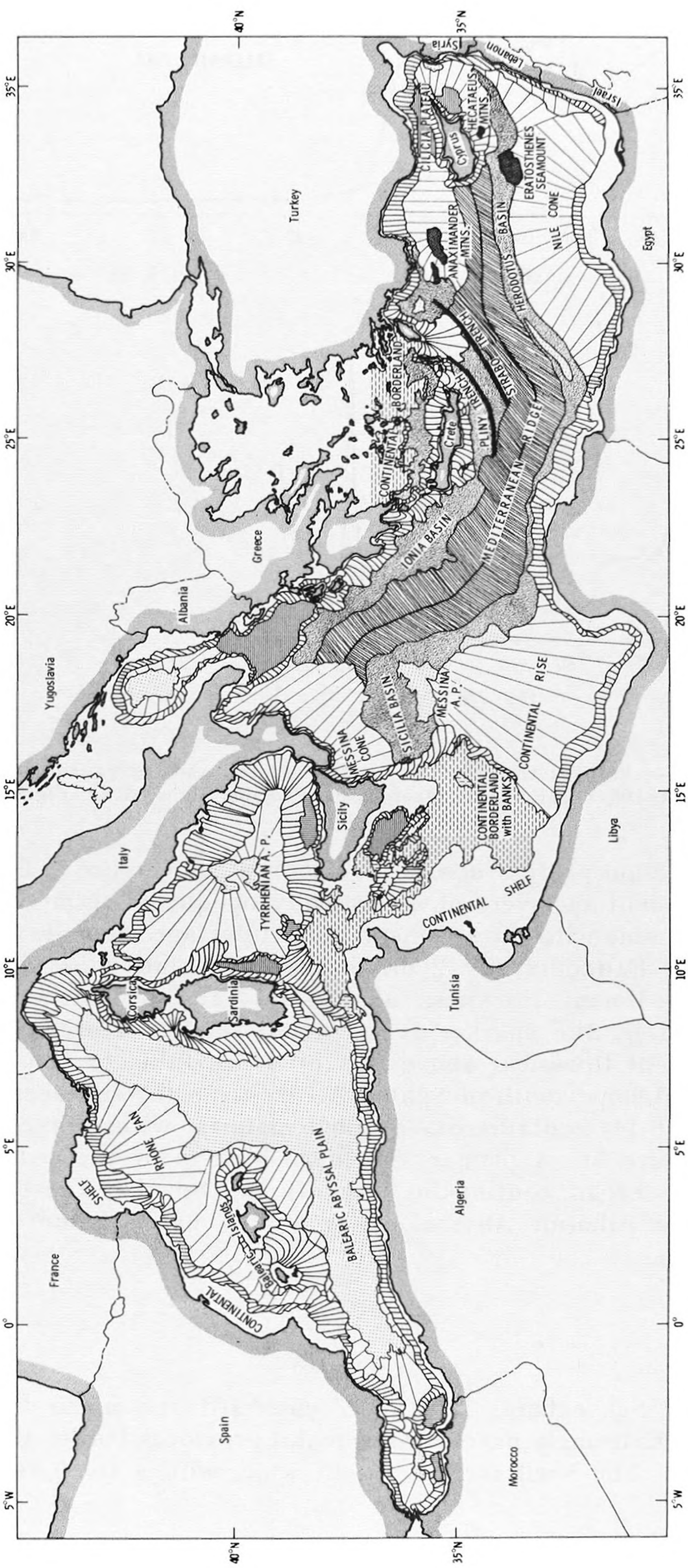
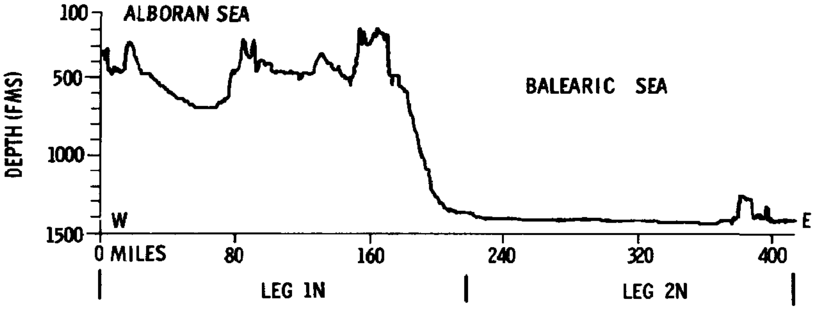


FIG. 3. — Physiographic province chart of the Mediterranean.



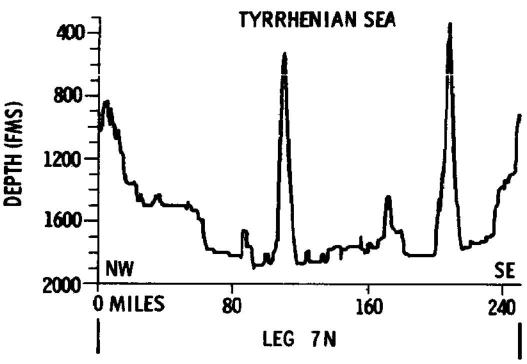


FIG. 4. — Bathymetric profiles in the western Mediterranean; all profiles at 100/1 vertical exaggeration. Profiles indexed in Figure 2.

Seismic reflection profiles across the Alboran Sea (Figure 5, Leg 51-52) show several sub-bottom layers of acoustically opaque material which are generally conformable with the sediment-water interface. Seismic refraction measurements by FAHLQUIST (9) 30 mi southeast of station 51 indicate an unconsolidated sediment thickness of 750 m. The deepest sub-bottom reflection defined by the sparker is an undulating interface at a depth of 700 m. Sediment thickness above this interface thins to 100 to 200 m on the continental slope south of Spain. A core from the southeast margin of the basin (AS 6-14) contains fine-grained material with a layer of sand (Table 2 and Figure 6). A primary northern source for the sediments is suggested by the broad continental rise off the Spanish coast and the placement of the Alboran Abyssal Plain at the base of the Moroccan continental slope.

Balearic Sea

The Balearic Sea extends from 2°W eastward and north to Corsica and Sardinia (*). Extremely narrow continental provinces border the basin's southern margin. The shelf is 2- to 10-mi wide, with a steep continental

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(*) *IHB Note :* These limits are not the same as those defined in the IHB Special Publication 23.

slope (1/10) extending to a narrow continental rise. Provinces adjacent to Corsica and Sardinia are wider and less steep than the southern boundaries. The northwest margin of the basin contains wide shelves (15- to 40-mi) and continental slopes with gradients ranging from 1/8 to 1/20. Canyons (two of which are shown in Figure 7-C) are prevalent on the Rhone Fan (Menard, Smith and Pratt [10]). The western canyon in Figure 7-C is built up on the east side, forming a natural levee.

The Balearic Abyssal Plain (Figure 4, Leg 2N) is 700-mi long and 45-to 130-mi wide, deepening to the south with a maximum depth of 1650 fm. The Rhone River and its associated fan is the principal source of sediments which smooth the plain (Menard, Smith, and Pratt [10]). Evidence of turbidity current deposition north of Africa has been noted by Heezen and Ewing [11] and no doubt Corsica, Sardinia and the Balearic Islands contribute a minor amount of sediment.

TABLE 2
MEDITERRANEAN CORES

Station	*Core n°*	*Latitude*	*Longitude*	*Water Depth (fm)*	*Core Length (cm)*
52	AS 6-14	35°38′.0 N	3°05′.0 W	538	910
51	AS 6-13	36°32′.0 N	2°20′.0 W	337	985
48	AS 6-12	37°03′.01 N	0°09′.0 E	1472	465
44	AS 6-11	38°05′.0 N	6°58′.0 E	1552	845
40	AS 6-10	42°03′.0 N	7°03′.0 E	1550	505
32	AS 6-8	36°22′.0 N	11°13′.0 E	51	555
33	AS 6-7	37°19′.6 N	12°39′.5 E	100	770
25	AS 6-3	37°34′.9 N	16°17′.0 E	1195	940
30	AS 6-6	33°10′.0 N	17°35′.0 E	1295	825
27	AS 6-9	36°22′.0 N	18°35′.0 E	2212	895
18	AS 6-4	37°50′.0 N	18°15′.0 E	1710	735
15	AS 6-5	34°13′.0 N	21°30′.0 E	1360	559
11	AS 6-1	33°28′.0 N	24°12′.5 E	1087	815
13	AS 6-2	35°47′.5 N	25°22′.5 E	1030	670

Seismic reflection profiles from the present survey (Figure 5, Legs 6S, 39-40, and 45-46) show the high acoustic reflectivity of the coarse sediments on the plain. Leg 45-46 contains a sub-bottom reflection continuously identified over a distance of 110 mi and occurring between 0.3 and 0.65 sec (300 to 650 m) below the sediment-water interface. Sediment thickness above this layer decreases over protrusions above the regional dip of the layer and on the Balearic insular rise. Profiles (Figure 5) on Legs 6S and 39-40 to the northeast fail to delineate this particular strong reflector; perhaps the reflector is the result of less acoustic penetration due to the proximity to the dominant sediment source, the Rhone Fan. Seismic refraction profiles by Fahlquist [9] indicate unconsolidated sediment thicknesses of over 1.2 km on the northern part of the Balearic Abyssal

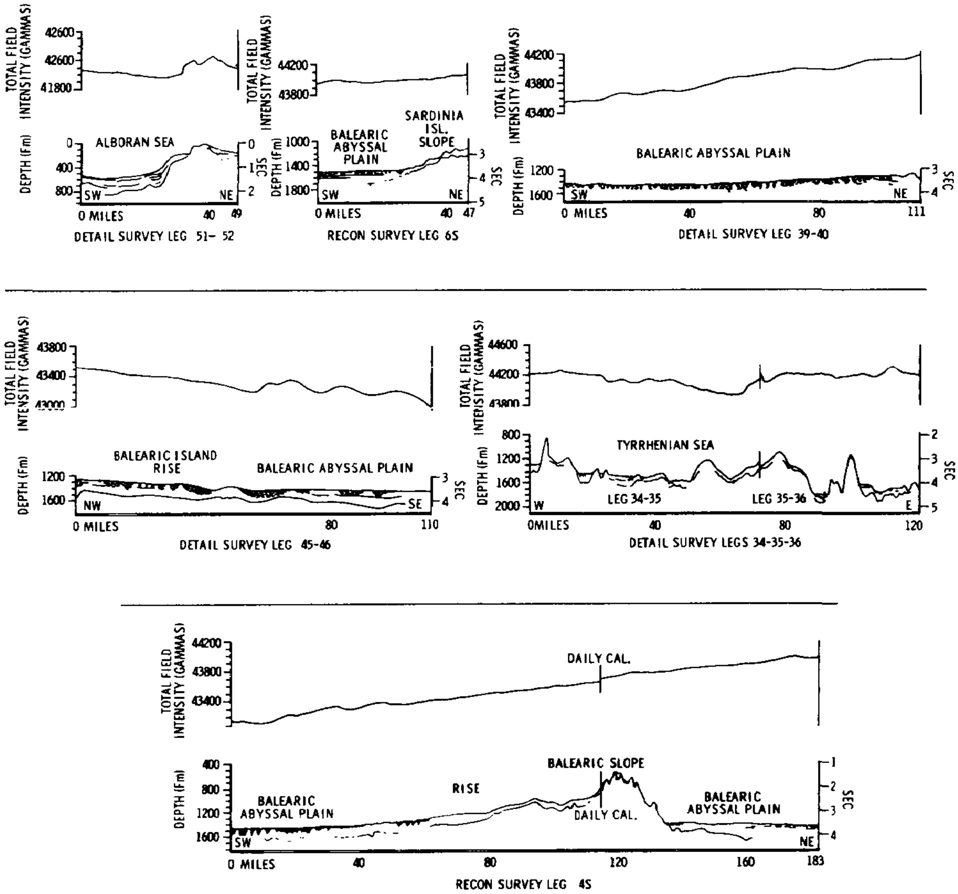


Fig. 5. — Tracings of seismic profiles in the western Mediterranean; all profiles at 20/1 vertical exaggeration. Travel times are two-way time. One second of travel time in sediments equals approximately 1 kilometre. Profiles indexed in Figure 2.

Plain. Based on the strong acoustic reflectivity characteristic of abyssal plain sediments and the mechanisms for abyssal plain formation (Heezen [12]; Heezen and Laughton [13]), it is apparent that sediments transported by turbidity flows form the Balearic Abyssal Plain. A turbidity-current origin for the plain sediments is supported by cores from this survey (AS 6-10, AS 6-11, and AS 6-12, Figure 6 and Table 2) and by previous work reported by Bourcart [14] and Pettersson [15]. Core AS 6-10, taken in 1550 fm of water near the Rhone Fan, contains sequences of turbidites and fine-grained material throughout the entire core. Turbidites are graded sequences of sediments deposited by sand and silt laden density currents. These currents are often generated by slumping of sediments on an unstable slope, such as the seaward margin of a delta. Core AS 6-11, raised in the southeast portion of the abyssal plain, contains several turbidites in addition to a sand layer 20-cm thick. Core AS 6-12, taken on the Balearic Abyssal Plain 70 mi northwest of Orleansville, Algeria, contains several turbidites in addition to a 15-cm thick sand layer. This

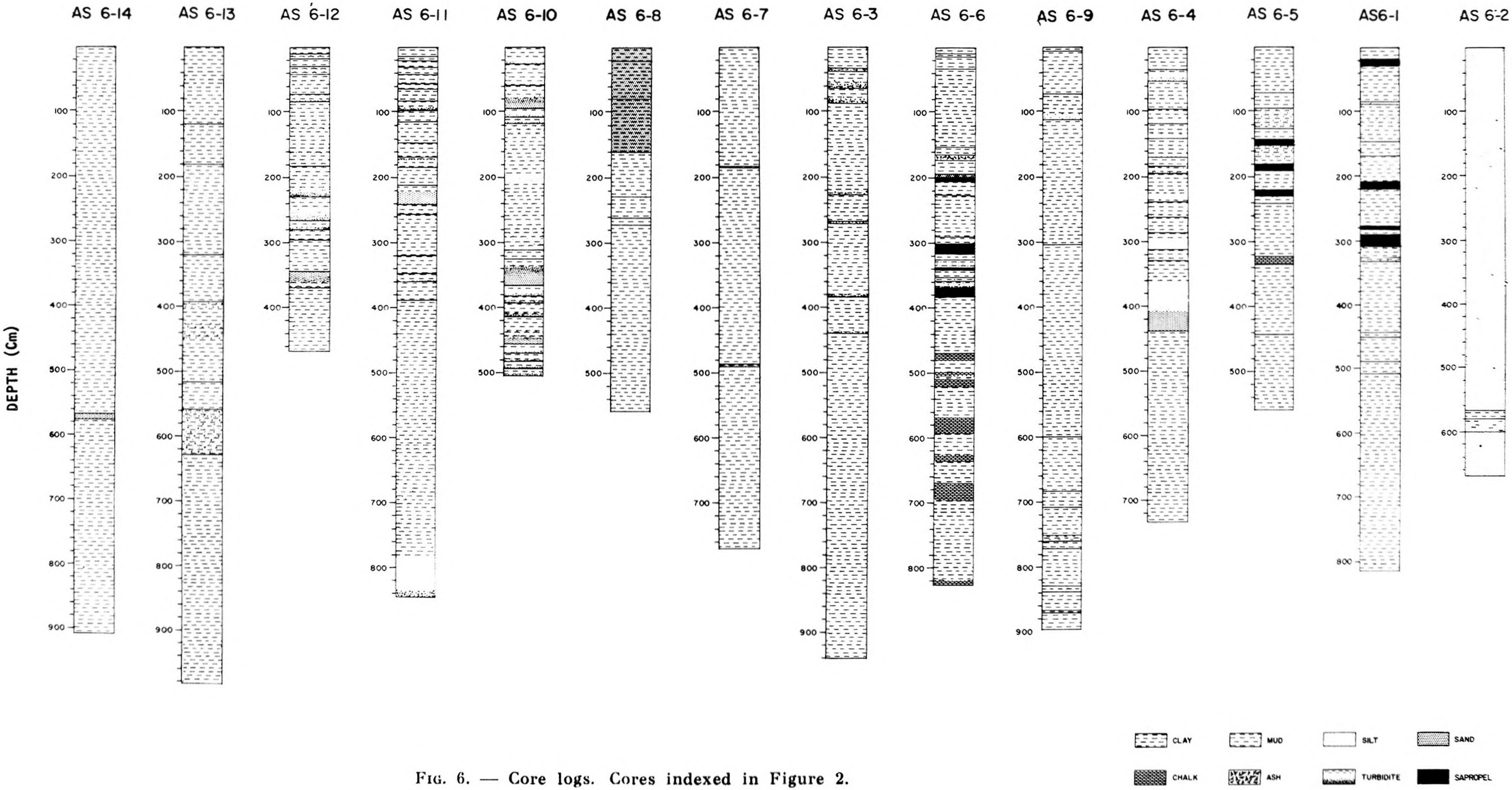


FIG. 6. — Core logs. Cores indexed in Figure 2.

core location is in the vicinity of submarine cable breaks associated with the 1954 Orleansville earthquake. The short core length (465 cm) attests to the coarse nature of the sediment penetrated.

Knolls rising above the plain in the vicinity of the Balearics have been interpreted as diapiric structures — probably salt domes (HERSEY [3]). Diapiric folds are layers of sediments bowed upward by the injection of a mobile core into the firm overlying sediments. The distribution of diapiric structures extends through a broad region in the western Mediterranean (GLANGEAUD [16] and GLANGEAUD, ALINAT, POLVECHE, GUILLAUME, and LEENHARDT [17]). Seismic reflection profiles by the *Arctic Seal* and the *Atlantic Seal* indicate additional buried structures with similar outlines throughout this basin. MENARD, SMITH, and PRATT [10] and HERSEY [3] have noted abyssal hills in the northeastern Balearic basin between 41° to 42°30′ N and 5°30′ to 7° E (Figures 7 and 8). Several profiles taken during the present survey — two of which are presented in cross section (Figure 5 and 7 A-B-C, Legs 39-40 and 4 S) — show a buried extension of the abyssal hills to the northeast and an area to the southwest. Miles 54-67 of Leg 39-40 (Figure 5) show five acoustically transparent buried structures surrounded by acoustically opaque sediments. Mile 10 shows one of these hills protruding above the surface and, again, there are no internal reflections, but high reflectivity in the surrounding sediments. Leg 4 S contains a series of hills, several protruding to 10- to 20-fm above the surface which occur for approximately 70 mi along Leg 4S. Survey tracks 46-47-48 to the north of 4S note similar buried structures.

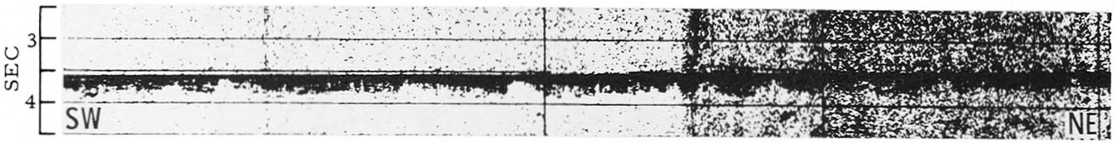
Tyrrhenian Sea

The Tyrrhenian Sea is bounded by Corsica and Sardinia to the west, Sicily to the south, and Italy to the east and northeast. The continental and insular slopes are wide in the southern portion of the basin. Several terraces occur on the island slopes of Sicily and Sardinia, the most prominent of which is east of Sardinia in 800 fm of water.

An abyssal plain is situated in the southeastern part of the basin at a depth of 1860 fm. Studies by RYAN, WORKUM and HERSEY [6] from the Tyrrhenian Abyssal Plain show that coarse sand layers are often continuous throughout the plain. These investigators propose that, upon entering the deeper reaches of the basin, turbidity flows have sufficient energy to cover the entire abyssal plain before depositing the suspended load. Hersey [18] noted that enclosed basins frequently exhibit this phenomena of "ponded" sediments. Seismic reflection profiles show more than an 800-m maximum thickness of sediment on the abyssal plain.

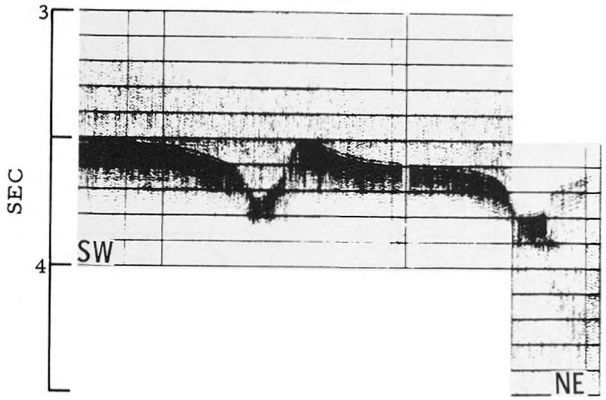
FIG. 7. — Photograph of seismic records.
Travel times are two-way travel time. One second of travel time in sediment equals approximately 1 kilometre. Profiles indexed in Figures 2 and 8.
(A) diapiric structures, 19″ seismic record;
(B) diapiric structures, corresponding 11″ seismic record;
(C) small canyon on Rhone Fan;
(D) diapiric structures, 19″ seismic record.

A



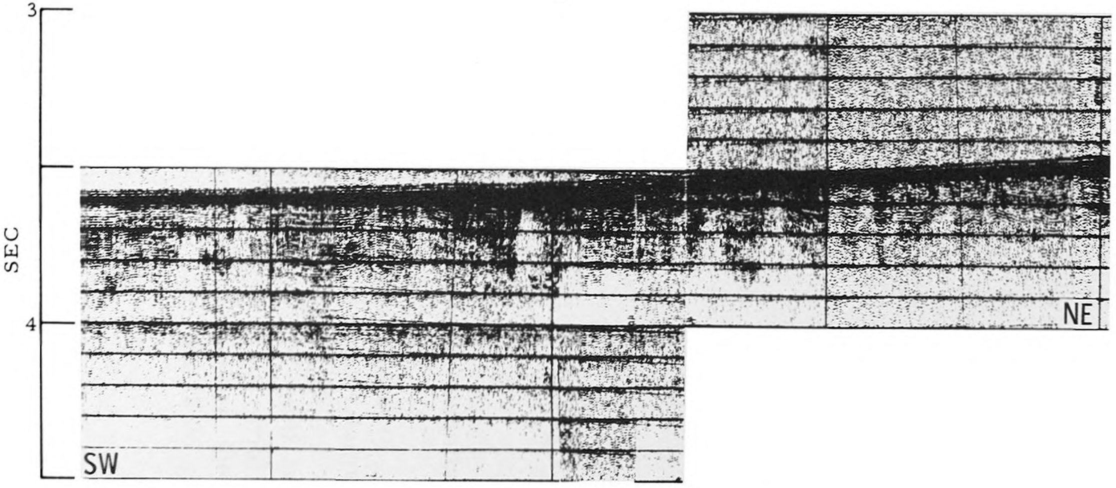
PORTION OF 19'' RECORD-LEG 39-40

C



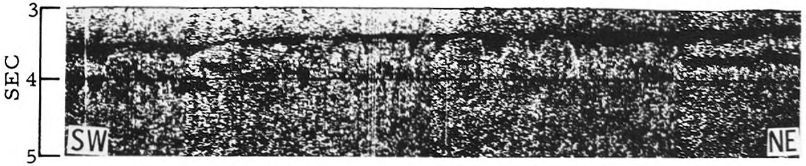
PORTION OF 11'' RECORD-LEG 41-42

B

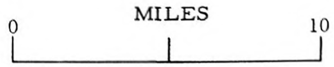


PORTION OF 11'' RECORD-LEG 39-40

D



PORTION OF 19'' RECORD-LEG 4S



Reflection profiles by Ludwig, Gunturi and Ewing [19] reveal sediment thicknesses of 300 m in the lows between hills with little or no accumulation on the steep flanks of knolls and seamounts. The southern margin of the Tyrrhenian Sea has 500-600 m of sediment in the basin lows (Figure 5). Ryan, Workum and Hersey [6] have traced several turbidites to Naples Canyon and a canyon east of Sardinia. Volcanic ash layers resulting from eruptions of volcanoes surrounding the Tyrrhenian Sea are also prevalent in the basin sediments.

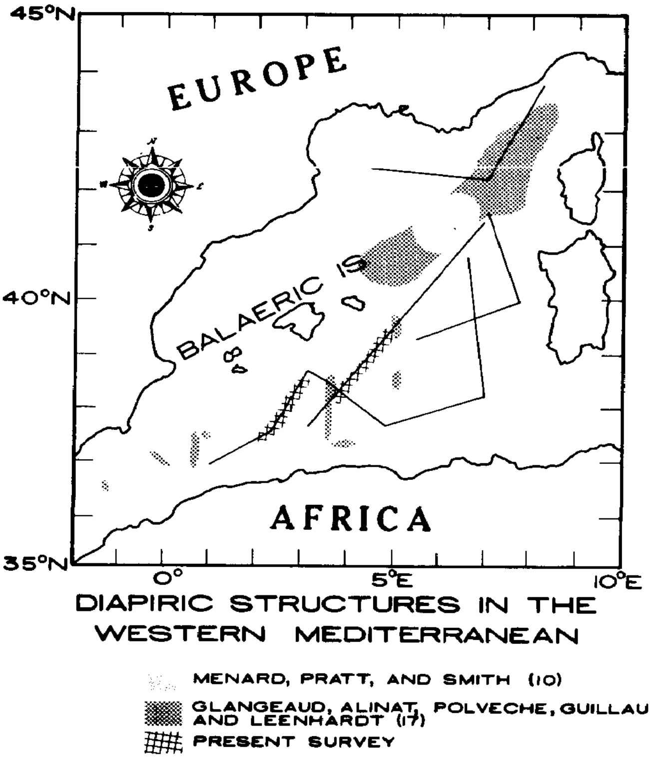


Fig. 8. — Index chart of diapiric structures.

EASTERN MEDITERRANEAN

Continental Borderlands between Sicily and Tunisia

Broad continental shelves and borderlands with shallow banks characterize the region between Sicily and Tunisia. A series of deep narrow depressions oriented NW-SE occupy the central area. A shallow (less than 200 fm) continental borderland extends from the southern tip of Sicily southwest to Tunisia. The eastern flank of this borderland is steep, descending to the Sicilia Basin at depths of 2 000 fm (Figure 9, Leg 32-31-28).

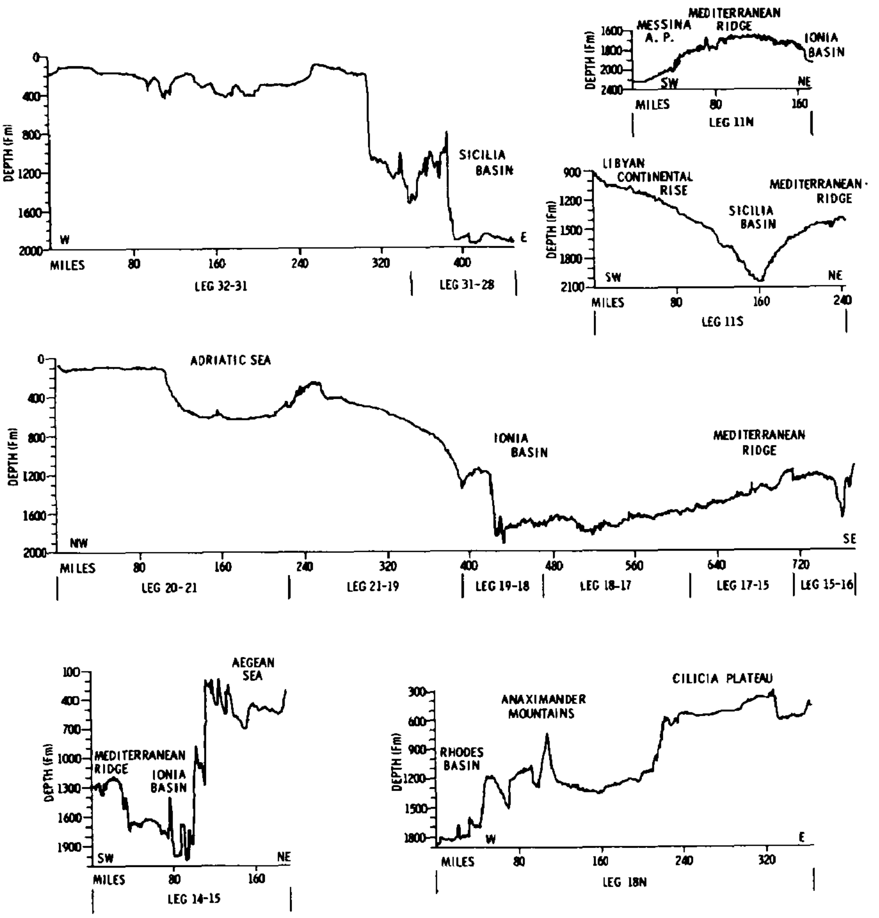


FIG. 9. — Bathymetric profiles in the eastern Mediterranean; all profiles at 100/1 vertical exaggeration. Profiles indexed on Figure 2.

A reflection profile west of Sicily (Figure 10, Leg 10S) shows sediment on the borderland has accumulated in basement depressions to a thickness of 600 m. Sub-bottom layering within these depressions reflects coarse material brought in by gravitational flow. However, this shallow region is characterized in general by sediment accumulation on the order of 100 to 200 m. A seismic profile of Leg 32-31 (Figure 10) shows similar thicknesses for the eastern portion of the borderlands. Both profiles provide evidence of fractures in the basement.

Ionian Sea

The Ionian Sea is that portion of the Mediterranean extending southeast from Italy to approximately Crete. A segment of the Mediterranean Ridge divides the Ionian Sea into two basins — the Sicilia Basin and the Ionia Basin. The Sicilia Basin lies at the bases of wide continental rises off the coasts of Italy and Libya, abutting the Mediterranean Ridge to the northeast (Figure 9, Legs 11N and 11S) and bounded to the west by a steep slope

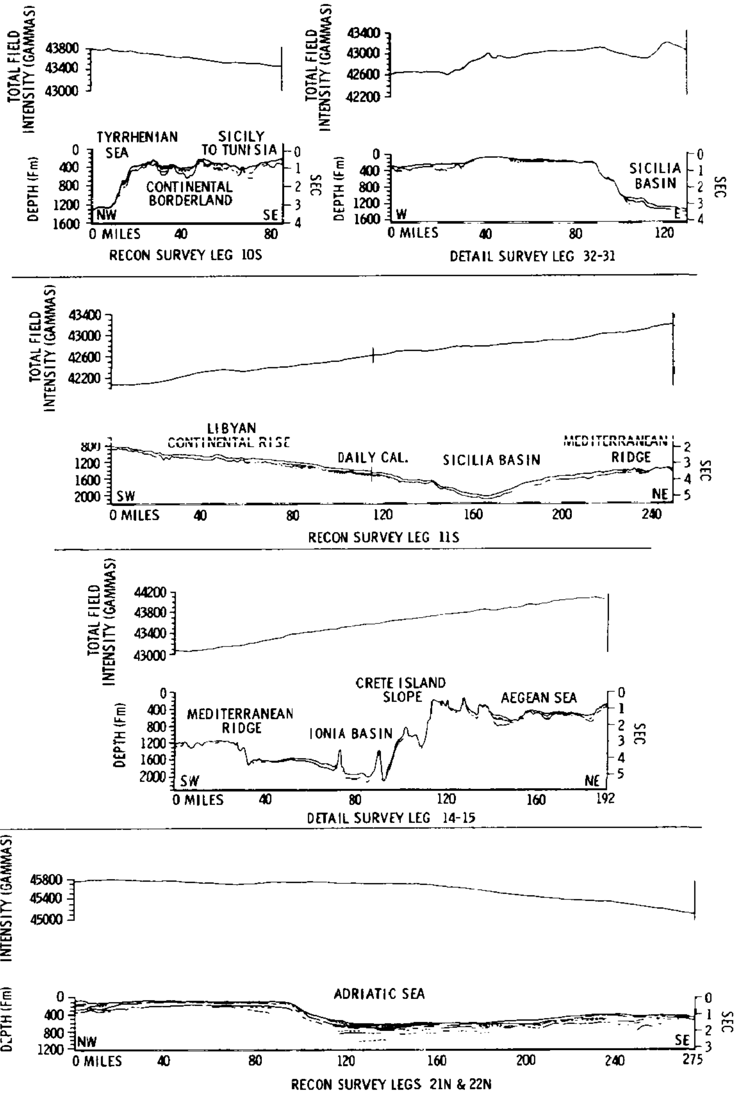


FIG. 10. — Tracing of seismic profiles in the eastern Mediterranean; all profiles at 20/1 vertical exaggeration. Travel times are two-way travel time. One second of travel time in sediments equals approximately 1 kilometre. Profiles indexed in Figure 2.

southeast of Malta (Figure 9, Leg 32-31-28). The central part of the basin reaches depths of 2350 fm. Messina Abyssal Plain lies at a depth of 2115 fm and a smaller abyssal plain is present in the southern portion of the basin at a depth of 2 050 fm. Messina Cone profiles by RYAN and HEEZEN [5] show scarps extending across the cone, suggesting that sedimentation has been "unable to keep pace with deformation related to the gradual subsidence of the basin floor".

Turbidity currents originating on the Messina Cone have carried sediments to the Messina Abyssal Plain in the Sicilia Basin. RYAN and HEEZEN [5] describe Sicilia Basin cores containing as much as 2 m of coarse sand which they attribute to the 1908 Messina turbidity current, an event triggered by an earthquake in the Strait of Messina. Cores taken by the *Atlantic Seal* in the Sicilia Basin area include AS 6-3, AS 6-6, and AS 6-9. Core AS 6-3 was raised on the Messina Cone in 1195 fm of water. Turbidite layers are common in the core's upper 450 cm.

A seismic reflection profile across the southeast portion of the Sicilia Basin (Figure 10, Leg 11S) shows a sediment thickness of 200 m, reflecting the decrease in sediment accumulation with distance from the Messina Cone. Profiles from the region near the Messina Abyssal Plain indicate sediment accumulations in excess of 600 m. Seismic records along Leg 32-31 (Figure 10) show a lack of sediment accumulation on the steep slope on the western margin of the Sicilia Basin.

The Ionia Basin lies at the base of the steep continental slope bordering Greece (Figure 9, Leg 14-15). This deep, elongated basin extends NW-SE from the base of the Italian continental rise to the island slope at the west margin of Crete. A steep slope oriented NW-SE separates the southern Italian Continental Rise from the marginal plateau off Greece and Albania. This plateau effectively separates the Ionian Sea from the shallow region associated with the Aegean Sea (Figure 3). The Mediterranean Ridge forms a steep boundary to the southwest (Figure 9, Leg 14-15 and 11 N). The basin topography is more rugged than that of the Sicilia Basin, suggesting less sediment influx and/or more intense tectonic deformation. The greatest depths (2783 fm) reported for the Mediterranean occur in this basin (HERSEY [3]). Abyssal plains occur in several of the deep basins.

Sediment accumulations in the southwestern portion of the Ionian Sea consist of pelagic lutites (includes fine-grained sediments derived from land and calcareous remains of organisms), organic-rich (sapropelic) muds, turbidites, and volcanic ash layers (RYAN and HEEZEN [5]). Sapropelic muds accumulated sporadically during the Pleistocene represent anaerobic (oxygen poor) conditions brought on by the stagnancy of bottom waters (Figure 6). Layers of tephra (volcanic ash) are common in the sediments in the Eastern Mediterranean. NINKOVICH and HEEZEN, [20] and [21], have shown the areal extent of two such eruptions of Santorini. Core AS 6-6 (Figure 6) contains an ash layer at a depth of 165 cm, similar to the depths in which an ash occurs in cores 180 to 220 mi north as described by NINKOVICH and HEEZEN [20]. This tephra layer, if synchronous with NINKOVICH and HEEZEN's lower ash layer, would extend the limits of the layer approximately 70 mi southwest.

Seismic reflection profiles across the Ionia Basin (Figure 10, Leg 14-15) show sediment accumulations of 200 to 250 m in depressions and no accumulation on the steep flanks of seamounts within the basin. Sediment thickness decreases on the flanks of the bordering Mediterranean Ridge.

Adriatic Sea

Two small basins are present in the Adriatic (Figure 9, Leg 20-21). The larger basin to the southeast contains an abyssal plain at 765 fm. A smaller basin elongated normal to the general topographic trend is situated in the Central Adriatic, with depths of 140 fm. The northwest third of the Adriatic is filled to shelf-level and has gradients as low as 1/1000. The Adriatic shoals to less than 500 fm through the Strait of Otranto where it joins the Ionian Sea (Figure 9, Leg 21-19).

Sediment accumulations in the Northwestern Adriatic consist primarily of Po River muds along the Italian coast, extending seaward 15 to 30 mi, and late Pleistocene sands on the outer shelf (VAN STRAATEN [22]). Po River muds are apparently trapped in the shallow basin at 43° N. Seismic reflection profiling (Figure 10, Legs 21 N and 22 N, 0 to 15 mi and Figure 13-C) shows deep sub-bottom layers dipping below the margin of the shallow northwestern basin. Echograms by VAN STRAATEN [22] show shallow sub-bottom reflections more closely paralleling the basin margin. The shallow layers may represent a seaward outbuilding of the shelf over deeper, older structures. Toward the southeast, the deep reflecting horizons shoal slightly before plunging below the major basin in the Adriatic. Discontinuities in the sediment layers at the basin margin suggest slumping. Sediment thickness in the southeastern basin exceeds 1 km (Figure 10, Leg 21N and 22N). The deeper horizons are less conformable near the southeastern margin of the basin, and some faulting is evident.

Aegean Sea

The Aegean Sea contains a shallow continental borderland between Greece and Turkey and an E-W oriented marginal basin north of Crete (Figure 3 and Figure 9, Leg 14-15). The major portion of the Aegean Sea lies north of the MGS survey limits; only the southern edge of the borderland and the marginal basin were surveyed by the *Arctic Seal* and *Atlantic Seal.* The marginal basin seaward of the continental borderland increases in depth from 500 fm at the western margin to 1370 fm on the east. The basin is bounded to the south by the Crete insular slope. Two small abyssal plains have been developed in the eastern part of the basin.

Sub-bottom reflectors in the western part of the Aegean Sea (Figure 10, Leg 14-15) indicate a relatively rough basement only partially smoothed by unconsolidated sediments. Station 13 was occupied on the marginal basin at the base of the steep island slope north of Crete. The core from this station (AS 6-2) is composed almost exclusively of silt, reflecting the nearby source. Figure 11 shows two of a series of photos taken at this station. Strong westerly currents are seen in Figure 11-C. A portion of the dark-colored rock outcrop (11-B) appears to have broken loose, and unconsolidated sediments fill the fracture. The massive nature of the outcrop and the lack of bedding suggest that the rocks are composed of igneous material.

Levant Sea

The Levant Sea adjoins the Ionian Sea to the east and extends through the eastern terminus of the Mediterranean. The Mediterranean Ridge, bordered on both sides by basins, extends through the Levant Sea to Cyprus. The basin on the south side appears to be continuous from the Sicilia Basin to a point southeast of Cyprus; it is a narrow, trench-like feature at the base of the continental slope north of Libya (Figure 12, Leg 13S), broadening

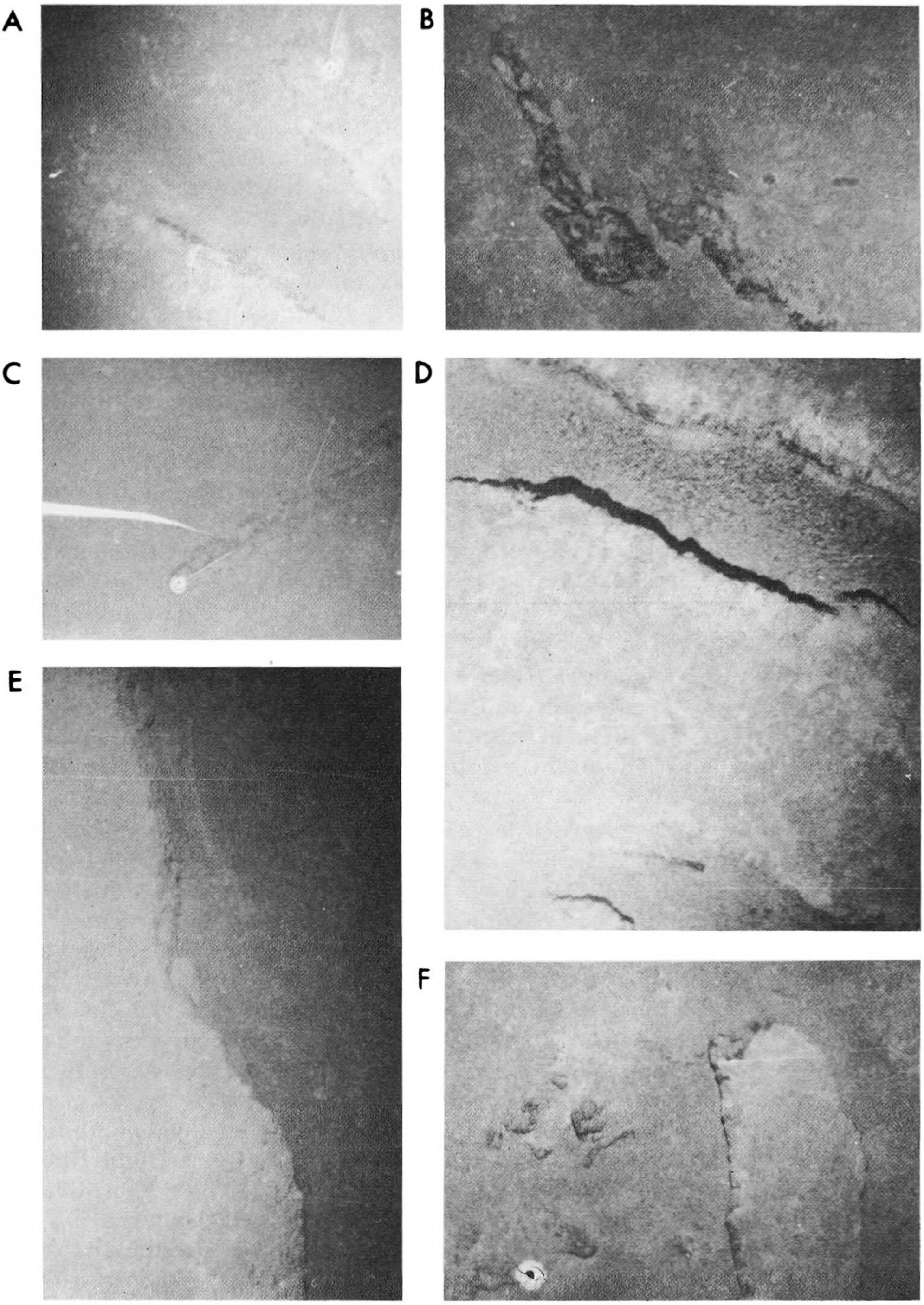


Fig. 11. — Bottom Photographs.

(A) Station 11, 33°28′.0 N, 24°12′.5 E; depth 1 085 fathoms, Core AS 6-1. Note small scoured channel.

(B-C) Station 13, 35°47′.5 N, 25°22′.5 E; depth 1 030 fathoms, Core AS 6-2. Note evidence of strong westerly bottom current and outcrops.

(D-E-F) Station 15, 34°13′.0 N, 21°30′.0 E; depth 1 360 fathoms, Core AS 6-5. Note loose rocks, outcrops or else erosion of consolidated sediments.

to 25 to 30 mi seaward of Egypt. The Herodotus Abyssal Plain is developed in this portion of the basin. The basin extends eastward to southeast of Cyprus where it merges with the continental rise off the coast of Lebanon. It shoals from 1950 fm north of Libya to 1300 to 1400 fm southeast of Cyprus. The Nile Cone, dominant feature off the coast of Egypt and Israel, is divided by an area of abyssal hills into the Rosetta Fan and the Damietta Fan. Figure 13-A shows several abyssal hills on the lower reaches of the Nile Cone. Sediments have largely levelled the hills.

The region of extreme relief immediately south of Crete (Figure 3), containing knolls and seamounts rising as much as 1700 fm above the surrounding terrain (Figure 12 and 13, Leg 14S), comprises the Hellenic Trough. A seismic profile on Leg 14S (Figure 13-B) indicates faulting along the northern side of the trough. These features parallel the Mediterranean Ridge, with the Strabo Trench cutting into the ridge at its southwestern end. Pliny Trench extends to the island slope east of Crete, with depths of 2240 fm. Strabo Trench borders the Mediterranean Ridge for 150 mi before diverging into a small basin southeast of Rhodes. This basin reaches depths of 2450 fm and the central portion is floored with an abyssal plain appearing to tilt slightly northward toward the Aegean Sea (HERSEY [3]). North of the Mediterranean Ridge at 30° E, a group of seamounts known as the Anaximander Mountains rise 900 fm above the surrounding continental rise (Figure 12, Leg 18N).

The Levant Sea shoals considerably from Cyprus eastward. The continental margin between Turkey and Cyprus lies at a depth of 400 to 500 fm and forms the Cilicia Plateau. South of Cyprus is a seamount complex called the Hecataeus Mountains. Farther south, Eratosthenes Seamount rises to within 425 fm of the surface.

Cores from the Eastern Mediterranean are described by OLAUSSON [23] and EMERY, HEEZEN and ALLAN [4]. The principal sediments are globigerina ooze and detrial lutite (land derived, fine-grained sediments). Turbidites, sapropelic muds, tephra and sediment breccia (disarrayed fragments of sediments caused by slumping) also have been noted in Levant Sea sediments. Turbidites occur on the Rhodes and Herodotus Abyssal Plains and in the Pliny Trench. Seismic profiles across the Herodotus Basin (Figure 13, Leg 14S) clearly show the smoothing of abyssal hills by acoustically opaque sediments. The Nile Cone contains several reflecting horizons which are continuous for 20 to 30 mi. Profile records along Leg 18N (Figure 2) show sediment thicknesses of 300 to 600 m, thinning to 100 m across the Anaximander mountains between Cyprus and Rhodes. No evidence of basement is seen on the Cilicia Plateau north of Cyprus, despite sub-bottom penetration of 300 to 400 m through alternating flat layers of acoustically opaque and acoustically transparent sediments. East of the plateau, the horizontal continuity of the layering is disrupted and only partial smoothing of the basement occurs.

Mediterranean Ridge

The Mediterranean Ridge extends from the Italian continental rise southeastward between Crete and Libya to Cyprus and is the dominant

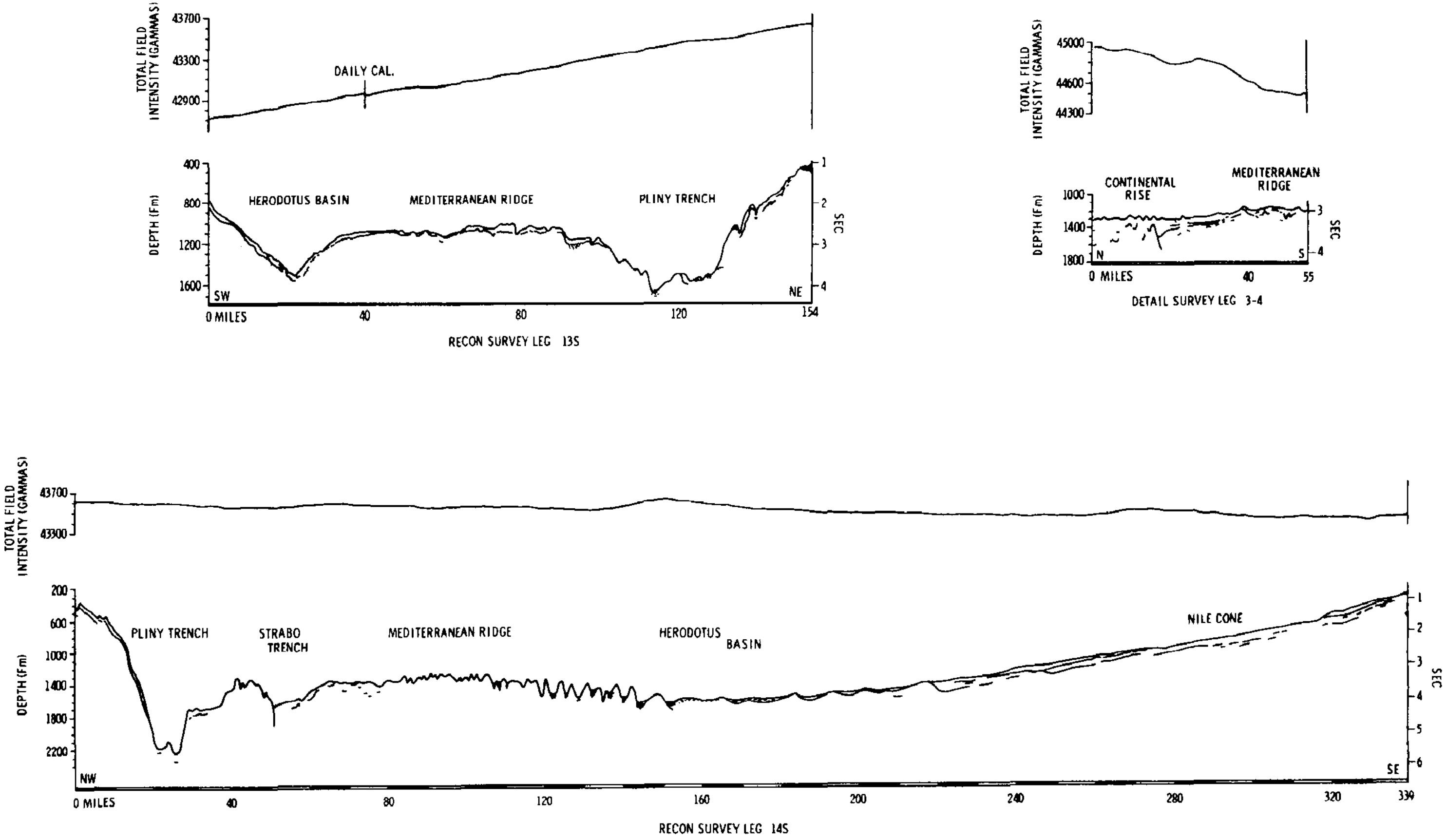
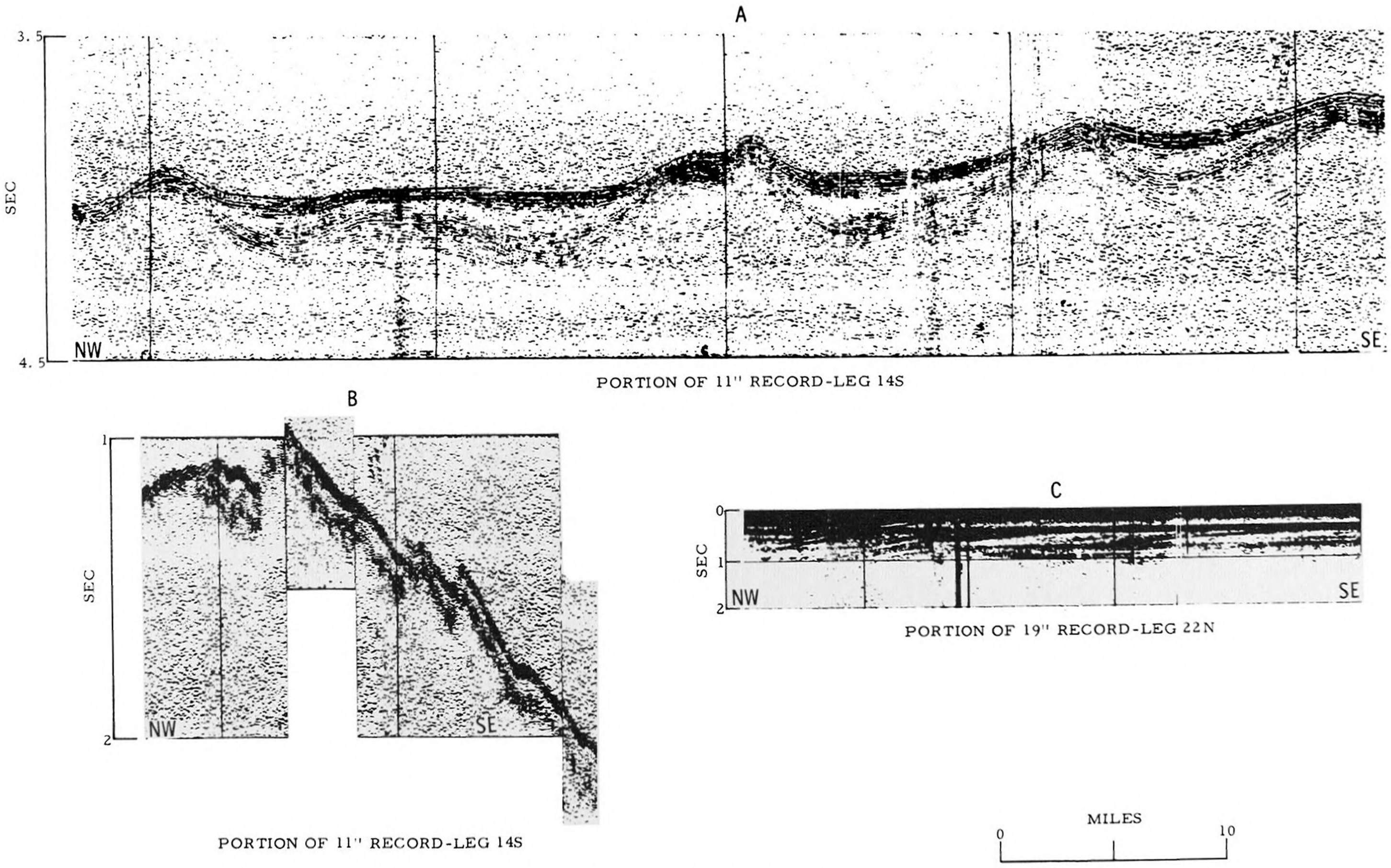


FIG. 12. — Tracings of seismic profiles in the eastern Mediterranean.
Profiles at 20/1 vertical exaggeration. Travel times are two-way travel time. One second of travel time in sediments equals approximately 1 kilometre.
All profiles indexed in Figure 2.



PORTION OF 11" RECORD-LEG 14S

PORTION OF 11" RECORD-LEG 14S

PORTION OF 19" RECORD-LEG 22N

Fig. 13. — Photograph of seismic records.

Travel times are two-way travel time. One second of travel time in sediments equals approximately 1 kilometre. Profiles indexed in Figure 2.

(A) Abyssal hills at base of Nile Cone;
(B) Island slope south of Crete;
(C) Beds dipping below northwest margin of basin in the Adriatic Sea.

physiographic feature in the Levant Sea. Figure 9 shows several bathymetric profiles of the ridge.

The shallow region northeast of Cyprus may represent a continuation of the ridge. The western portion of the ridge suggests a submarine extension of the Apennine Mountains. On a smaller scale, this median feature resembles the Mid-Oceanic Ridge (HEEZEN and EWING [24]) although an axial rift valley is not identifiable. The ridge varies from 40 to 100 mi wide throughout its length of approximately 1000 mi. Crest depths from Crete to Cyprus vary from 1200 to 1400 fm. The ridge deepens from 700 to 800 fm southwest of Crete to 1700 to 1800 fm at a base of the Italian Continental Rise. Throughout most of its length, the ridge is bounded by deep basins, including the Sicilia and Ionia Basins in the Ionian Sea and the Hellenic Trough and Herodotus Basin in the Levant Sea. The ridge's greatest relief occurs between Crete and Libya where it is flanked by Pliny and Strabo trenches to the north and by the Herodotus Basin to the south. Cores AS 6-1, AS 6-5, and AS 6-4 (Figure 6) were taken on the ridge, and the sediments reflect the relationship of the ridge to the surrounding topography. Cores AS 6-5 and AS 6-1 are from the portion of the ridge bounded by deep basins and, as a result, contain decreased amounts of terrigenous material (products of weathering of the land). The cores consist primarily of pelagic clays and calcareous sediment. Core AS 6-4 is from the northwest margin of the ridge near the Italian Continental Rise. Numerous turbidites and sand layers are present in the core and undoubtedly represent slumping on the adjacent continental rise.

Seismic profiling across the ridge (Figures 10 and 12, Legs 14-15, 11S, 13S, and 14S) show a generally thin layer of sediments 0 to 200 m thick. A series of bottom photographs at station 15 — three of which are shown in Figure 11, D-E-F — reveals an indurated (hardened), or at least semiconsolidated, sediment appearing to contain a small channel cut into the sediment (11-D), loose rocks (11-F) and an outcrop of consolidated sediment (11-E). The photographs at station 15 are of considerable significance because, if the outcrops represent basement, sediment accumulation has been virtually absent for some time. If the outcrops are not basement, the sediments still must be old enough to have become indurated as is evidenced by the vertical walls in the channel. Additionally, it appears that some agent of erosion — probably bottom current scour — is active on the ridge. An additional outcrop on the ridge is seen in photographs at station 11 (Figure 11-A). The outcrops may represent lithification (complex of processes that convert newly deposited sediment into indurated rock) of carbonates as proposed by FISCHER and GARRISON [25].

MAGNETICS

Underway total magnetic-field intensity data were collected during the survey, and representative values are plotted (Figures 5, 10, and 12) with corresponding bathymetric and seismic reflection profiles. The regional intensity was not removed prior to plotting, nor were secular changes or diurnal variations taken into account. The small variation in total intensity throughout the area permitted this approach in data presentation.

The Balearic Sea is characterized by a general lack of magnetic anomalies. Several small anomalies occur in the extreme southern part of the Balearic Abyssal Plain (Figure 5, Leg 45-46, 50 to 100 mi). The absence of anomalies over the greater part of the basin is due to the thick sequence of weakly magnetized sediments. A magnetic anomaly of 200-300 gamma amplitude is seen on detail Leg 51-52 (Figure 5) on the continental slope in the southern part of the Alboran Sea and is probably associated with tertiary volcanics which occur to the southeast along the African coast.

Several anomalies are associated with seamounts and knolls in the Tyrrhenian Sea (Figure 5, Legs 34-35-36). Volcanic activity is prominent in this part of the Mediterranean, and the anomalies most likely reflect some form of volcanism.

Magnetic profiles from the region between Sicily and Tunisia are shown on Figure 10 (recon Leg 10S and detail Leg 32-31). The westernmost profile (recon Leg 10S) shows no magnetic anomaly; faulting is evident along the track. Small anomalies are associated with the eastern and western margins of a shallow bank on detail Leg 32-31. The easternmost anomaly is closely associated with the slope separating the continental borderland from the Silicia Basin to the east. The magnetic profile plotted in conjunction with the seismic reflection profile in the Adriatic Sea (Figure 10, recon Leg 21N and 22N) is extremely featureless, the only change being a gentle regional gradient. Most of the magnetic profiles across the Mediterranean Ridge show no anomalies (Figure 12). This lack of anomalies over the ridge has been noted by EMERY, HEEZEN and ALLAN [4] who suggest that the ridge consists of sedimentary rocks. Anomalies are conspicuously absent across the Pliny and Strabo trenches. An Aegean Sea profile (Figure 10, detail Leg 14-15) contains no anomalies although EMERY, HEEZEN and ALLAN [4] note several north of the island of Crete.

The nature of the magnetic field over the Mediterranean Sea suggests the presence of thick sections of sedimentary rocks. Significant magnetic anomalies do occur over areas of volcanism, the two prominent regions being the Aegean Sea and the Tyrrhenian Sea.

SUMMARY

Seismic profiling in the western Mediterranean suggests that sediments in excess of 1 km have been deposited in the three major basins, forming abyssal plains. The sediments are primarily clays interspersed with layers of sand and silt, which is indicative of turbidity-current transportation. Dome-like structures in the Mediterranean, interpreted as salt domes, are similar to knolls in the Gulf of Mexico which are described by EWING, ERICSON and HEEZEN [26]. These diapiric structures, buried and rising above the sea floor, are present in a large part of the Balearic Sea.

Sediment distribution in the Eastern Mediterranean is more complex due to the region's tectonics and paleo-oceanographic conditions. The dominant sediment type is globigerina ooze. A median ridge divides the Eastern Mediterranean. Different sediment sources feed each of the relativly small basins, most of which show some depositional smoothing by turbidity currents. Seismic profiling in the Eastern Mediterranean (HERSEY [3]) and *Arctic Seal* and *Atlantic Seal* records (Figures 10 and 12; Legs 11S, 13S, 14S, and 14-15) show less sediment accumulation on the Mediterranean Ridge than in the bordering basins, which have thicknesses of 200 to 800 m. Eastern Mediterranean topography is characteristic of a tectonically active region. Expressions include the median ridge with its faulted cobblestone topography (HERSEY [3]), trenches and deep marginal basins bordering the ridge, and the rectilinear nature of the Ionia and Sicilia Basins (RYAN [27]). Mediterranean Ridge photographs taken by the *Atlantic Seal* provide evidence of the region's tectonic activity and/or the greatly reduced rate of deposition on the blocky median ridge.

Seismic profiles by HERSEY [3] indicate that parts of the Mediterranean Ridge and the basin southeast of Rhodes are underlaid by folded/faulted structures which may be former basin areas similar to those now existing in the Western Mediterranean. Additional seismic refraction and reflection work is needed to elucidate completely the structural picture in the Eastern Mediterranean.

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