1. INTRODUCTION

OBJECTIVES

Leg 13 of the Deep Sea Drilling Project was scheduled to explore the origin and development of a small ocean basin–The Mediterranean. The cruise has generated considerable interest particularly among European geologists, as the Mediterranean is considered a modern example of a geological feature that has been designated as an intercontinental geosyncline. The rocks of an ancient Mediterranean, also known as the Tethys, are now exposed in the Alpine chains of Europe and Africa, and have provided considerable insight concerning the evolutionary trends of ocean basins of the past. Drilling in the Mediterranean was expected to serve as a link for the integration of existing geological data in the framework of the new discoveries of marine geophysics.

Our drilling program was designed to resolve some specific problems and to gather data for the evaluation of various competing hypotheses on the geological history of the Mediterranean. The three major aspects were tectonic, sedimentary, and biostratigraphic. Our objectives were stated in a drilling proposal of the JOIDES Mediterranean Advisory Panel, dated February, 1970. For the sake of historical accuracy, the following sections have been written on the basis of this proposal, and certain passages are referred to in order to document our pursuit of these goals.

Genesis of the Mediterranean Basins

Conventional interpretations have related the origin of the Mediterranean and the adjacent mountain chains to an interaction between Europe and Africa. The Mediterranean Sea has been considered by some as a relic of the ancient Tethys seaway–an oceanic realm inferred to have evolved as Africa drifted away from North America at the end of the Triassic Period. A younger Alpine phase of folding has destroyed parts of this seaway during a subsequent northward approach of Africa.

A cursory glance at the physiographic panorama of the Mediterranean (Figure 1) reveals that the present Mediterranean is a composite of three basins: the eastern Mediterranean comprising the Levantine, Aegean, and Ionian basins, the central Tyrrhenian Basin with its characteristic volcanic seamounts, and the western Balearic-Alboran province centered around an extensive abyssal plain.

The Tethys idea may well be applicable to account for the origin of the eastern Mediterranean basins. The Mediterranean Ridge complex can be viewed as an embryonic mountain chain rising out of a thick pile of crumpled sediments on the relic crust. There was a slight possibility that drilling there might yield the oldest sediments yet to be recovered from the ocean floor. The selection of Sites 126 and 131 was based, in part, upon such hopes.

The Hellenic Trough of the Hellenic island arc marks the contemporary shear zone between the African and Aegean lithospheric plates, and an understanding of the tectonic processes occurring in this province might provide an actualistic model for the interpretation of the development of thrusted nappes. Drilling along the trench margins was anticipated to reveal the deformation pattern of the sedimentary carpet as it is scraped up where one lithospheric plate plunges under another. Drilling on the Mediterranean Ridge seaward of the trench would serve to yield information for evaluating the chronology of the tectonic deformation. Sites 129, 130, and 131 were chosen on a north to south transit to provide a composite structural cross section, extending from the outer convex side of the island arc, across the compressional ridge system to the stable margin of the African continent. Site 127, Hellenic Trench, was intended to "spud into the trench sediments a few hundred meters seaward of the inner trench-wall, so as to enter at subbottom depths of 200 to 300 meters into the deformed sequences at the base of the inner wall. The facies of the trench fill should be comparable to the Alpine Flysch formations. The succession there might provide a time table of trench development."[1]

The western Mediterranean basins have not been considered a relic of the Tethyan Sea. Geological evidence suggested that a large part of the present western basins was occupied by a landmass during the Tertiary. The foundering of this land area to abyssal depth has been proposed as convincing evidence of an oceanization process (e.g., van Bemmelen, 1969). Alternatively some of the same data have led other individuals to propose that these basins formed as a result of the drifting of microcontinents (i.e., Sardinia and Corsica in the reconstructions of Argand, 1922; Carey, 1958). Sites 121 through 124 and 132 through 134 were drilled in order to examine these alternatives and to attempt to date the age of the intervening ocean basin crust.

Sedimentary and Diagenetic History of the Mediterranean

Several of the sites chosen were targeted in regions where the geological interpretation of reflection profiles has indicated a thin, but nevertheless relatively complete sedimentary sequence of the upper Cenozoic. Site 124 on the Balearic Rise, Site 125 on the Mediterranean Ridge, and Site 132 in the Tyrrhenian Basin are all located in environments well above the level of carbonate compensation which were believed to be not greatly affected by bottom transported continental clastics. Continuous coring there afforded an opportunity to examine the sedimentary

[1] Quotation from the Drill Proposal of the JOIDES Mediterranean Advisory Panel, February, 1970.

Figure 1. *Physiographic panorama of the Mediterranean Region prepared from bathymetric studies by Bruce C. Heezen, Marie Tharp, and William B. F. Ryan, and painted by Heinrich C. Berann.*

history and concurrent volcanic activity during the late Cenozoic.

Many prominent subbottom reflecting interfaces are present in seismic reflection profiles across each of the Mediterranean basins, and some of these interfaces can be shown to be continuous over large distances and, in fact, can be correlated from basin to basin (e.g., Mauffret, 1968; Leenhardt, 1968; Biscaye *et al.*, 1971; and Ryan *et al.*, 1971). Some of the existing piston cores contain fragments of lithified carbonate rocks, which indicate *in situ* lithification of selective horizons. It had been suspected that the lithification and diagenesis were related to repeated periods of isolation of the Mediterranean from the Atlantic, which was thought to have had a profound effect on bottom water temperatures, salinity, and degree of oxygen ventilation in the individual enclosed troughs. Deep coring was expected to provide direct answers to the specific time of the various episodes of isolation.

The presence of salt layers under the Mediterranean had been suggested for some time by the repeated discovery of diapiric structures in the Balearic and Levantine basins. The age of the salt has been considered Triassic by some and Cenozoic by others. A sampling of this salt would yield not only significant clues as to the geologic history of the Mediterranean, but would also provide materials for the study of oceanic evaporites. Although the possibility of encountering salt in one of our cores was not excluded in our consideration of site-selection, plans were not made to drill on the diapiric structures, themselves, because of potential pollution hazards.

Several other special problems were taken into consideration in the drilling proposal. Holes had been targeted in the axes of the deepest basins to study the history of changes in the carbonate compensation level. It had also been intended to recover from these holes cores of correlatable layers of loess and volcanic tephra. A program was designed to investigate the distribution in space and in time of the sapropels first recognized in Quaternary piston cores. Other holes were located on trench plains which would be compared in their geomorphologic and tectonic setting to Alpine Flysch troughs so as to permit us to obtain materials for further research on models of flysch sedimentation.

Biostratigraphy of the Mediterranean

A number of important time stratigraphic boundaries have their type localities in the circum-Mediterranean regions. However, the outcrop sections on land, as one might expect, sometimes are tectonically disturbed and often contain hiatuses. Particularly puzzling is the absence of a continuous Miocene-Pliocene marine sequence.

Through deep-sea drilling it was hoped to obtain uninterrupted sections across important faunal and climatic boundaries of the Neogene at deep-sea sites proximal to important type localities. Further, a biostratigraphic and paleomagnetic correlation with the climatic history of the Mediterranean was expected (Sites 125 and 132).

CRUISE NARRATIVE

Glomar Challenger left Lisbon, Portugal, at midnight, August 13th, and returned there on the morning of October 6th. Although the principal objectives of Leg 13 were to drill in the Mediterranean, the first site of the cruise was located in the Atlantic, southwest of Portugal, because the late Cenozoic tectonic history of the Mediterranean is closely tied to the development of a plate boundary in the Atlantic along the Azores-Gibraltar seismic belt. The drilling vessel then occupied fourteen sites in the Mediterranean, seven in the western basin and an equal number in the eastern basin. A total of 28 holes were drilled.

The objectives of Hole 120 on the Gorringe Bank were to sample the basement and oldest sediments at the eastern border of the Atlantic on the Iberian plate, where tectonic movements has raised the basement within reach of the drill string. The eagerness of several members of our staff to get into the Mediterranean led to a compromise at Lisbon, where we agreed to spend as little time as possible in obtaining our results, staying preferably not more than 36 hours on station. Continuous coring was thus not contemplated. Not surprisingly, we missed both the unconformity between the Tertiary and the Cretaceous and the bedrock-sediment contact. On the other hand, we did manage to reach the basement, and only 14 meters of the oldest sediments were not sampled. We were rewarded with samples of plutonic ophiolites (gabbro and serpentinite) in addition to radiolarian chert and spilitic basalt. The findings at Site 120 eventually proved very significant to the interpretation of the history of the Alpine-Mediterranean system.

Metamorphic Basement

We entered the Mediterranean at dawn of August 18th. Our track led us up the western approach to the Strait of Gibraltar where the reflection profiles showed a current-swept, rugged sea bed. The first hole east of Gibraltar was drilled on a deeply buried basement high along the northern margin of the bathyal plain of the western Alboran Basin. A marked angular unconformity in the sedimentary sequence was recognized, but it wasn't until later in the cruise that we realized that this horizon is correlatable to the same Horizon M that had been charted in other Mediterranean basins. The objective at Site 121 was to penetrate into the bedrock, in order to obtain evidence relevant to the various theories on the origin of the western Mediterranean. After descending through 872 meters of sediments, we sampled crystalline rocks which were at first mistaken as basalt. However, petrographic investigations on shore eventually proved that we actually hit a high-grade metamorphic terrain similar to those in the nearby Rif and Betic mountains. The age of the oldest sediments (Upper Miocene) turned out to be younger than most of us had predicted. Although we obtained some dolomite chips from the sedimentary section, and later found tiny selenite crystals in Upper Miocene sediments, we did not suspect then we would soon find a major evaporite series of Late Miocene age underlying the entire Mediterranean sea floor.

In making passage eastwards it became possible to recognize Reflector M on the shipboard airgun profiles, and the acoustic interface could be traced across the submerged portion of the Balearic platform and down the Valencia Trough. Site 122 was originally scheduled to be the only drill location there. Our intention was to spud the hole into the axis of a deeply cut channel where hundreds of meters of the youngest sediments had been removed, allowing the basement to be reached at a shallower subbottom depth. We eventually learned that this maneuver gained us no advantage because thick, soft sediments could be penetrated within a few hours of drilling. Furthermore, the coarse sandy deposits in the channel axis proved a great handicap to our open-hole drilling.

The main objective of Hole 122 was to determine the age and nature of the basement high, which is associated with a >400 gamma magnetic anomaly. At this site we were to experience the first of our many encounters with technical difficulties. Just as we reached the level of Reflector M, the inner core barrel became jammed inside the drill pipe. The only solution was to raise the drill string, after which we were advised to move on to another location to avoid a recurrence. The culprit of the whole episode–a bed of pea-sized gravel–was to give us the first insight into the secrets of the Mediterranean crisis of salinity. We did not reach the bedrock, nor did we penetrate through the M-Reflector, itself. Nevertheless, the composition of the gravels derived from an erosion of a formerly exposed sea floor told us that the basement was volcanic and that the Mediterranean reflector represented the top of an evaporite series.

Hole 123 could be considered a distant offset of Hole 122, being some 10 nautical miles farther down the Valencia Trough. This hole was again situated in the channel, and although we encountered a few beds of sand and gravels, they posed no technical problem. We soon penetrated into acoustic basement, which consists of a massive deposit of volcanic ash. Then, the drill string got stuck in the hole. The drilling crew worked in vain all night trying to free the pipe. A charge was then lowered through the drill string in order to shoot the pipe off at the mudline. However, as a tensional force was applied to the stuck pipes preliminary to blasting, the string freed itself. We not only managed to save equipment, but also found ourselves in an excellent position to push ahead. Another 80 meters were drilled, now some 140 meters beneath the crest of the volcanic ridge, when it was decided to stop in order to avoid sticking the pipe again.

First Clue as to the Origin of the Mediterranean Evaporite

Having obtained at Site 122 some inkling that Horizon M tops a unit containing gypsum, we proceeded to seek for confirmation at an optimum location on the seaward edge of the Balearic Rise. Our target was a buried nonmagnetic basement high, newly discovered by the *Jean Charcot* during her presite surveys. We considered that if we could manage to drill through the reflector there, we might not only obtain a suite of evaporite rocks, but might also determine the environment in which they were formed. After penetrating rapidly through the Quaternary and Pliocene soft oozes at Site 124, we encountered the M-reflector at 359 meters and obtained our initial proof of the widespread existence of an Upper Miocene evaporite layer, and the first indication of its shallow-water origin. At this level, the drilling rate slowed down markedly. We managed to penetrate only 60 meters further during the next two days and had to abandon the hole after six continuous hours of drilling and coring effected no perceptible penetration.

The samples we obtained from the evaporite section were nevertheless very informative. Not only were gypsum and anhydrite found, but also diatomites, containing brackish- or freshwater species. The shipboard scientific staff began to discuss the various alternative hypotheses of evaporite origin. Now it was August 29th, some two weeks after the start of the cruise, and we had another six weeks ahead of us. We decided that we should first proceed to the eastern Mediterranean to work out some detailed stratigraphy on the Pliocene and Pleistocene and hopefully find a place where we could reach beyond the evaporites. Our other western sites could be drilled on our track back to Lisbon, when we should have a better idea of Mediterranean history and might have developed new insights into our problems. Furthermore, we had to prepare for a midcruise rendezvous near the Island of Crete with the shore-based support group.

Library of Ancient Civilizations

The *Glomar Challenger* departed the Balearic Rise Site at 18 hours on the 29th of August and proceeded across the Balearic Abyssal Plain where numerous piercement structures were observed on the seismic reflection profile (Figure 2). These features are rooted in a horizon just below the M-Reflector which was nicknamed by our colleague Guy Pautot the *couche flauante* (flowing bed). Prominent magnetic anomalies, probably marking the submarine continuation of the Tertiary volcanic province, were recorded over the southeastern margin of Sardinia.

We continued to recognize the M-Reflectors in our passage through the Straits of Sicily where they are covered by sediment of variable thickness. The descent down the precipitous Malta Escarpment was revealed on the profiler on the evening of August 31st (Figure 3). Upon reaching the base of the scarp, echoes from Horizon M came back strong and clear. Here the superficial blanket of sediment is remarkably transparent and relatively thin; diapiric structures were noted, and several of them crest just above the surface of the Messina Cone.

After a break of three days we arrived at the "cobblestone terrain" of the Mediterranean Ridge where we proceeded to spud in Hole 125, and continuously core the sedimentary sequence above Reflector M. The initial operations proceeded rapidly and recovery was satisfactory. However, we soon ran into technical difficulties and were not able to obtain full barrels. The problem was eventually diagnosed to have been caused by a broken flapper valve which was discovered while splitting open a core liner. So the drill string was pulled up, the defective valve removed, the bit changed, and a second hole was begun a few hundred meters away where continuous coring was carried on. The sequence of pelagic ooze at this site contains an almost unbroken record of the sedimentary history of this area. We discovered that the eastern Mediterranean suffered repeated episodes of deep-water stagnation when the bottom-dwelling fauna was completely obliterated. Several intercalated tephra layers will provide material for absolute age determinations.

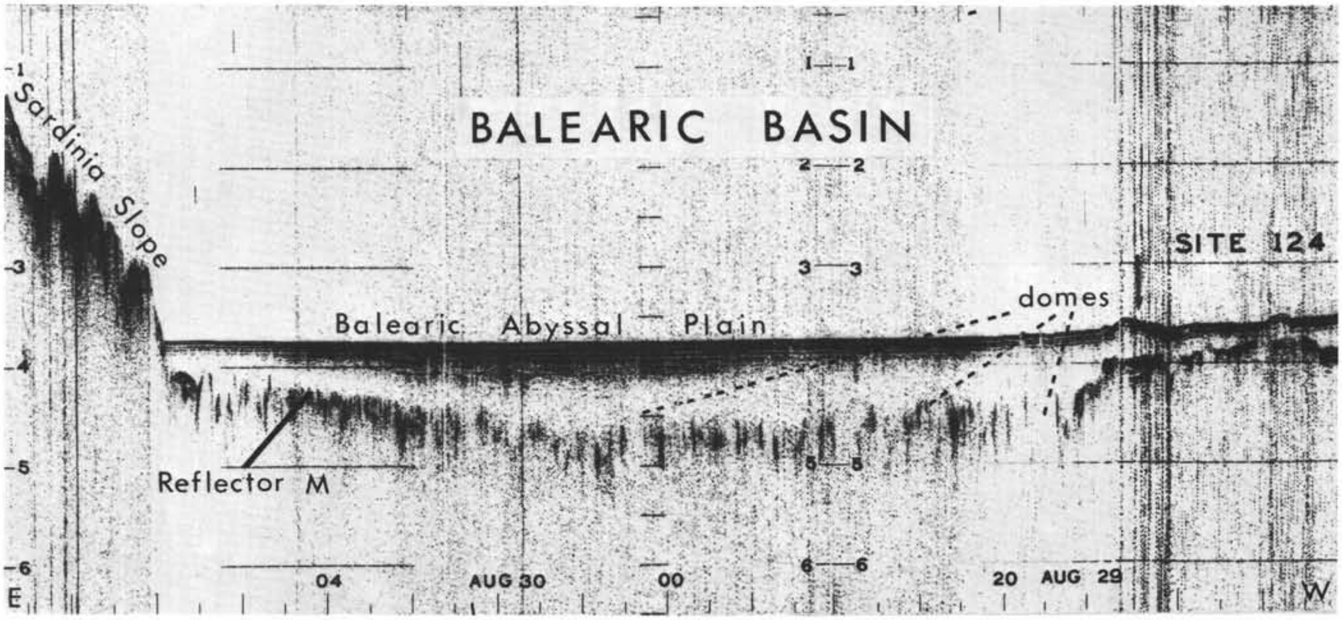


Figure 2. *Seismic profile across the Balearic Abyssal Plain showing the lateral continuity of the M-Reflectors pierced by diapiric structures inferred to be salt domes.*

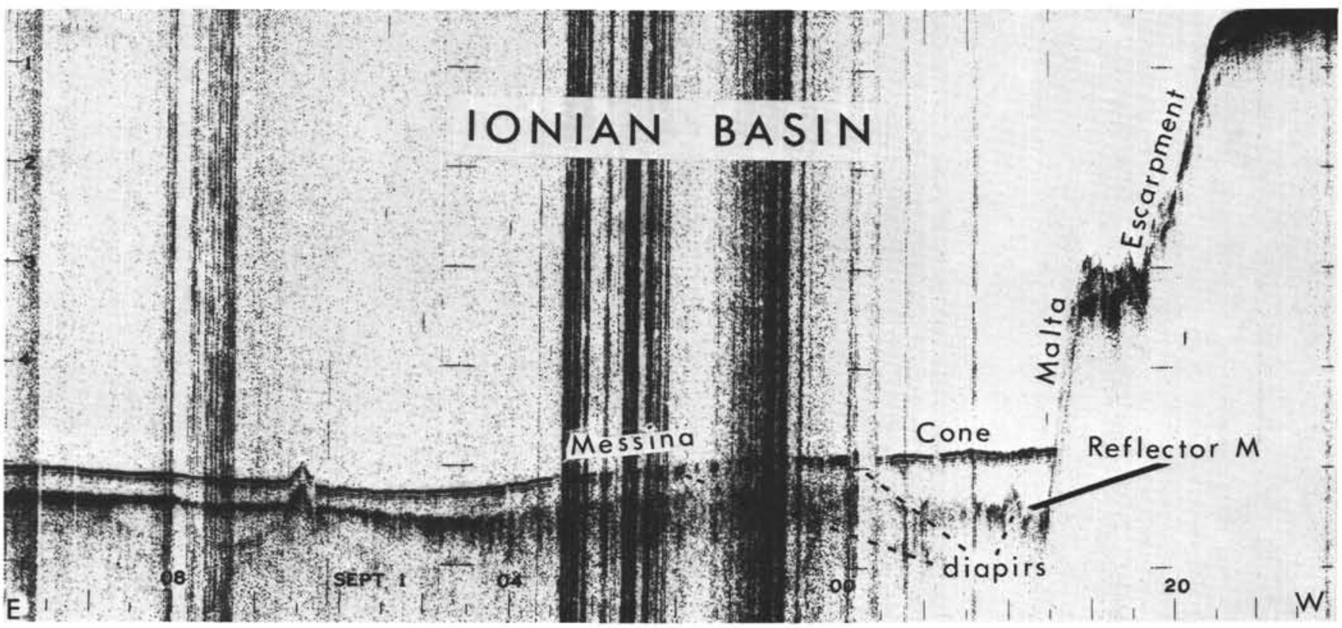


Figure 3. *Seismic profile across the Malta Escarpment and Messina Cone of the Ionian Basin showing the extension of the M-Reflectors into the eastern Mediterranean. Here, the crests of the diapirs rise above the general level of the sediment-draped cone.*

A Window in the Evaporites

In Hole 125A the drill string was able to penetrate some 40 meters into dolomitic rocks of the evaporite series below Horizon M when it once again was suddenly stopped. This time the bit orifice was plugged tight and, as we had experienced at Site 122, a gypsum bed, churned by the drill bit into a sticky mud, effectively halted further penetration. We decided then to take advantage of a nearby huge cleft which appeared to have been cut through the M-Reflectors deep into the Mediterranean Ridge. This strategy worked, and we were able to sample Middle Miocene marine sediments which underlie the evaporites. Unfortunately, the type of button bit we used was totally ineffective in penetrating the waxy middle Miocene shales. In an attempt to get around the obstacle of impeded drilling, an offset hole (126A) was drilled, but the same difficulty was encountered. On the morning of September 6th, after seven hours without progress, we had to abandon this part of the program. Nonetheless, we made our deepest stratigraphic penetration into sediments of the contemporary Mediterranean basin.

Mélange Under the Trench Wall

The *Glomar Challenger* was targeted next to drill the inner wall of the Hellenic Trench west of Crete. The track crossed the northeastern flank of the Mediterranean Ridge and the subsurface M-Reflectors were observed to plunge deeply under a wedge of thickly stratified trench fill.

Site 127 was designated by the Mediterranean Advisory Panel to test the hypothesis of plate subduction in an oceanic trench. Thanks to excellent navigation, the acoustic positioning beacon landed on the flat trench floor approximately 500 meters from the foot of the inner wall and was placed right on the target chosen by the Panel. It was such precise positioning which gave us the opportunity to drill through a Cretaceous limestone underlain by Pliocene oozes. Suspecting that we had hit a tectonic mélange, we drilled Holes 127A and B to check if the inner wall of the trench contains a flysch wedge of deformed trench sediments. Beneath a thin Quaternary veneer we encountered the same Cretaceous carbonate rocks mixed with Neogene oozes. Dense limestones and dolomites prevented deep penetration. The *Glomar Challenger* was then moved to Site 128, some 3.4 km to the southwest, to explore the stratigraphy and structure of the trench fill near the outer wall. After penetrating 480 meters of correlatable Quaternary clastics and sapropels, the drilling rate became unproductive and the hole was terminated.

We departed the Ionian Sea on the 12th of September after having effected a rendezvous with the U.S.S. *Buttes* at Site 127 at which time supplies were brought on board and an exchange of the secretarial staff was made. The drilling operations had proceeded more or less according to schedule. By minimizing the time-consuming unproductive drilling, we spared sufficient time to extend our drilling profile to the Levantine Basin.

In the region of the Strabo Trench along the eastern portion of the Hellenic arc, we continued to investigate subduction tectonics. Three holes were drilled at Site 129, two through the trench floor and one on the northern, inner wall. The trench floor is underlain by Quaternary olistostromes, and the drill string encountered upper and middle Miocene rocks on the trench wall. The structure is apparently very complicated. These holes were terminated when the drilling rate slowed down to less than 1 meter/hour.

Age of Mountain Building

We steamed southeastward onto the southern flank of the Mediterranean Ridge in the Levantine Basin to determine the chronology of the broad uplift of the submarine mountain chain. Reflector M could be seen buried under an ever-increasing thickness of deformed strata.

In the vicinity of Site 130 these strata have been interpreted (Hersey, 1965) to be deformed sediment of Nile provenance deposited on a former abyssal plain. The Mediterranean Advisory Panel predicted that the timing of the final uplift would be reflected by a sequential change in sedimentary facies, from abyssal-plain turbidites to pelagic deposits. The prediction was realized and the uplift of this part of the Ridge was dated as mid-Pleistocene.

The surprising result of Site 131 on the Nile Cone was that a strong subbottom acoustic reflector, which had previously been correlated with Reflector M, turned out to be a cemented Pleistocene sandstone. The previous hypothesis that the Nile turbidites had somehow bypassed the Nile Cone turned out to be unfounded.

The thick Quaternary sequence at Site 131 prevented penetration to the evaporite sequence and precise dating of the beginning of evaporite deposition, though we did manage to find anomalously high interstitial salinities which confirmed its presence there.

The Record of a Deluge

Hole 132 was spudded on a rise above the Tyrrhenian Bathyal Plain. An excellent suite of Neogene sediment was obtained, including the sharp contact between the Miocene and Pliocene. The superposition of deep-sea biogenic ooze on evaporites of shallow-water origin represents a record of a sudden drowning of a desiccated deep basin–an event which we were to call the "final deluge."

After completing Site 132, we decided to return to the Balearic Basin to further investigate the mysterious nonmagnetic "basement highs." From the flexotir profiles of the *Jean Charcot* we noticed that asymmetrical structural features are present beneath both margins of the Balearic Plain. Instead of returning to Site 124 on the west side of the plain, we chose a new location on the east. Furthermore, we decided to spud Hole 133 on the eastern shallower flank of the high, so as to avoid the necessity of drilling through a thick section of evaporites on the steeper flank.

Some of us thought that the high could possibly be a volcano similar to that under the Valencia Trough and were puzzled by the absence of magnetic anomalies. The alternative was that subsurface hyperbolic echoes were reflections from a buried fault scarp against which the abyssal plain sediments are ponded. We drilled into massive beds of flood plain silts (>150 m thick) under a thin veneer of Quaternary ooze. We also found in some core barrels well rounded pebbles of schists and phyllites. Eventually, the pipe stuck again and after the drill string was freed, we were advised that we should not venture much deeper into these loosely compacted detrital sediments.

Recovery of Halite

Although the quickest way to reach bedrock would have been to drill on the thinly veneered westward slope of the basement high, we chose to spud our next hole in the soft sediments of the abyssal plain in order to avoid the danger of having the bottom hole assembly twist off.

At 1717 hours on the 28th of September the vessel arrived on Site 134, about 3 km to the west. This was to be our last site and therefore our last chance to settle a number of questions. We were anxious to clear up remaining uncertainties on the termination of the salinity crisis, to examine the age and nature of the basement, to precisely locate the fault bounding the east side of the Balearic Abyssal Plain, and to core the more soluble salts of the evaporite series.

The remaining time was far too short to plan for continuous coring. It was not certain which of the several reflectors on the *Jean Charcot* site survey profiles represented the top of the evaporites. After drilling rapidly through the first two hundred meters, we adopted the strategy of drilling two pipe joints (18 m) and coring one (9 m). The Pliocene-Miocene contact was found in the lower section of Core 7.

Crystalline halite was recovered in Core 8 from a subbottom depth of 340 to 349 meters. Although we would have liked to sample the preevaporite basement in this hole, a study of the seismic record revealed that the salt might be several hundred meters or more in thickness. After two more salt cores were obtained, the penetration rate became unproductive. Furthermore, our last core sampled a foraminiferal ooze that gave a strong gasoline smell and so we abandoned and cemented Hole 134.

We had a maximum of two more days on location and anticipating the slow pace through the hard rocks, we managed to traverse the fault scarp with a series of five holes, and to sample metagraywacke and phyllite basement from 47 to 213 meters beneath the abyssal plain–a feat which could not have been accomplished if we had drilled a single hole without a bit change.

SUMMARY

During our 54 days at sea, the *Glomar Challenger* cruised 4646 nautical miles, drilled 28 holes at 15 sites, cored 1423.5 meters in 201 coring attempts, with 44.3 per cent recovery or 640.3 meters (see Table 1). Total time distribution for Leg 13 is shown in Figure 4. Water depth of the holes ranged from 1163 to 4654 meters. The maximum penetration was 867 meters (at Site 121), with an average of 224.1 meters per hole. Total penetration was 6277 meters of stratigraphic sections, more than that of any previous leg. We successfully used the beacon-release mechanism; one beacon was used at three different sites. We also successfully tested the sidewall coring apparatus. These achievements can be credited to the cooperative efforts of many individuals and organizations; notably, JOIDES for planning of the Deep Sea Drilling Project, for logistical support, and for execution of the technical operations by Captain Clarke and his crews.

In retrospect, we would like to think that our cruise was a more-than-ordinary success. Perhaps the main achievements can be summarized in a single sentence: The *Glomar Challenger* brought home samples from hundreds of meters beneath the Mediterranean bottom for investigation of this modern analogue of the Alpine Geosyncline.

EXPLANATORY NOTES

Organization of the Reports

Because of the widespread interest in the scientific program of Leg 13 expressed prior to, and immediately after, the cruise, and because of the extremely diverse nature of the sediments and their components, we have sought help from colleagues in various fields of specialization to analyze the numerous samples obtained from the drill cores, and we are grateful for their enthusiastic response. Consequently, the initial cruise reports of Leg 13 include not only summaries by the shipboard participants, but also contributions by members of the international scientific community.

We have tried to organize the volume into parts so that basically descriptive information is separated from interpretations and syntheses. Part I includes individual reports of each drill site written exclusively by the shipboard staff familiar with the recovered materials. Each site chapter contains graphic summaries of the individual drill cores, as well as photographs of the split face of the archive core half. Part II presents supplementary analytic data contributed by shore based laboratories with facilities and instrumentation not available on board the *Glomar Challenger*. Chapters in this part are further grouped into five sections under the headings of (a) Geophysical Results; (b) Sedimentary Petrology; (c) Petrology and Geochemistry of the Basement Rocks; (d) Geochemistry of Evaporites, Fossils, and Interstitial Fluids; and (e) Micropaleontology. Part III is an attempt to summarize and catalogue the various subjects investigated. The six chapters in this part serve as a sort of annotated index organized along the lines of scientific descriptions and scientific problems. We reserved Part IV for interpretative papers involving broad regional syntheses and discussions of more fundamental geological problems. These chapters are authored by members of the shipboard staff and their associates. Our purpose was to present a preliminary understanding of how the drilling results might be interpreted within the framework of existing geological knowledge. We recognize the limited scope and subjectiveness of views contained therein and hope that they may serve as catalysts for more exhaustive studies in the future.

Responsibility of Authorship

The Site Reports of Part I have been jointly authored by the shipboard scientific staff. In general, the section on Background and Objectives was written by W.B.F. Ryan; Operations Narrative by K.J. Hsü; Biostratigraphy mainly by M.B. Cita, with contributions from H. Stradner and W. Maync; Lithostratigraphy by W. D. Nesteroff, F. Wezel and G. Pautot; and Physical Properties by J. Lort. Summary and conclusions were authored by the Co-Chief Scientists who also assumed responsibility for the initial revision and editing of all sections.

All contributors to particular chapters in Parts II, III and IV are listed in the respective chapter or subchapter headings.

The graphical barrel summaries have been prepared by W. D. Nesteroff in cooperation with the shipboard sedimentologists and paleontologists. The artwork has been laid out by James Connelly.

The final editing was carried out at Scripps by Peter Supko, Ansis Kaneps and their associates.

Basis for Numbering Sites, Holes, Cores and Sections[2]

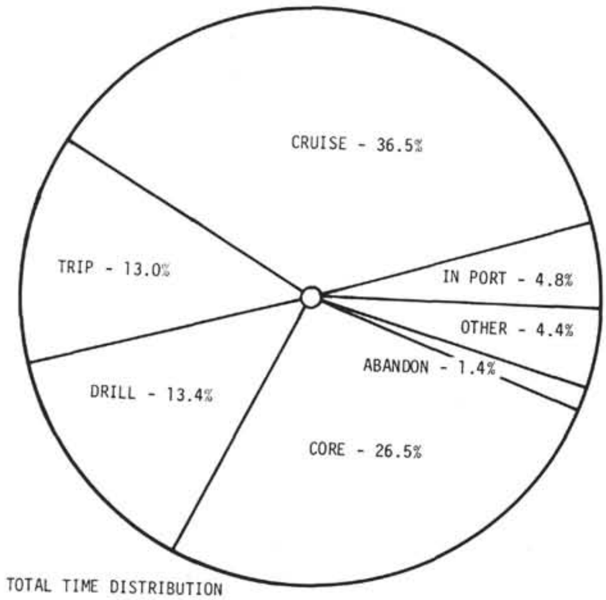
A site number refers to a single hole or group of holes drilled in essentially the same position using the same acoustic beacon. The first hole at a site (e.g., Site 134) was

[2]Since technical procedures for handling cores and the methods of drilling are practically identical from leg to leg, we have elected to reprint here thorough descriptions provided in the *Initial Reports of the Deep Sea Drilling Project, Volume 12* by Laughton, A. S., Berggren, W. A. *et al.* (1972). Only minor changes have been made pertinent to Leg 13 operations.

TABLE 1
Drilling Statistics for Leg 13

Site	Hole	Latitude	Longitude	Water Depth (m)	No. of Cores	Cores With Recovered Sediment	Cored (m)	Recovered (m)	Drilled (m)	Total Penetrated (m)	Average Rate of Penetration (m/hr)	Time on Hole (hrs)	Time on Site (hrs)
Gorringe Bank – Atlantic													
120	0	36°41.39′	11°25.94′W	1711	8	8	25.5	6.2	227.5	253.0	6.5	56.5	56.5
West Alboran Basin													
121	0	36°09.65′N	04°22.43′W	1163	24	23	161.0	46.5	706.0	867.0	13.0	66.5	66.5
Valencia Trough													
122	0	40°26.87′N	02°37.46′E	2146	4	3	30.0	5.6	132.0	162.0	23.2	25.0	25.0
Valencia Basement Ridge													
123	0	40°37.83′N	02°50.27′E	2290	8	7	71.0	19.7	327.0	398.0	26.4	38.0	38.0
Balearic Rise													
124	0	38°52.38′N	04°59.69′E	2726	15	14	71.0	41.0	351.0	422.0	7.1	74.5	74.5
Mediterranean Ridge – Ionian Basin													
125	0	34°37.49′N	20°25.76′E	2782	11	8	97.0	47.5		97.0	5.7	27.5	
125	A			2782	11	10	91.0	17.7	30.0	121.0	7.4	28.0	55.5
Cleft in Mediterranean Ridge – Ionian Basin													
126	0	35°09.72′N	21°25.63′E	3730	6	5	30.0	18.6	99.0	129.0	6.5	26.5	
126	A	Offset 460 m	SW of 126	3733	1	1	1.0	0.9	65.0	66.0	8.8	15.0	41.5
Inner Wall Hellenic Trench													
127	0	35°43.90′N	22°29.81′E	4654	19	19	136.0	92.5	301.0	437.0	8.2	65.5	
127	A	Offset 600 m	NE of 127	4636	5	5	31.0	23.2	49.0	80.0	7.6	14.0	
127	B	Offset 430 m	NE of 127	4640	1	1	1.0	0.5	165.0	166.0	21.4	9.5	89.0
Outer Wall Hellenic Trench													
128	0	35°42.58′N	22°28.10′E	4640	11	11	91.0	73.7	390.0	481.0	13.4	52.5	52.5
Strabo Mountains													
129	0	34°20.96′N	27°04.92′E	3048	4	3	13.0	2.8	99.0	112.0	5.6	28.0	
129	A	Offset 667 m	NW of 129	2832	3	3	13.0	1.7	68.0	81.0	8.1	11.5	
129	B	Offset 695 m	SW of 129	3042	2	2	15.0	1.4	27.0	42.0	8.2	18.5	58.0
Mediterranean Ridge – Levantine Basin													
130	0	33°36.31′N	27°51.99′E	2979	7	7	67.0	23.2	496.0	563.0	21.7	36.5	
130	A	Offset 30 m	S of 130	2982	1	1	11.0	1.0	0.0	11.0	7.4	7.5	44.0
Nile Cone													
131	0	33°06.39′N	28°30.69′E	3035	1	1	9.0	8.0	40.0	49.0	14.0	13.5	
131	A	Offset 600 m	W of 131	3037	5	5	45.0	7.5	227.0	272.0	22.6	21.0	34.5
Tyrrhenian Rise													
132	0	40°15.70′N	11°26.47′E	2835	27	26	223.0	168.3	0.0	223.0	6.0	49.5	49.5
Western Sardinia Slope													
133	0	39°11.99′N	07°20.13′E	2563	8	6	68.0	6.0	124.0	192.0	9.2	31.0	31.0
Balearic Abyssal Plain													
134	0	39°11.70′N	07°18.25′E	2864	10	7	73.0	22.9	291.0	364.0	14.3	30.5	
134	A	Offset 890 m	E of 134	2864	2	1	14.0	1.8	36.0	50.0	8.3	7.0	
134	B	Offset 790 m	E of 134	2869	1	1	5.0	0.2	67.0	72.0	43.0	3.0	
134	C	Offset 609 m	E of 134	2869	0	0	0.0	0.0	131.0	131.0	37.4	4.5	
134	D	Offset 430 m	E of 134	2871	3	3	15.0	1.3	199.0	214.0	25.2	9.5	
134	E	Offset 340 m	E of 134	2869	3	2	16.0	0.6	206.0	222.0	27.7	17.5	72.0
Summary of the 15 sites (28 holes)[a]													
Total					201	183	1423.5	640.3	4853.5	6277.0		788.0	788.0
Percent						91.0	22.8	44.3	77.2				
Average				3045	7.2	6.5	50.8	22.9	173.3	224.0	11.7	28.1	52.5
Maximum				4654	27.0	26.0	223.0	168.3	706.0	867.0	43.0	74.5	90.0
Minimum				1163	0.0	0.0	0.0	0.0	0.0	11.0	5.6	3.0	25.0

[a]Statistics, except for totals and "time on site," are based on holes, not sites.



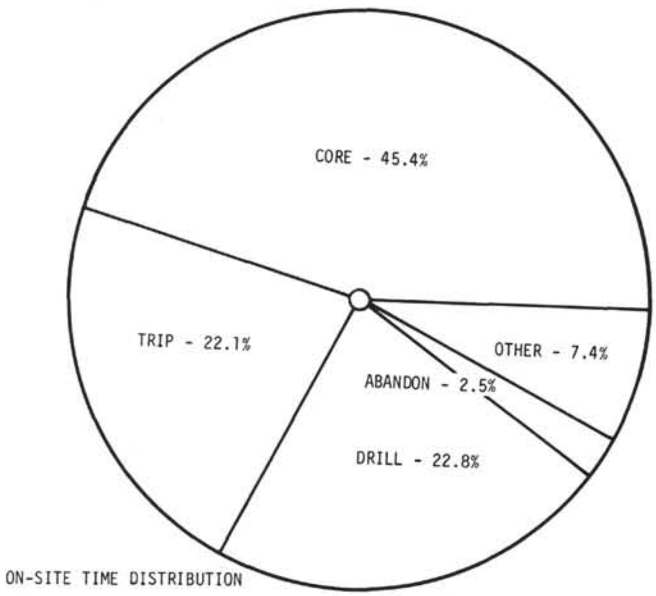


Figure 4. *Distribution of ship time during Leg 13 in the Mediterranean Sea.*

given the number of the site (e.g., Hole 134). Second, third, and subsequent holes drilled by withdrawing from the first hole and redrilling were labeled "A", "B", etc., (e.g., Hole 134A, 134B).

A core was usually taken by dropping a core barrel down the drill string, and penetration was effected for 9 meters as measured by the amount the drill string was lowered through the derrick floor before recovery. The sediment was retained in a plastic liner 9.28 meters long inside the core barrel, and in a 0.20 meter long core catcher assembly below the liner. The liner was not always full.

On recovery the liner was cut into sections of 1.5 meters measured from the lowest point of sediment within the liner (Figure 5).

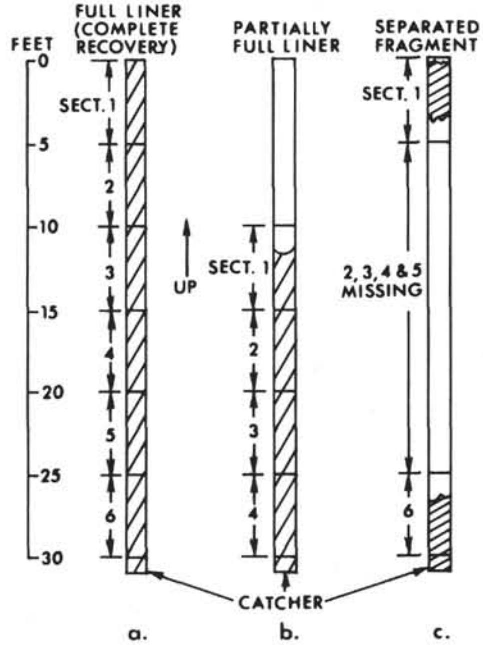


Figure 5. *The method of labeling sections of cores when recovery is complete, incomplete, and divided. The cores have been lines up so that the top of Section 1 is always coincident with the top of the cored interval, according to the method of calculating downhole depth of samples. Core catcher samples are always considered to have come from the bottom of the cored interval, regardless of the depth assigned to the adjacent section above.*

Often the top of the recovered sediment column did not coincide with the top of a section. The sections were labeled from 1 for the top (incomplete) section to a figure as high as 6 for the bottom (complete) section, depending on the total length of core recovered.

In the event there were gaps in the core, resulting in empty sections, these were still given numbers in sequence. Core catcher samples were always considered to have come from the bottom of the cored interval regardless of the depth assigned to the adjacent section above.

On occasions, over 9 meters of core were recovered. The small remainder was labeled Section 0 (zero) being above Section 1. On other occasions the sum of the lengths of numbered sections exceeds the total length of core recovered and also the cored interval, resulting in an overlap of nominal depth downhole of the bottom of one core and the top of the core below. In such cases a special note has been made.

In many of the holes it was found desirable to drill with high water circulation but with a core barrel in place in order to penetrate faster. The drilled interval was often considerably greater than the 9 meters of the core barrel, the principle being that the high water circulation prevented sediments from being recovered. However, some of the harder layers were probably recovered during this procedure. It was difficult, therefore, to assign the correct depth in the hole to these sediments and each case had to be considered on its merits.

At times a center bit insert was placed within the bottom hole assembly instead of an empty core barrel. This insert has a small orifice and a chamber behind the orifice which collects some cuttings and washings from the drilled intervals. Samples from the center bit are labled CB and are assigned consecutive numbers. Their depths correspond to the drilled interval.

Upon completion of a hole and retrieval of the drill string, materials caught within the teeth of the drill bit or splines of the bottom hole assembly were collected and marked drill bit samples, DB, prefixed by the number of the hole.

Before being processed, all samples taken from cores were numbered according to the system described in the Shipboard Handbook for Leg 13. The label "13-124-3-2, 25 cm" thus refers to Leg 13, Hole 124, Core 3, Section 2, sampled 25 centimeters from the top of that section. The label "13-124-3,CC" refers to the core catcher sample at the base of Core 3.

It is appreciated that with this labeling system, the top of the core material recovered may be located, for example, 1.3 meters below the top of Section 1 and the bottom may be at 1.5 meters in Section 2 (if the total recovery is 1.7 meters). In relating this to downhole depths, there is an arbitrariness of several meters. However, it is impossible to assess where exactly in the hole the sample came from. Sometimes the core barrel will jam up with a hard sediment after sampling a few meters; this will then really represent the first few meters penetrated. At other times the circulation of water may wash away the upper softer part of a core and recovery will represent the lower part. Separated lengths of core in a core liner may be caused by the drill bit being lifted off the bottom during coring in rough sea conditions. Similarly, there is no guarantee that the core catcher sample represents the material at the base of the cored interval.

The labeling of samples is therefore rigorously tied to the position of the samples within a section as the position appears when the section is first cut open and as logged in the visual core description sheets. The section labeling system implies that the top of the core is within 1.5 meters of the top of the cored interval. Thus, the downhole depth of 12-124-3-2,25 cm is calculated as follows. The top of the cored interval of Core 3 is 298 meters. The top of Section 2 is 1.5 meters below the top of the cored interval, that is, at 299.5 meters. The sample is 25 cm below the top of Section 2, that is, at 299.75 meters.

For the purpose of presenting data for the entire hole in the hole summary sheets, where one meter is represented by less than one millimeter, the top of the recovered sediment is always drawn at the top of the cored interval. The error involved in this presentation is always less than 1.5 meters when compared with depths calculated from the sample lable.

Handling of Cores

The first assessment of the core material was made rapidly based on samples from the core catcher.

After a core section had been cut, sealed and labeled, it was brought into the core laboratory for processing. The routine procedure listed below was usually followed:

1) Weighing of the core section for mean bulk density measurement,
2) GRAPE analysis for bulk density,
3) Gamma ray counting for radioactivity.

After the physical measurements were made, the core liner was cut using an electric saw, and the end caps with a knife. The core was then split into halves using a cheese cutter if the sediment was a soft ooze. At times, when compacted or partially lithified sediments were included, the core had to be split using a machine band saw or diamond wheel.

One of the split halves was designated a working half. Penetrometer readings were taken to provide a measurement of the degree of sediment consolidation. Samples, including those for grain size, X-ray mineralogy, interstitial water chemistry, and total carbonate content, were taken, labeled, and sealed. Larger samples were taken from suitable cores for organic geochemical analysis.

The working half was then sent to the Paleontology Laboratory. There, samples for shipboard and shore-based studies of nannoplankton, foraminifera, and radiolarians were taken.

The other half of a split section was designated an archive half. The cut surface was smoothed with a spatula to bring out more clearly the sedimentary features. The color, texture, structure, and composition of the various lithologic units within a section were described on standard visual core description sheets (one per section) and any unusual features noted. Smear slides were made of the sediments of each section at changes in lithology and were examined microscopically. The archive half of the core section was then photographed. Both halves were sent to on board cold storage after they had been processed.

Material obtained from core catchers and not used up in the initial examination was retained in freezer boxes for subsequent work. Sometimes significant pebbles from the core were extracted and stored separately in labeled containers where each fragment was given a separate number. On other occasions, the liners contained only sediment-laden water. This was usually collected in a bucket and allowed to settle, the residue being stored in freezer boxes.

At several sites, hard cores were obtained either of basement or indurated sediment. Each separate core fragment was numbered and labeled consecutively from the top downwards, and its orientation indicated by an upward-pointing arrow. Where possible, the fragments were arranged in their original relative orientation and then sliced longitudinally for examination and separation into working and archive halves.

All samples are now deposited in cold storage at the DSDP East Coast Repository at the Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York.

Comments on the Drilling Characteristics

Since water circulation down the hole is an open one, cuttings are lost on to the sea bed and cannot be examined. The only information about sedimentary stratification between cores, obtained from other than seismic data, was from an examination of the behavior of the drill string as observed on the drill platform. In drilling, the harder the layer being drilled, the slower and more difficult it is to penetrate. However, there are a number of other variable factors which determine the rate of penetration, so it is not possible to directly correlate this rate with the hardness of the layers. The following parameters are recorded on the drilling recorder and all influence the rate of penetration.

1) Bit weight. This can vary in three steps from zero, when the bit is suspended, up to 40,000 pounds when two of the three bumper subs are collapsed and the whole bottom-assembly bears on the bit. The aim of the driller is to maintain constant bit weight by lowering the drill string when necessary. However, this is extremely difficult to do in conditions of swell where the heave of the drill platform may exceed the available extension (15 feet) of the bumper subs.

2) Revolutions per minute. The revolutions per minute (rpm) are related to the torque applied to the top of the drill string, and a direct analysis of the two should give the resistance to drilling. However, the revolutions-per-minute record is not adequately expanded to do this. Nevertheless, visual observations of the drill rotation are useful in assessing the behavior of the bit. In particular, one can see that when the drill bit becomes jammed, rotation stops and then speeds up as it becomes free and the drill string untwists.

3) Torque. The amount of torque applied to the drill from the hydraulic drive is a more sensitive measure of drill bit behavior and is well recorded. In Hole 134D, for instance, the drill string "torqued-up" erratically during the penetration of fractured hard rocks.

4) Pump pressure and strokes per minute of water circulation. Two pumps were available to circulate water down through the drill string, past the bit and up to the sea bed in the annulus between the drill and the hole. Both pressure and rate of flow of water (in strokes per minute) were recorded. Changes in circulation were one of the major factors influencing the rate of penetration. In softer sediments, more penetration was achieved by jetting the sediment out of the way than by cutting, so that while drilling ahead, high strokes per minute were used, whereas during coring minimum strokes were used consistent with flushing out cuttings and keeping the hole clean. Often during the cutting of a core, the holes in the bit became blocked and bursts of higher circulation ("circulation breaks") were required to clear them before proceeding. These bursts of circulation were sometimes responsible for forcing soupy sediments into the core liner between harder sections. The relationship between pump pressure and rate of flow depends on the resistance to flow determined by the restrictions in the circulation path near the drill bit and in the return to the sea bed. The upward flowing water is laden with sediment cuttings and therefore exerts a net downward pressure which sometimes has to be overcome by injecting drilling muds into the circulation system. Drilling mud was also used to flush out chips of hard rocks, although only limited use of mud was possible since the circulation system was not closed.

5) Penetration. The progress of the drill string into the bottom is recorded on the drilling recorder every 0.25 meter and every 1.0 meter. Hence, penetration rates can be measured in meters per hour.

An exact interpretation of these various factors in terms of the properties of sediments is not possible. Gross variations can be seen from the drilling records, but the more subtle changes are best assessed on the spot at the time of drilling. The driller who is constantly at the control console can assess these factors and with his long experience can make the best estimate as to the nature of the bottom.

Throughout all the drilling operations, one of the scientific party was on the drilling platform in close contact with the driller, the tool pusher, and the drilling recorder. Notes were made on the drilling characteristics, and an interpretation of the hardness of the bottom was recorded in a note book. A majority of the site reports contain a graphical presentation of drilling rates and characteristics on which comments from the notebook have been quoted verbatim.

In some cases, the inability to make hole was clearly the result of hard layers, such as anhydrite, indurated sandstones, limestones or metamorphic basement, as indicated by the core material recovered. In other cases, however, no hard layers could be sampled and it appeared that waxy sediments had built up on the bit and spun around in the hole thus preventing water circulation and cushioning the bit.

Lithologic Nomenclature

For oceanic sediments of an inland sea such as the Mediterranean, where terrigenous influx is important, we have adopted a classification of unconsolidated sediments distinguished on the basis of their carbonate skeletal content. Recognizing that it is difficult to accurately assess the relative percentage of the various biogenic components in smear slides or washed residues, a loose usage has been practiced. Very fine-grained sediment with little or no fossil material has been classified as clay; its lithified counterpart has been termed a shale. When biogenic carbonate predominates, the sediments have been referred to as an ooze, either a foraminiferal ooze or a nannofossil ooze depending on the relative abundances of the two. The lithified equivalents are either limestone or a chalk.

Oozes which contain an abundant terrigenous component, be it clay sized or silty, have been referred to as marl oozes, and their indurated equivalents have been called marls.

For other sediments of unusual composition we have followed general geological usage (i.e., sapropels, dolomite, tephra etc.).

Nomenclature of Acoustic Reflectors

The designation and naming of acoustic reflectors of the Mediterranean basins have been done separately by various scientific and industrial teams working in the region. There has been some confusion because of the multiple naming of the same acoustic interface. Deep-sea drilling has led to the identification of some of the reflectors, and these are discussed in various site reports. For the sake of convenient reference, we propose the following nomenclature.

In the western and eastern Mediterranean basins, we have recognized a very prominent set of seismic reflectors, which have been referred to as the M-Reflectors by Wong and Zarudzki (1969), by Ryan *et al.* (1971), and by Biscaye *et al.* (1971), although other names have been used to designate the same set of reflectors. Since the top of the set has been identified as the top of the Mediterranean Evaporite of Miocene age, we recommend that the letter prefix "M" be retained.

Other reflecting interfaces could be recognized above the top of the M-Reflectors. Sice they belong to Pliocene and Pleistocene strata they have been designated P-Reflectors, and referred to individually as P-alpha, P-beta, etc.

A third set of reflectors could be recognized below the M-Reflectors, under an interval of noncoherent echo returns, which we identify as halite deposits. They have been designated the N- and O-Reflectors. Whether these represent older beds of the Mediterranean Evaporite formation, or whether they represent preevaporitic limestone or marl formations cannot as yet be ascertained. This problem is discussed in Chapter 37.

The correlation of reflectors from the western Alboran Basin to other parts of the Mediterranean was not available prior to the cruise. At Site 121 we adopted on shipboard an informal and arbitrary set of names corresponding to colors. Although this usage has been incorporated in the Site Report of Chapter 3, we consider it to be provisional.

Many of the internal reflecting interfaces are conformable to subadjacent layering and thus lettered reflections can be considered to be equivalent to the tops of sedimentary strata. In other cases, unconformities and discontinuities are present, and we use the word "Horizon" to designate such interfaces.

The identification of individual reflectors will be discussed in the site reports and will be summarized in Chapter 37. Where we were able to make direct correlations with reflector nomenclature of published papers, we did so. The recognition of such reflectors and their stratigraphical significance have proved to be of considerable value for the interpretation of the geological history of the Mediterranean.

Physical Properties

The sediments cored in every hole were first sectioned, then numbered and processed before the systematical sampling was carried out. Physical property measurements made on board ship include:

1) Section weight and determination of bulk density assuming a constant volume for each section;

2) Porosity, determined after drying;

3) GRAPE analysis to determine bulk density variations and porosity;

4) Gamma-ray counting to estimate natural radioactivity;

5) Penetrometer readings to estimate the extent of induration of the sediments.

The equipment for measurement of sonic velocity did not function during the cruise. Also no heat-flow or thermal conductivity measurements were made.

Other parameters measured in shore-based laboratories include geochemical data from interstitial waters, carbon, and calcium carbonate content of sediments, water content, and grain size determinations, etc. The shipboard measurements of density, and natural gamma data are presented in graphical form in the barrel summaries located in the appendix of the volume. Complete listings of the physical properties data are available at the west coast Repository of the DSDP (Scripps Institution of Oceanography).

The GRAPE System seemed to produce consistently high values for densities measured on the sediments cored during this leg. Grain density determinations appear to be consistently low. Shore analyses produced values of grain densities that were in many cases very high. Details are discussed in Chapter 39, where an assessment of the reliability of shipboard determinations is also attempted.

Grain Size Carbon and Carbonate Analyses

Grain size distribution was determined by standard sieve and pipette analysis. The sediment sample was dried, then dispersed in a Calgon solution. If the sediment failed to disaggregate in Calgon, it was dispersed in hydrogen peroxide. The sand-sized fraction was separated by a 62.5-micron sieve with the fines being processed by standard pipette analysis following Stokes settling velocity equation (Krumbein and Pettijohn, 1938, pp. 95-96) which is discussed in detail in Volume IX of the *Initial Reports of the Deep Sea Drilling Project.* Step-by-step procedures are in Volume V. In general, the sand-silt-, and clay-sized fractions are reproducible within ± 2.5 per cent (absolute) with multiple operators over a long period of time. A discussion of this precision is in Volume IX.

The carbon-carbonate data were determined by Leco induction furnace combined with a Leco acid-base semiautomatic carbon determinator. Normally, the more precise seventy-second analyser is used in place of the semiautomatic carbon determinator, but it was not used for these samples because it was undergoing modifications.

The sample is burned at 1600°C and the liberated gas of carbon dioxide and oxygen volumetrically measured in a solution of dilute sulfuric acid and methyl red. This gas is then passed through potassium hydroxide solution, which preferentially absorbs carbon dioxide, and the volume of the gas is measured a second time. The volume of carbon dioxide gas is the difference between the two volumetric measurements. Corrections are made to standard temperature and pressure. Step-by-step procedures are in Volume IV of the *Initial Reports of the Deep Sea Drilling Project* and a discussion of the method, calibration, and precision are in Volume IX.

Total carbon and organic carbon (carbon remaining after treatment with hydrochloric acid) are determined in terms of per cent by weight, and the theoretical percentage of calcium carbonate is calculated from the following relationship:

Per cent calcium carbonate ($CaCO_3$)=(% total C - % C after acidification) X 8.33

However, carbonate sediments may also include magnesium, iron, or other carbonates; this may result in "calcium" carbonate values greater than the actual content of calcium carbonate. In our determinations, all carbonate is assumed to be calcium carbonate. Claimed precision of the determination is as follows:

Total carbon (within 1.2 to 12%)	=±0.3% absolute
(within 0 to 1.2%)	=±0.06% absolute
Organic carbon	=±0.06% absolute

Calcium carbonate (within 10-100%) =±3.0% absolute
(within 0-10%) =±1.0% absolute

The analytical data of the grain size, carbon and carbonate contents are presented numerically in the barrel summaries of each site chapter in Part I of the volume.

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