14. BOUNDARY OF SARDINIA SLOPE WITH BALEARIC ABYSSAL PLAIN – SITES 133 AND 134

The Shipboard Scientific Party[1]

SITE DATA

Occupied: September 27-October 1, 1970.

Position: On the crest and along the flank of a buried nonmagnetic basement ridge which is onlapped by horizontally stratified sediments of the Balearic Abyssal Plain at the western margin of continental slope of Sardinia.

Number of Holes Drilled: One at Site 133 and six at Site 134.

Hole 133 – Just eastward of the crest of the basement ridge near the foot of the Sardinia Slope.
Latitude: 39° 11.99′N
Longitude: 07° 20.13′E

Hole 134 – On the Balearic Abyssal Plain 2.6 km west of Hole 133 and 1.1 km west of the plain/slope boundary.
Latitude: 39° 11.70′N
Longitude: 07° 18.25′E

Holes 134A, 134B, 134C, 134D, and 134E are on the abyssal plain along an east-to-west traverse between Holes 133 and 134. They are located 890 meters, 790 meters, 610 meters, 430 meters, and 340 meters east of Hole 134, respectively.

Water Depths: 2563 meters for Hole 133 on the Sardinia Slope and 2864 meters for all the Site 134 holes on the Balearic Abyssal Plain.

Cores Taken: Hole 133: eight; Hole 134: ten; Hole 134A: two; Hole 134B: one; Hole 134C: one; Hole 134D: three; Hole 134E: three (wireline cores) plus two (sidewall cores).

Maximum Penetration: 364 meters (in Hole 134).

Deepest Unit Recovered: Paleozoic (?) phyllites and metagraywackes from the basement ridge and Late Miocene rock salt (halite) from beneath the abyssal plain.

MAIN RESULTS

Metamorphic rocks were sampled from the nonmagnetic basement ridge at the foot of the western Sardinia slope in five drill holes and were also found as occasional erratic cobbles and pebbles in marine sediments which cover the ridge. The recovered metagraywackes and phyllites are strikingly similar in composition, grain-size, and metamorphic fabric to basement rocks from another buried ridge beneath the Gulf of Lyon, France on the opposite side of the Balearic Basin.

As had been the case at previous sites, Horizon M corresponds to the top of the late Miocene Mediterranean evaporite. The facies represented on the shallower landward flank of the basement ridge is terrestrial. It includes sequences of poorly bedded variegated silts and shales with well-rounded pebbles and cobbles, believed to be alluvial deposits (i.e., channel or arroyo detritus). No fossils nor carbonate were detected, and nonresistant minerals such as angular and unweathered feldspars are common constituents of the silts.

The evaporite facies recovered from beneath the abyssal plain, on the other hand, consists of playa salts (i.e., banded halite and laminated anhydrite) with an interbed of fossiliferous marl containing significant quantities of gasoline-range light hydrocarbons. Evidence of a shallow-water origin for the salts includes diagenetic recrystallization of the halite hopper crystals and desiccation cracks.

The margin of the abyssal plain where Horizon M onlaps the basement ridge is characterized by nodular gypsum and dolomitic silts of the supratidal *sabkha* facies.

Stratigraphic gaps and angular unconformities are present in the overlying marine calcareous oozes of Pliocene and Pleistocene age. The Miocene/Pliocene and Pliocene/Pleistocene boundaries were cored, and they both are represented by discontinuities; the latter one recorded in a thin mineralized iron and manganese crust (hardground) reflecting a period of nondeposition estimated as approximately one million years.

BACKGROUND

Our discovery of pelagic sediments of a supposed open marine bathyal facies lying directly on evaporites containing autochthonous neritic faunas initiated an intense shipboard dialogue[2]. While one group of our scientific party elaborated working hypotheses that the Mediterranean Sea had formerly been a restricted shallow epicontinental platform with a patchwork of interconnected lagoons, and that this platform had abruptly foundered to abyssal depths at the close of the Miocene period, another group argued that deep basins had predated the evaporite epoch and that the Mediterranean had merely dried up in a series of desiccation cycles which suddenly were terminated by a permanent invasion of marine water from the Atlantic. The evidence for intertidal and supratidal environments for

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[2] The reader is referred to Chapters 21 and 43 for more elaborate presentations of the dialogue concerning the environmental setting leading to the deposition of the Mediterranean evaporite layer in Late Miocene times.

parts of the evaporite series was considered very strong by all of us.

One of the principal points of discussion, however, was the fact that no transgressive (i.e., transitional) facies from shallow to deep-water sedimentation had been detected at any of the drill sites visited so far.

Testing the Various Models of Evaporite Deposition

To some of the scientific party this lack of a detectable gradient in the paleo-depth of deposition was considered as a fatal blow to the subsidence model. Nevertheless, those who preferred this model could argue that such a facies probably did exist, but somehow it had not yet been cored in the deep sea due to stratigraphic gaps in previous drill holes. In fact, there was already rather convincing evidence that lowermost Pliocene marine sediments are missing above the evaporite layer on both the Balearic Rise (Site 124) and the Mediterranean Ridge (Site 125), as has been documented already in Chapters 6 and 7, respectively.

During one of the many shipboard discussions, one of us proposed that we should not look for evidence in the overlying marine sediments but in the evaporites themselves. This person suggested that we should search our available seismic reflection profiles and bathymetric charts for a depositional setting around the margins of the basins where Reflector M (hitherto correlatable with the roof of the evaporite layer) not only lay in direct contact with a buried basement high[3], but where it occurs at different depths on either side of the high (e.g. deeper in the seaward side and shallower on the landward side). It was argued that with the subsidence model, one would have predicted a basically uniform evaporite facies distribution across the shallow platform (Figure 1A), and that the relief of the basin would only have been created after the "salinity crisis" when the center of the basin started to founder (Figure 1B). This hypothesis predicted that Reflector M would have been subsequently displaced to the two observed levels by normal faulting in the developing graben.

With the desiccation model, on the other hand, the basin configuration would have had considerable preexisting topographic relief so that while the deepest parts were reduced to shallow lakes and salinas, vast tracts of the margins would have been exposed (Figure 1C). It was predicted by proponents of the desiccation model that markedly different sedimentary facies should be developed at different bathymetric levels and that the materials which make up Reflector M on the deeper side of a marginal basement high should be recognizably different from those which make up the reflector on the shallower, landward side (Figure 1D).

We thus had a new scheme for testing the two contrasting models for the origin of the evaporite which fortunately relied on the inherent properties of the evaporites themselves rather than on the nature of the overlying marine oozes, which were susceptible to winnowing or removal.

Non-Magnetic Basement Ridges

With time left on the leg for the investigation of only one more region of the Mediterranean before steaming back to Lisbon, it was decided to push ahead with an examination of the two working hypotheses, provided that we could also find a way to reexplore the nagging question as to the mechanism for oceanization of the western Mediterranean Basin[4].

In 1964 the R/V *Chain* of the Woods Hole Oceanographic Institution under the scientific direction of J. B. Hersey had detected buried basement ridges beneath the lower continental slope of western Corsica and Sardinia. The seaward (westward) facing flank of the ridges descends steeply below the stratified sediment fill of the Balearic Abyssal Plain and has the appearance in seismic reflection profiles of a fault scarp (Figure 2). The ridges themselves have in the past apparently acted as topographic barriers to the dispersal of sediment from Corsica and Sardinia, since small elevated slope basins occur along their landward (eastward) margins (Hersey, 1965). Furthermore the basement ridges possess no magnetic signature unlike other peaks further upslope with magnetic anomalies (Glandgeaud *et al.*, 1966; Vogt *et al.*, 1971), which are thought to be offshore continuations of an Oligocene-Miocene belt of andesite vulcanism (De Jong *et al.*, 1969). The nonmagnetic ridges along the western margin of Sardinia looked suspiciously like those buried beneath the surface of the Gulf of Lyon[5] along the southern coast of France, and not unlike those detected some time ago beneath the eastern continental margin of North America (Drake *et al.*, 1959). The discovery of the ridges in the Mediterranean generated considerable interest because they are amenable to direct sampling by deep-sea drilling, whereas those on older margins are blanketed by great thicknesses of sediment.

Selection of a Site

The western margin of Sardinia (Figure 3) had been explored in the Spring of 1970 by the R/V *Jean Charcot* of the Centre Océanologique de Bretagne during her site survey campaign. In her underway reflection profiling using a Flexotir sound source, an ideal setting had been found which would permit the realization of the aforementioned drilling objectives. These records (see Figures 4 and 5) were once again reexamined on board the *Challenger* as we were preparing to abandon Site 132 in the Tyrrhenian Basin.

The basement ridge west of Sardinia lies at the very distal edge of the continental slope and has effectively

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[3] By basement we mean the acoustic basement with a noncoherence in its reflection characteristics as discussed by Ewing and Ewing (1971).

[4] Theories on the oceanization of the western Mediterranean had been elaborately put forth in a symposium of Nov. 28, 1968 sponsored by the Netherlands Upper Mantle Project Commission in cooperation with the Royal Geological and Mining Society of the Netherlands, and organized by Prof. R. W. Bemmelen (see references under Royal . . ., 1969). Testing these theories had been considered by the Mediterranean Advisory Panel to be a major scientific objective of Leg 13.

[5] The presence of a buried basement high in the Gulf of Lyon was initially brought to the attention of the Mediterranean Advisory Panel by P. Magnier during one of the planning sessions in Zurich. The ridge had been drilled into by the Compagnie Francaise des Petroles in an exploratory well, Mistral 1 (42° 59.6'N; 3° 53.9'E), and schists of Paleozoic age had been recovered (see Chapter 29.1).

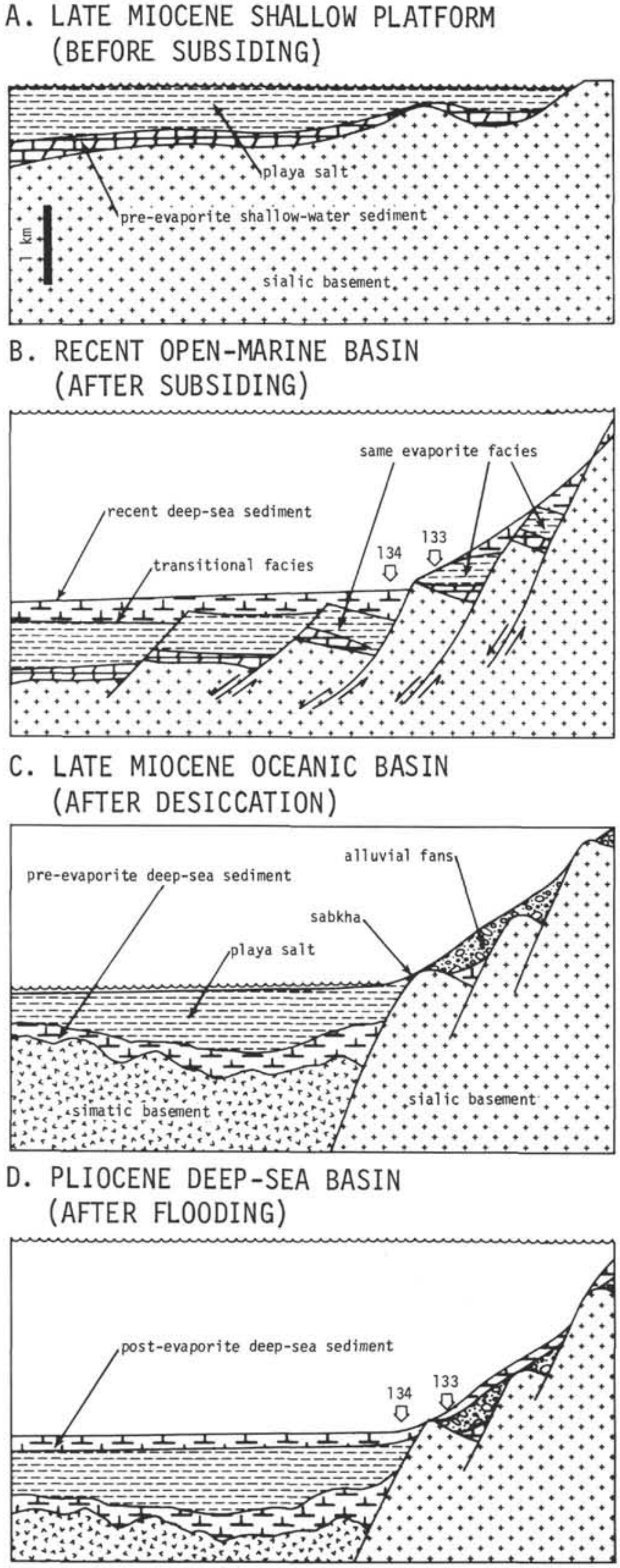

Figure 1. *Proposed models of evaporite deposition. In the upper model* (A *and* B) *a rather uniform layer of salt, originally formed in a restricted and shallow epicontinental sea is downdropped in a phase of post-depositional foundering. In the lower example* (C *and* D) *the deep-basin configuration preexists the deposition of the evaporite layer, which occurs on shallow playas and marginal tidal flats following desiccation. One might expect to sample much the same type of evaporite facies at different bathymetric levels in the basin with the former model, whereas one would certainly expect to find a significantly different facies on the margins of the basin than in the center with the latter model. The great subsidence illustrated in* B *originates from an external tectonic cause (orogenic), and the lesser amount of downwarp in* D *results from isostatic adjustments following the return of the water layer (loading).*

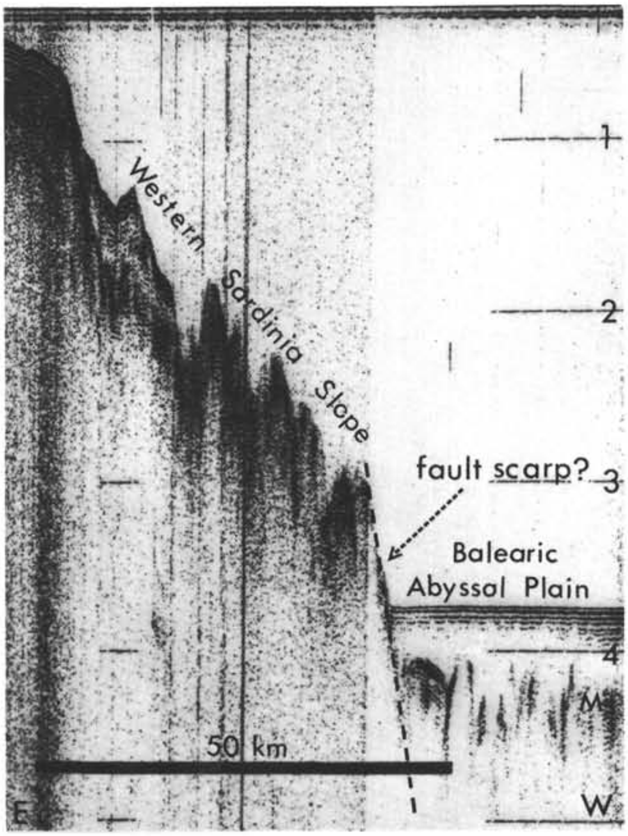

Figure 2. *Reflection profile across the boundary of the southwestern continental slope of Sardinia and the Balearic Abyssal Plain. Note the steep escarpment at the base of the slope which has been interpreted by some investigators to be a fault scarp. This profile made by the* Glomar Challenger *is about 45 km south of the location of Sites 133 and 134. Vertical scale is in seconds (two-way travel time) and the vertical exaggeration is ≈ 25:1.*

dammed an upslope sedimentary basin which is presently isolated from the Balearic Abyssal Plain. The seaward edge of the ridge drops deeply beneath the surface of the plain, and the observed ponding nature of the sedimentary strata

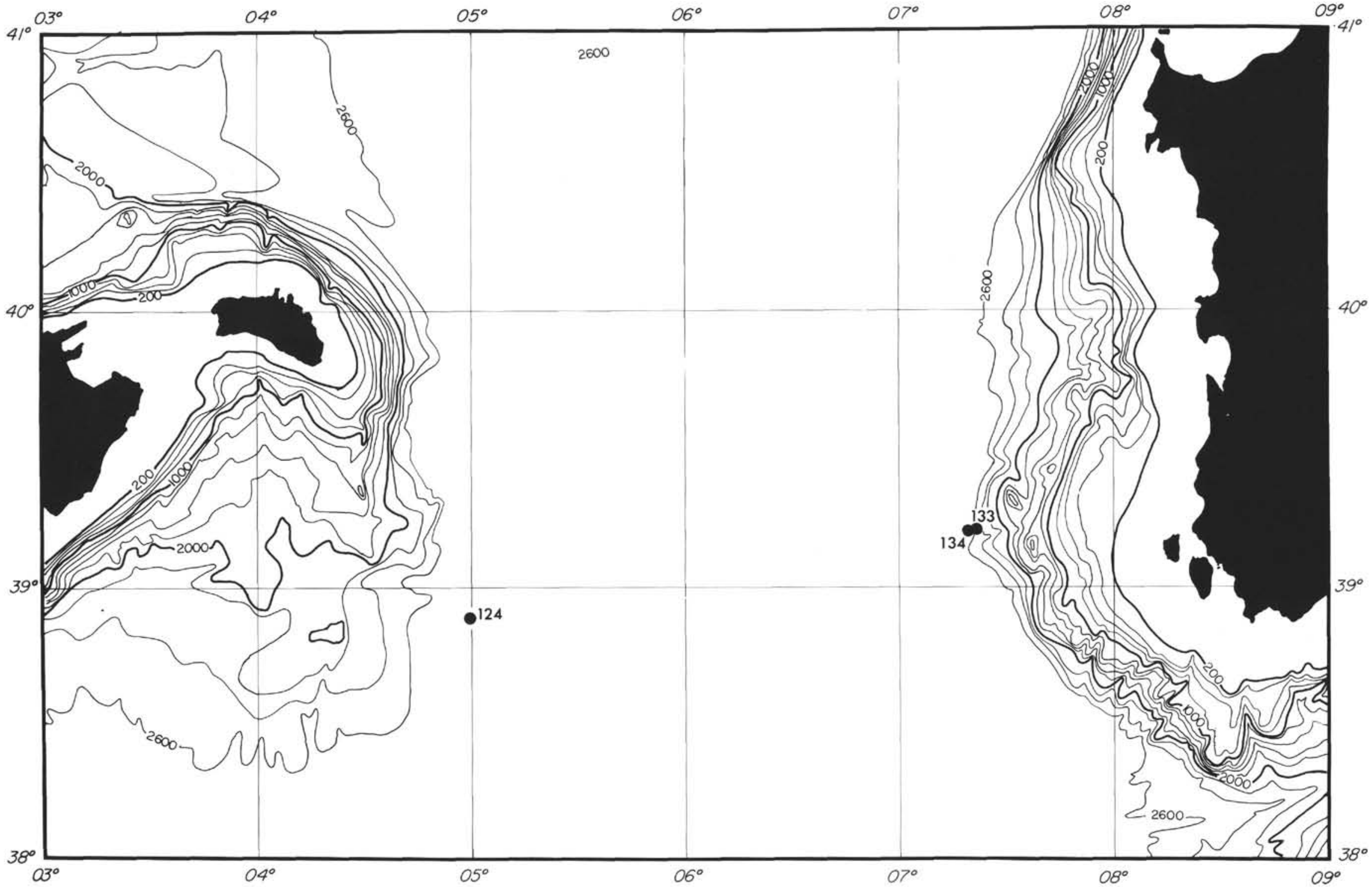

Figure 3. *Balearic Abyssal Plain. Contours in meters adapted from Chart 310 of the Defense Mapping Agency Hydrographic Center.*

therein argues that the ridge predates the abyssal plain. Horizon M can be observed at a subbottom depth of ≈ 0.35 second beneath the abyssal plain to the west of the ridge where it can be directly traced into a field of diapiric structures thought to be a southern extension of the Balearic "salt dome province" of Hersey (1965), Menard *et al.* (1965), Glangeaud *et al.* (1966); Leenhardt *et al.* (1970) Mauffret (1968, 1969), Watson and Johnson (1968), Fahlquist and Hersey (1969), and Wong *et al.* (1970).

In the slope basin east of the ridge, Horizon M not only is much shallower in the acoustically stratified sequence, but it occurs at a level almost 600 meters higher than where it is found in the abyssal plain. The M-Reflectors and some deeper strata in the slope basin wedge out against the eastern flank of the basement ridge which can be interpreted to indicate that here the relief of the ridge also predates their deposition.

The margin of the Balearic Abyssal Plain shown in the *Charcot* profile is located only about 50 km eastward of a 65-km-long seismic refraction profile (No. 194) reported in Fahlquist and Hersey (1969). This profile reveals a great thickness of sedimentary materials with intermediate compressional-wave velocities (i.e., 3.44 to 3.89 km/sec) whose uppermost surface corresponds to Horizon M in vertical reflection profiling. These layers occur above a refracting interface at a depth of 6.7 to 7.6 km with a characteristic compressional-wave velocity of 5.23 to 5.29 km/sec, interpreted to be acoustic basement (perhaps oceanic layer No. 2 of Raitt, 1963). The relatively high velocity (7.21 to 7.24 km/sec) measured below this layer at a depth near 10 km is similar in magnitude to that obtained at Profile No. 193 in the Tyrrhenian Basin near Site 132, only it is approximately 3 km deeper. This high velocity layer has been considered by Fahlquist and Hersey (1969) to be of upper mantle origin and gives the Balearic and Tyrrhenian basins their oceanic complexion (see Menard, 1967 for a further discussion of this point).

Another interesting aspect about the potential drilling site on the Sardinia margin surveyed by the *Jean Charcot* is that if one hypothetically restores the microplates of Sardinia and Corsica (see Alvarez, 1972) to a constrained predrift fit against Europe using slope isobaths and other geological and geophysical[6] criteria, the proposed location for the *Challenger* drilling becomes almost directly contiguous with the site of the exploratory *Mistral* Hole in the Gulf of Lyon (Figure 6). In fact, the two drilling areas are only separated by 55 km.

Objectives

From a series of discussions on board the drilling vessel, there emerged a plan of attack which could treat several geological problems together. One goal would be to determine whether the facies of the evaporite is different on either side of the basement ridge. Another would be to drill near the edge of a continent only 50 km from thin ocean-like crust and sample basement rocks to learn if they represented intruded plutons or subsided sialic blocks. And still another would be to test a predrift reconstruction so as to find out if rocks from two sides of the Balearic Basin at conjugate points have any similarity in composition and/or age. If so, the oldest marine sediments transgressive above the basement rocks might reflect the age at which the initial breakup and distension took place, since drilling into the basement in the center of the present deep-sea basin was out of the question with the existing technical capabilities of the Deep Sea Drilling Project.

The biostratigraphers were also anxious to get another continuous section across a pelagic ooze/evaporite contact at Horizon M, as well as to sample once again the Pliocene/Pleistocene boundary. There was considerable curiosity as to whether zonations worked out in the enclosed eastern and central Mediterranean basins could be extended to the western basin with its more direct connection to the Atlantic. Then there was the hope, too, of grinding through the salt layer into preevaporitic sediments.

Strategy

Consequently a series of holes was contemplated along an east to west transverse of the *Charcot* profile of Figures 4 and 5. The *Challenger* would be directed to proceed in the most direct course around Sardinia and approach the drilling area from the landward side.

The first target (Hole 133) was picked in the elevated slope basin as close to the eastward flank of the basement ridge as was practical to ensure its penetration. Recognizing that up until now drilling and coring of the pre-Horizon-M strata had been very time consuming, the eventual location for our preliminary try was planned for the 2130-hour (May 17, 1970) intercept on the *Charcot* track (see Figure 5).

After completion of this first hole, additional offsets would be incorporated in the program in order to eventually take the *Glomar Challenger* westward out over the abyssal plain so as to explore the salt layer there. These offsets are described in this Chapter in the section entitled "Operations".

Challenger Site Approach

The *Glomar Challenger* proceeded to circumnavigate the southern coast of Sardinia at 0200 hours on September 27, 1970 and continued at 10 knots northwest to the selected drilling target.

The edge of the continental shelf was reached at 0345 hours. Reflector M could be traced at a depth of about 0.3 second below the sea bed, practically all the way from the shelf break to the base of the slope where, as illustrated in Figure 7, it becomes much more reverberant. At the moment that the strongly reflective M-horizon was noticed to abut abruptly against the eastern flank of the targeted basement ridge, a free-floating buoy was ejected (0734 hours) to mark this event (Figure 8). The vessel, however, continued on her course of 297° until the abyssal plain was reached approximately six minutes later, at which time the streamed geophysical gear was retrieved. This operation was not accomplished until 0802 hours when the *Challenger*

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[6] The reconstruction presented is remarkably close to that first proposed by Argand (1922) and involves a slight decoupling of Corsica from Sardinia.

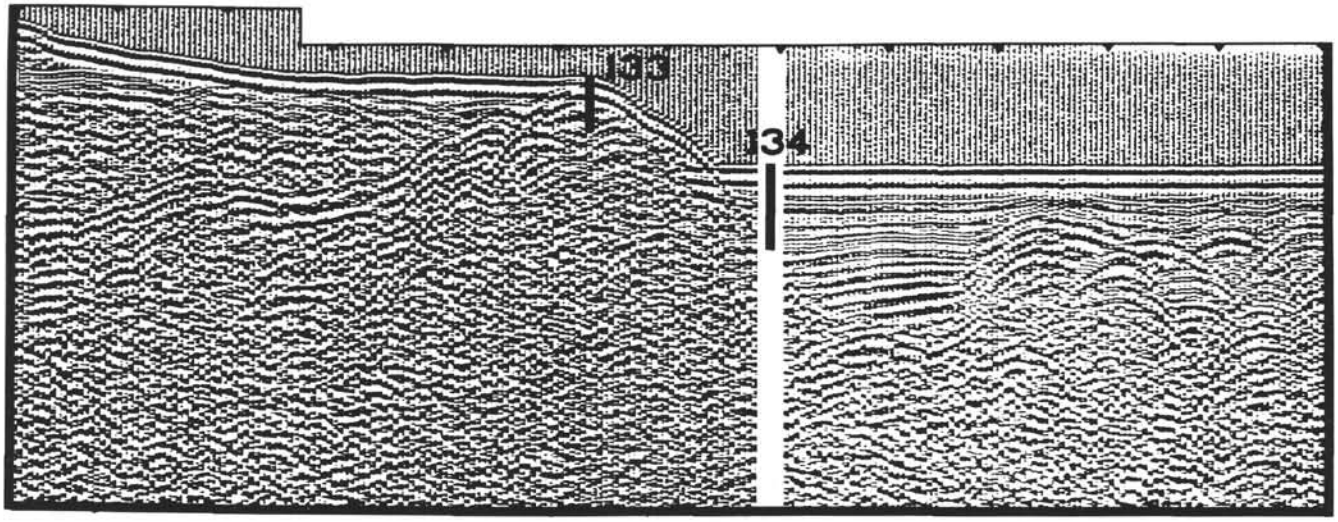

Figure 4. *Seismic reflection profile (Flexotir sound source and variable area recording) across the buried nonmagnetic basement ridge at the seaward edge of the western Sardinia Slope. Site 133 is located near the crest of the ridge and Site 134 on the Balearic Abyssal Plain. The profile made by the R/V* Jean Charcot *(Centre Océanologique de Bretagne) has a vertical exaggeration of ≈ 4:1.*

reversed course to the left to proceed back to the marker buoy over the ridge.

Because the vessel was still out over the western escarpment of the ridge when the buoy was approached at 0820 hours, she continued for a short while further eastward until 0827 hours when she came dead still in the water in preparation for dropping the acoustic positioning beacon. This operation was executed at 0834 hours with a water depth reading of 1332 tau (equivalent to a value of 2544 meters corrected for sound velocity). Details of the *Challenger* approach to Site 133 are shown in Figure 9. A mean position determined from numerous satellite fixes obtained while on station puts the actual drill hole only a few hundred meters north of the *Charcot* profile opposite the 2127-hour shot point shown in Figure 4.

OPERATIONS

The *Glomar Challenger* stayed on location at Site 133 for a little more than one day (from 0834 hours on September 27 until 1545 hours on September 28). A single hole was drilled which terminated at 192 meters below bottom in detrital cobbles, sandstones, and shales which caused great technical difficulties in effecting penetration. The core inventory for Hole 133 is given in Table 1.

The Drilling of Hole 133

The drill bit touched bottom at a drill string length of 2563 meters below sea level. The superficial soft sediments were easily washed aside as we attempted to bury the bottom hole assembly for greater security.

The first hard layer was encountered at 49 meters below bottom; this correlates well on the seismic reflection record with the subsurface level of Horizon M. Core 1 was cut here into very hard materials which induced a great deal of erratic torquing of the drill string and bouncing of the bit. Only five meters were drilled in a little over an hour, and when the core barrel was retrieved we discovered a thin layer of washed sand and oozes of Quaternary age underlain by an unfossiliferous, compacted, reddish brown detrital silt with rounded cobbles of metamorphic rock.

Three more cores were taken continuously down to 81 meters and more unfossiliferous variegated silts and shales with cobbles were obtained.

Cores 5 and 6 were cut at spacings of ten meters, and this penetration was accompanied by more erratic torquing. Circulation was required to keep the hole clear and prevent jamming; thus, recovery was very poor. In Core 6 additional rounded cobbles of metamorphic rock were noted, this time they were imbedded in a partly indurated clayey sand.

During the cutting of Core 7, the drill bit repeatedly grabbed at the formation, each time momentarily halting rotation of the drill string. At one point the bit became completely stuck and considerable time was lost circulating and flushing the hole with drilling mud in order to free it.

Our drilling superintendent and operations manager became more and more concerned with the possibility of a cave-in of the uncased, open hole as had happened previously while drilling into a basement ridge at Site 123 in the Valencian Trough. However, with their permission another attempt was made to push on, this time to 192 meters, where we completed the cutting of Core 8. As before, high pump pressures were necessary to keep the hole open, and this washing process apparently removed all the loose material and left us with only a single large cobble of dense metamorphic rock in the core catcher.

When the next pipe joint was made up so as to begin penetration again, the drill was found to be jammed tight in the hole. Much effort was exerted trying to lift it free, and the entire drilling vessel shook for over an hour and a half during this attempt before it finally became unstuck once more.

Offsetting to Site 134

A reexamination of the *Charcot* seismic profile showed that at 192 meters below bottom the drill string was close

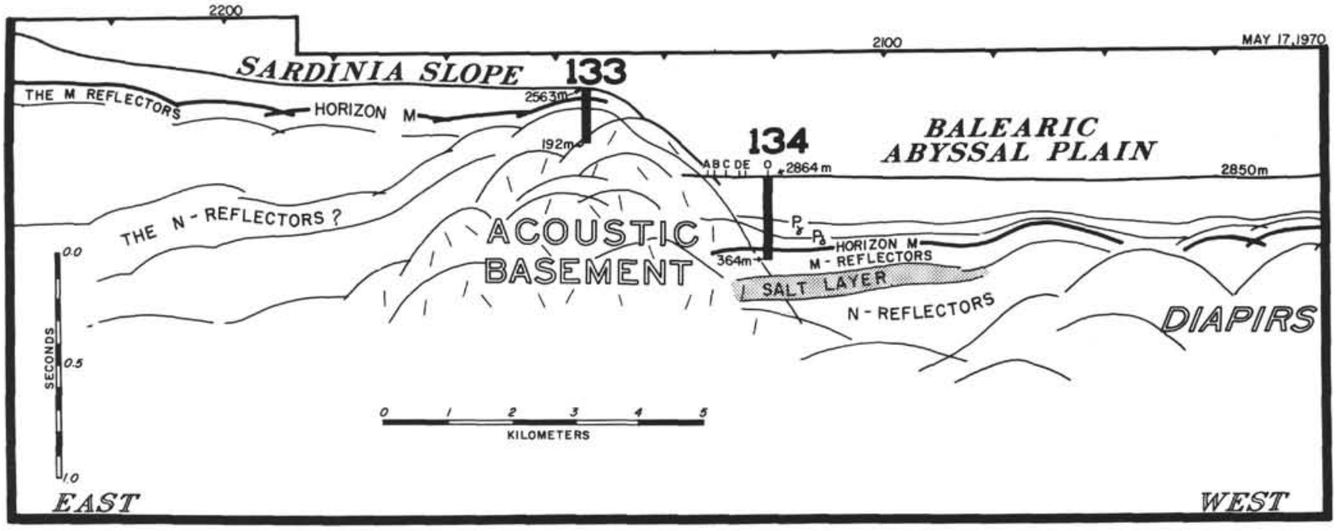

Figure 5. *Schematic interpretation of the* Charcot *profile of Figure 4. Both Reflector Pδ and Horizon M correspond to visual angular unconformities and represent significant gaps in sedimentation as discusses in the test. The "salt layer" identification is after criteria discussed by Montadert* et al., *(1970) and Auzend* et al., *(1971). Note the occurrence of Horizon M east of the ridge at an elevation almost 600 meters above the level where it is found beneath the abyssal plain. The letters* A, B, C, D, *and* E *mark the location of offset holes for Site 134, each of which terminated in the westward flank of the basement ridge.*

to entering the crest of the acoustic basement ridge. It was reasoned that if the vessel could be moved a few kilometers to the west, a new attempt could be made to enter the seaward side of the high without first having to penetrate into the pre-Horizon-M strata.

Realizing that we would be moving on far enough to require a new acoustic positioning beacon, and recognizing that we had only a few more days of drilling time left, it was decided to locate the first of the new Site 134 holes at the western end of the transit and then eventually work our way back to the basement ridge problem later. By starting on the abyssal plain we could spend an appreciable amount of time there, if necessary, for the purpose of verifying the facies of the evaporite on the downdropped side of the basement high, and hopefully for penetrating into pre-evaporite strata.

For the offset maneuver, the bottom hole assembly was again raised some 200 meters above the mudline, and at 1545 hours on September 28 the vessel was slowly directed toward the west, inserting larger and larger offsets into the dynamic positioning computer.

An echogram recorded during the voyage from Hole 133 to the abyssal plain is shown in Figure 10 with a horizontal scale calibrated in the distance in feet from the Site 133 beacon. The edge of the abyssal plain was reached after traveling 5000 feet (1.5 km) and the acoustic signal fram the beacon was lost at 6000 feet (1.8 km). From then on the *Challenger* dead reckoned westward at a speed of approximately 1 knot until a new beacon with a different frequency was dropped at what was subsequently calculated to be 8100 feet (2.4 km) westward from the old beacon (see caption to Figure 11). With the new beacon (i.e., Site 134) on the sea bed the vessel was given an additional offset further westward so as to bring the total separation from Hole 133 to Hole 134 to a value of 8600 feet (2.6 km).

Arrival at Site 134

The *Glomar Challenger* arrived at Site 134 at 1717 hours and stayed there for four days until 2030 hours on October 1st when she departed for Lisbon. Using the newly emplaced beacon, a total of six holes were drilled to accomplish the objectives of sampling the buried westward flank of the basement ridge and the onlapping salt layer. The original hole (i.e., 134) bottomed in halite at 364 meters below bottom. The core inventory is given in Table 2.

The Drilling of Hole 134

The drill bit touched the sea bed at a drill string length of 2864 meters below sea level and was subsequently washed down using rotation to a subsurface depth of 168 meters before beginning to core. A notably firm interval was first encountered at 86 meters as shown in the drilling rate curve of Figure 12. Core 1 was taken at 168 to 177 meters using slight circulation when the formation started to stiffen again, this time as the drilling bit approached the level of the Pγ-Reflector marked in the interpreted seismic profile of Figure 5. Core 1 core came up with just a trace of Quaternary-age marl ooze, so Core 2 was cut back-to-back with the circulation almost completely off. Significant torquing was observed at this time and the core barrel was recovered with a large cobble of schist, some gravel, and washed lithic sand.

Further down the hole, at 242 through 243 meters, another very hard interval was noted where thin stringers momentarily halted penetration and caused much torquing and shaking. This level is correlatable to the angular unconformity in the seismic profile noted as Reflector Pδ, which, as we learned at subsequent offset holes, corresponds to an appreciable gap in sedimentation accompanied by the formation of thin iron and manganese crusts (hardgrounds).

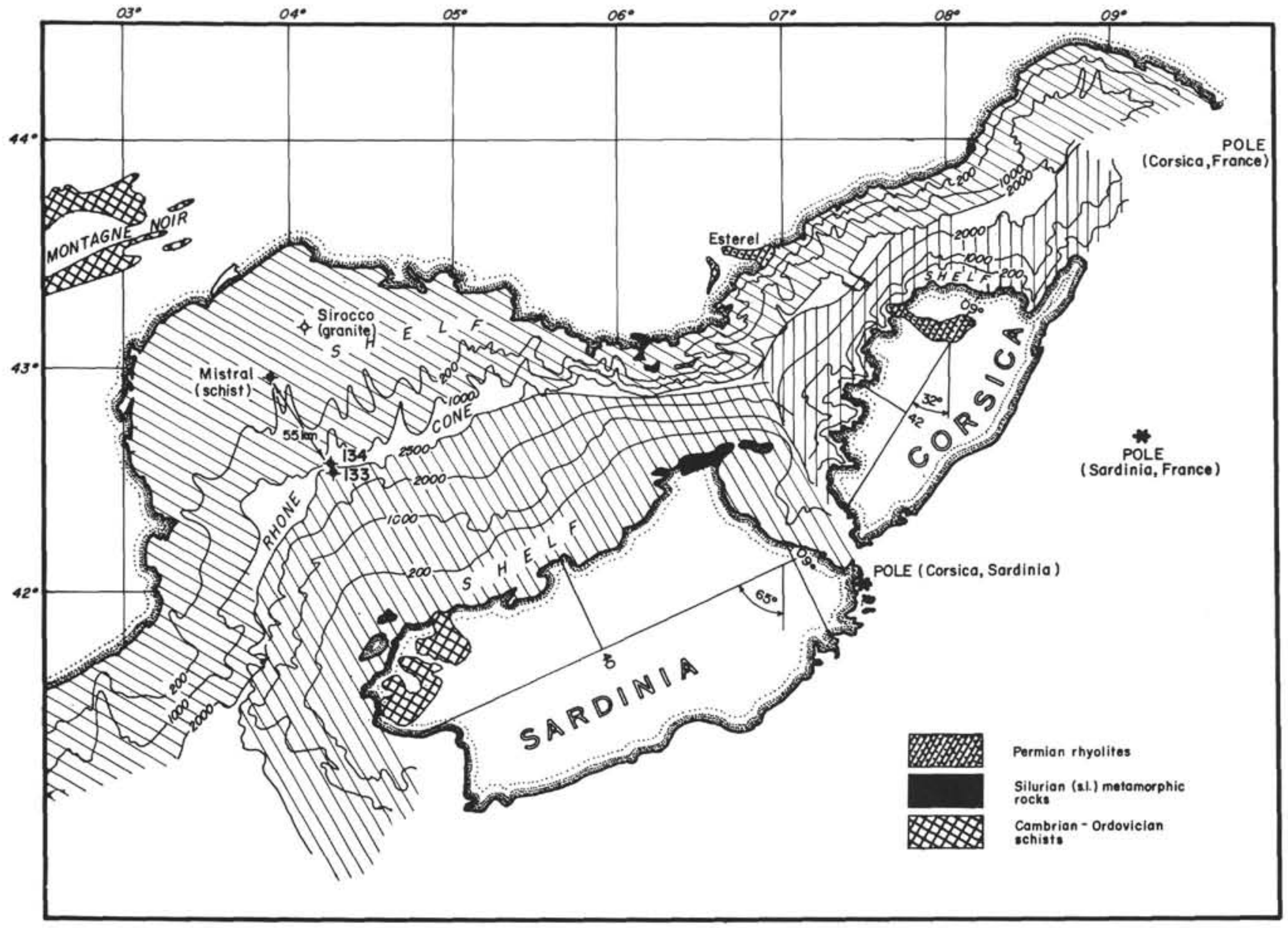

Figure 6. *An interpretation of a predrift reconstruction of the microplates of Corsica and Sardinia against the southern continental margin of France. This particular fit was suggested by Walter Alvarez (personal communication) and involves a slight decoupling of Sardinia from Corsica. Criteria for this reassembly involve the matching of the seaward edges of the continental slope (≈ 2000 m isobath) under which nonmagnetic basement ridges have been charted. The sediment blanket of the Rhone Cone has been ignored. Note the extension of a narrow belt of Permian rhyolites of Esterel seaward across a small submarine ridge on the lower continental slope and their continuation on into Corsica at a conjugate point in the reconstruction. The drill holes of Sites 133 and 134 have been rotated with the Sardinia microplate and are brought back to within 55 km of the* Mistral *hole, itself located on a buried basement ridge near the seaward edge of the continental shelf in the Gulf of Lyon.*

Cores 3, 4, and 5 were cored continuously to a little below the level of the unconformity and recovered Upper Pliocene marl oozes with pebbles of schist.

Subsequent coring intervals were spaced at intervals of 20 meters hoping that we might, in this fashion, core the first contact with the evaporite at Horizon M. The gamble paid off in Core 7 (317-326 m) when a sudden jump to erratic torque was noted at 323 meters followed by easy penetration for three meters; the core came up with an excellent preserved lithologic boundary between fossiliferous Lower Pliocene oozes with gravels and Upper Miocene dolomitic marl.

Below Horizon M, however, penetration was very slow, particularly in the cutting of massive rock salt (halite) in Cores 8 and 10. Thus, when the drilling rate dropped below a couple of meters per hour, and when reexamination of the reflection profiles indicated a thickness of the salt layer exceeding several hundred meters, it became evident that preevaporite sediment and/or bedrock would not be obtainable in the few remaining days of the expedition. Consequently, a decision was made to pull out of this hole and proceed eastward once more to try to sample the basement ridge at a place where it subcrops beneath the post-evaporitic strata at a shallower depth.

The Drilling of Hole 134A

For the offset back to the basement ridge at the foot of the western Sardinian Slope the bottom hole assembly was for the third time brought a few hundred meters above the mud line. Figure 11 shows the echogram obtained while moving back eastward, first to the beacon and then some 2400 feet further eastward to a total separation of 2900 feet (890 m) from the former hole. The new location put the *Glomar Challenger* only about 700 feet (210 m) from the boundary between the abyssal plain and the base of the continental slope.

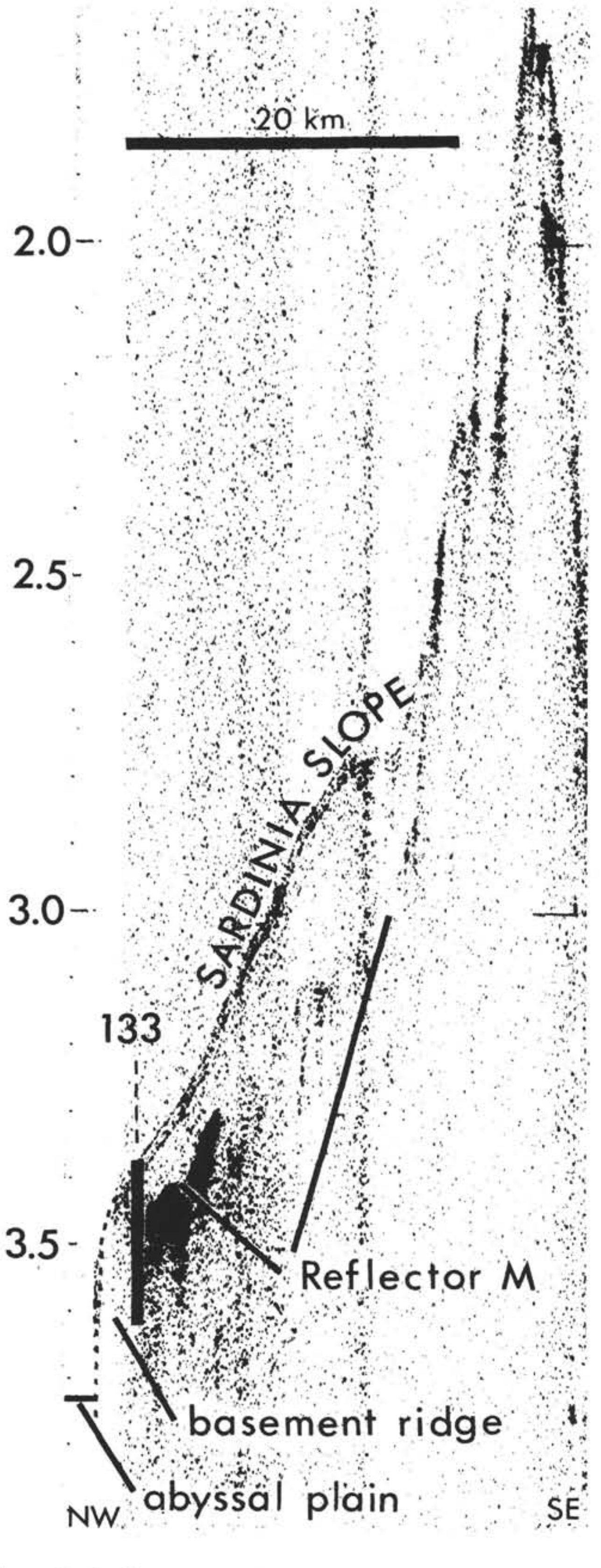

Figure 7. *Reflection profile of the* Glomar Challenger *across the western Sardinia Slope to Site 133 targeted on the landward (eastward) flank of the buried basement ridge (see dotted line). Note in this record, made with an airgun sound source, the marked increase in the acoustic reverberation of Reflector M when crossing the 3.3 seconds isobath. Vertical exaggeration is ≈ 50:1.*

Bottom contact with the surface of the abyssal plain at Hole 134A was felt with a drill string length of 2864 meters below sea level, as had also been the case at Hole 134.

As indicated in the drilling rate curve of Figure 13, a brief interval of bouncing was observed at just 30 meters below bottom, where the cutting of Core 1 was begun. Though this first attempt only recovered soft marl oozes and clays of Quaternary age, the basement was hit shortly after at 47 meters, where continuous wild bouncing and torquing was experienced. In fact no further penetration could be achieved after gaining only two meters in several hours. Nevertheless, we were delighted to learn that the autochthonous basement ridge consists of the same metamorphic rock which we had been obtaining as erratic rounded cobbles at the previous drill holes in the area.

Planning Additional Offsets

Since a single long hole could not be effected in the solid bedrock with the Varel 4 cone button bit being used, we decided to spend the remainder of the available time by sampling additional subcrops at successively greater depths along the seaward facing fault scarp. Figure 11 shows a cross section of the attempted reconnaisance of this structural feature. It became subsequently possible to use the depths of the first encounters with the basement lithology in combination with the reflection profile in order to interpret the dip of the onlapping post-Miocene strata and the approximate dip of the basement escarpment.

Holes 134B, C, D, and E were in effect laid out along the transit from Hole 134A to 134 at intervals of 2600 feet (790 m) 2000 feet (610 m), 1400 feet (430 m), and 1100 feet (340 m) from Hole 134, respectively. The drilling rate curves of these additional offset holes are also shown in Figure 13. Note in particular a trough (marked *X*), a peak (marked *Y*), and another trough (marked *Z*) in these graphs which appear again and again in each of the Site 134 holes as if corresponding to a true change in lithology traceable across the entire transit. The gradual increase in the depths of these respective intervals from east to west is another factor which has been helpful in calculating the onlap dips of the post-evaporite strata.

Obtaining a Basement Profile

Again, at none of the subsequent drill sites could the acoustic basement be penetrated for more than a few meters. One core of bedrock was obtained in Hole 134B at 65 to 66 meters, one in Hole 134C at 127 to 128 meters (with poor recovery), two in Hole 134D from 207 to 214 meters, and two in Hole 134D from 213 to 222 meters. Although only a few kilograms of rock were obtained, the successive offset strategy permitted us to carry out an intermittent sampling all along the subsurface scarp from 2911 to 3091 meters below sea level, which is equivalent to 180 meters of vertical section.

In addition, the offset holes obtained more samples of the Upper Miocene evaporite, this time secondary gypsum of the supratidal *sabkha* facies in Hole 134D at a level 126 meters above the salina halite of Hole 134 and 433 meters

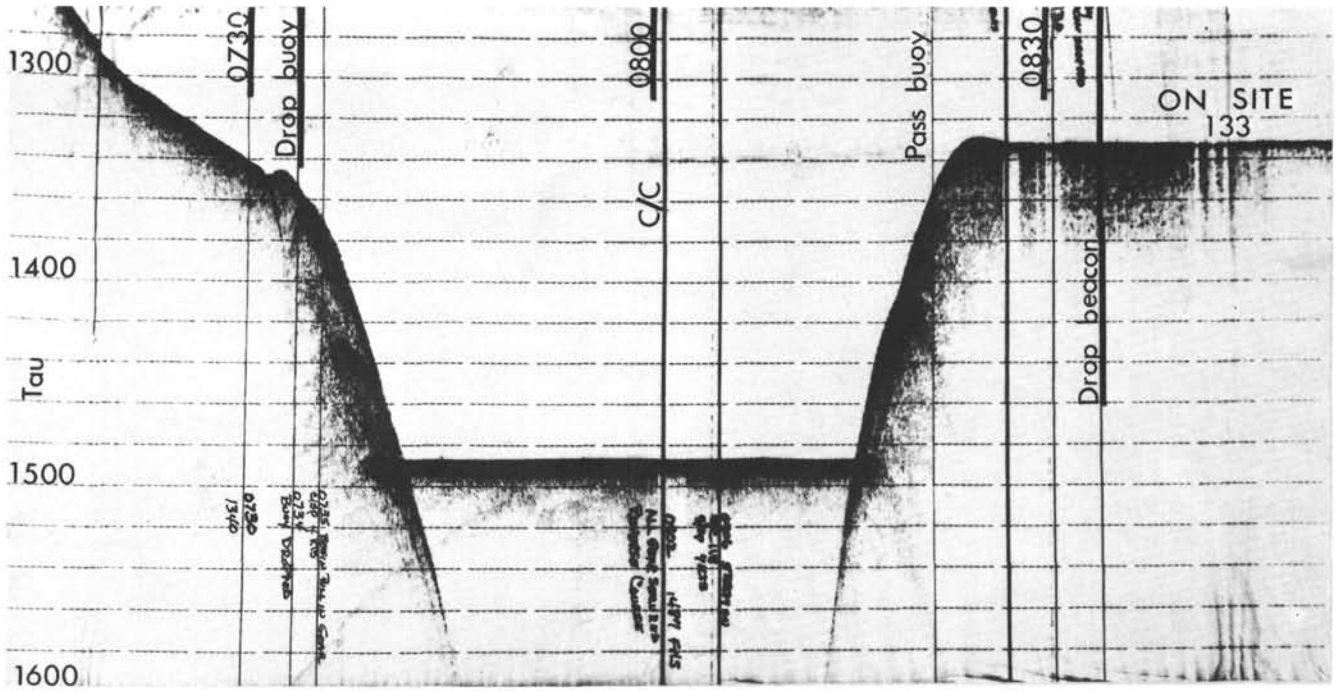

Figure 8. *Echogram recorded on the* Glomar Challenger *during her approach to Site 133. The vessel traversed the lower slope of Sardinia in a northwest direction and dropped a free-floating marker buoy at 0734 hours near the crest of the basement ridge being targeted. She subsequently proceeded across the relatively steep seaward scarp of the ridge to the abyssal plain where she then reversed course after retrieving the streamed geophysical sensors. Upon returning upslope, the* Challenger *continued past the buoy to come on station just beyond the crest on the ridge in order to spud into sediments filling the eastward (landward) slope basin. Vertical scale is in uncorrected units of reflection time where 1 tau = 1/400th second (two-way travel time).*

below the detrital silts of Hole 133. The hardground previously mentioned was recovered at Hole 134E at 199 meters. using a sidewall corer (SWC1), and although this core tube is only 40 cm in length, it revealed an extensive period of nondeposition (or erosion) between the Pliocene and the Quaternary.

The coring operations were terminated at 1420 hours on October 1st as a storm (*Mistral*) was brewing. When the drill bit arrived on deck it was discovered to be heavily damaged with the bearings on the majority of the roller cones crushed and inoperative. The drill rig was secured as the vessel drifted southeast with the tossing sea, and at 2000 hours the *Glomar Challenger* was homeward bound, having completed her first reconnaisance exploration of the Mediterranean.

BIOSTRATIGRAPHY

The principal biostratigraphic objective of obtaining a continuous section from the Late Miocene evaporite up into the overlying maring oozes within the Balearic Basin was successfully fullfilled. In addition, highly useful sedimentary sequences of the Lower and Upper Pliocene as well as of the Pleistocene were obtained in the spot coring program.

Fossiliferous oozes were also recovered from within the Miocene in a thin interbed of the evaporite layer, thus allowing us to place a good age assignment on this formation.

A Pleistocene-Miocene unconformity was verified on the western Sardinia Slope in Core 1 Hole 133. We believe there is good evidence to accept the variegated detrital sequence of the subjacent cores as a lateral time-equivalent of the Messinian evaporite found elsewhere in the western Mediterranean – on the Balearic Abyssal Plain (Hole 134), the Balearic Rise (Site 124), and in the Valencia Trough (Site 122).

The oldest sedimentary rocks obtained so far from the deep sea were recovered from the acoustic basement; however, they proved to be unfossiliferous, so that radiometric methods have been used to confirm their suspected Cambro-Ordovician age (See Chapter 29).

The best-represented fossil groups in the younger Neogene sediments are, as usual, foraminifera (mainly planktonic) and calcareous nannoplankton. Also present (see Chapter 36) are pteropods (in the Quaternary), and very rare ostracods. Siliceous microfossils including radiolaria, silicoflagellates, diatoms, and sponge spicules, were found in Core 10 of Hole 134, which belongs to the evaporitic sequence and underlies an important body of rock salt (see Chapter 34).

Sedimentation Rates (M.B.C.)

Calculations of the rates of sediment accumulation at the two drill sites visited have to be treated with caution since important gaps (hiatuses) occur in the sections penetrated. For instance at Hole 133 young Quaternary

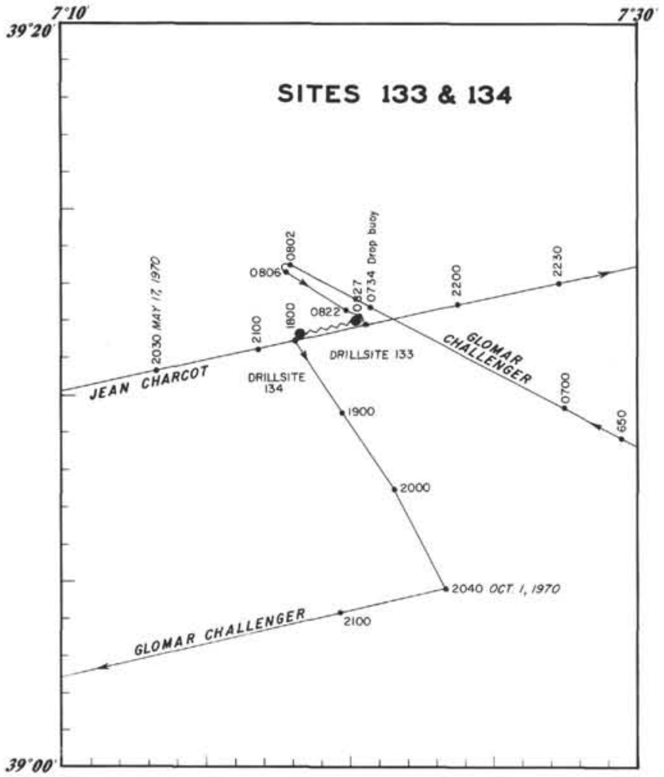

Figure 9. *Details of the* Challenger *approach to Sites 133 and 134. In plan view the drill holes lie only a few hundred meters north of the* Jean Charcot *reflection profile illustrated in Figure 4.*

ooze of the *Gephyrocapsa oceanica* Zone (nannofossil) with an age of perhaps 1 my sits directly on top of Upper Miocene silts with an estimated age of > 5.4 my.

At other places, Quaternary sediments overlap the Pliocene along another unconformity. This horizon, marked by the Pδ Reflector, occurs at 242 meters in Hole 134 and at 199 meters in Hole 134E, allowing us to estimate a rate of accumulation for the Quaternary that certainly exceeds 13 cm/10^3y.

Interval rates can also be evaluated for the Pliocene. Neither the uppermost foraminiferal zone (*Globorotalia inflata* Interval-zone) nor, its lowermost zone (*Sphaeroidinellopsis* Acme-zone) were found in Hole 134, either below the aforementioned unconformity (242 m) or above the evaporite at Horizon M (323 m), respectively. Estimating that perhaps 0.8 my of the Lower Pliocene is absent as well as 0.3 my of the Upper Pliocene, a much smaller figure of ≈ 3.5 cm/10^3y is arrived at for this older interval – a figure of the same magnitude as that derived for the Pliocene at Site 132 in the Tyrrhenian Basin where the sedimentation was also pelagic and where the sequence was continuously cored.[7]

Planktonic Foraminifera (M.B.C.)

Planktonic foraminifera are present in abundance in most of the cores recovered from Sites 133 and 134. They are discussed here according to their occurrence in the different holes and are arranged in order from west to east (i.e., from 134 to 134A to 133).

Hole 134

The occurrence of planktonic foraminifera and other fossil remains was investigated in twenty-two samples (Cores 1-7), and their range distribution is indicated in Table 3. They are Pleistocene (Cores 1 and 2) and Pliocene (Cores 3 to Section 5 of Core 7) in age. Three foraminiferal zones can be recognized in the Pliocene section, namely: the *Sphaeroidinellopsis subdehiscens* Interval-zone in Cores 3 and 5, the *Globorotalia margaritae evoluta* Lineage-zone in Core 6 (pars), and the *Globorotalia margaritae margaritae* Lineage-zone in Cores 6 (core catcher) and 7 (pars).

This latter core (317-326 meters) contains the Miocene/Pliocene boundary, which is characterized by a sharp break in both the lithology and the faunal assemblages. Five

TABLE 1
Core Inventory – Site 133, Western Sardinia Slope

Core	No. Section	Date	Time	Cored Interval[a] (m)	Cored (m)	Recovered (m)	Subbottom Penetration (m)		Tentative Lithology	Age
							Top	Bottom		
1	2	9/27	0620	2622-2627	5	2.3	49	54	sand, nannofossil oozes, cobbles of schist	Quaternary U. Miocene
2	0	9/27	1910	2627-2636	9	0	54	63		
3	1	9/27	2105	2636-2641	5	0.3	63	68	schist	U. Miocene
4	1	9/28	0030	2645-2654	9	0.5	68	81	schist sand (cave-in)	U. Miocene
5	1	9/28	0245	2664-2673	9	1.3	91	100	red silts and shales	U. Miocene
6	1	9/28	0445	2682-2691	9	0.4	109	118	red silts and shales	U. Miocene
7	1	9/28	0645	2711-2720	9	1.3	138	147	red silts and shales	U. Miocene
8	CC	9/28	1215	2756-2765	9	0.03	183	192	red silts and shales	U. Miocene

[a] Drill pipe measurements from derrick floor

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[7] For a further discussion of the comparative rates of Pliocene sedimentation in the various Mediterranean Basins the reader is referred to Chapter 47.1.

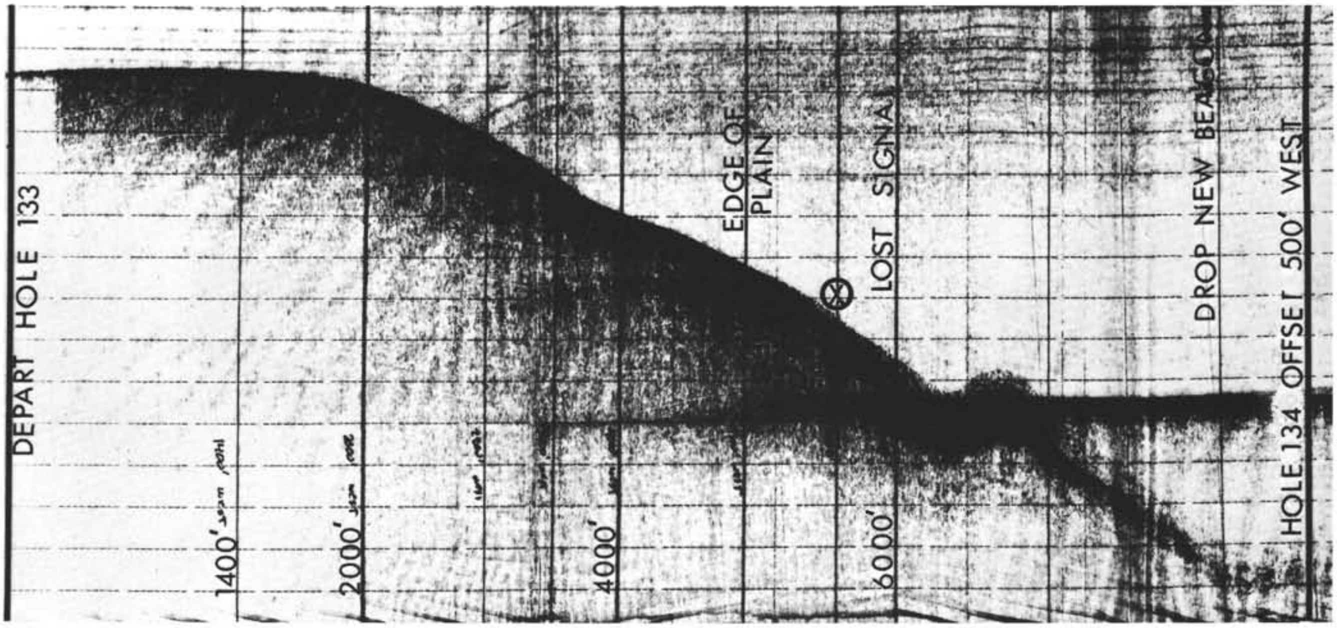

Figure 10. *An echogram recorded during the offset maneuver from Hole 133 on the Sardinia Slope to Site 134 on the Balearic Abyssal Plain. The horizontal scale is calibrated in the distance in feet from the Site 133 beacon as measured with the onboard dynamic positioning system. The signal from the Site 133 beacon was lost after a separation of 6000', so a new beacon was required for the drilling of the Site 134 holes. The first of these holes (134) was located 500' further west of the new beacon.*

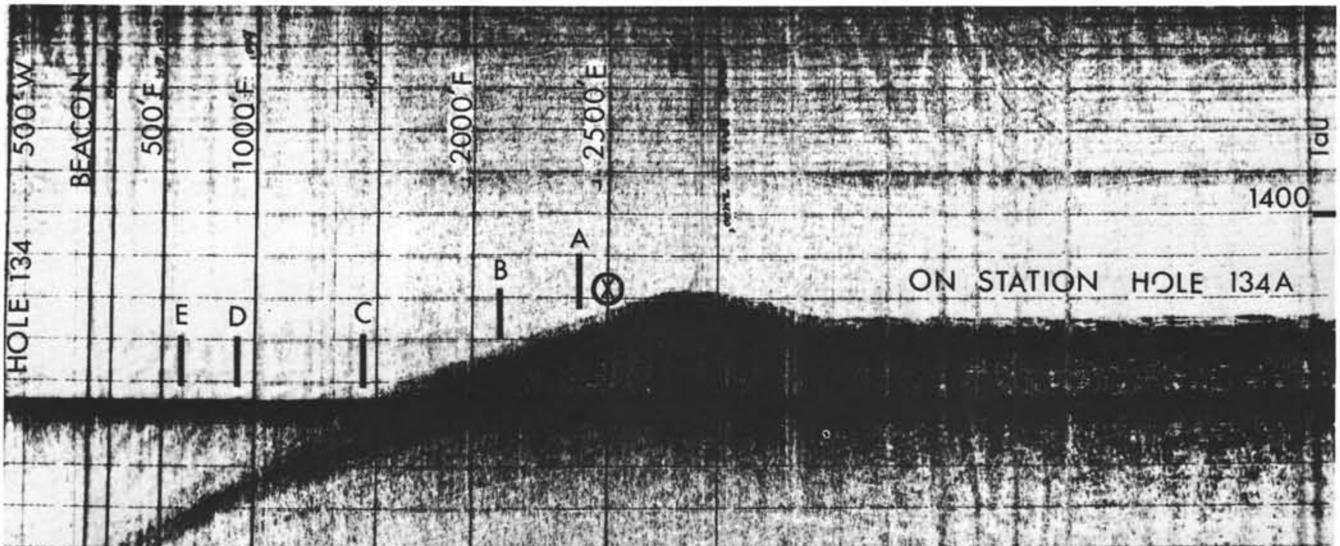

Figure 11. *Another echogram made when offsetting back towards the basement ridge from Hole 134 to Hole 134A. Note the circle with an X inside of it at 2500' from the Site 134 beacon. The side-echo pattern here corresponds to that in Figure 10 also marked with an X and allows us to compute a total separation of 8600' (2.5 km) from Hole 133 to Hole 134. The letters show the locations of Holes 134B, 134C, 134D, and 134E drilled in subsequent offsets back towards the beacon from Hole 134A. Note the the continuous presence of the echo sequences from the abyssal plain which confirms that all the offset holes were located seaward of the base of the slope. Vertical scale is in uncorrected units: 1 tau = 1/400th second.*

TABLE 2
Core Inventory – Site 134, Balearic Abyssal Plain

Core	No. Section	Date	Time	Cored Interval[a] (m)	Cored (m)	Recovered (m)	Subbottom Penetration (m)		Tentative Lithology	Age
							Top	Bottom		
Hole 134										
1	0	9/29	0005	3042-3051	9	Tr.	168	177	nannofossil ooze	Quaternary
2	CC	9/29	0120	3051-3057	6	0.05	177	183	sand, nanno, tephra gypsum pebble	Quaternary
3	2	9/29	0350	3122-3125	3	3	248	251	nannofossil ooze schist (pebble)	U. Pliocene
4	0	9/29	0610	3125-3134	9	0	251	260		
5	2	9/29	0745	3134-3143	9	2.0	260	269	nannofossil oozes	L. Pliocene
6	5	9/29	0945	3162-3170	8	7.5	288	296	nannofossil oozes rock fragments	L. Pliocene
7	5	9/29	1135	3201-3200	9	6.7	317	326	nannofossil oozes, sandstone flat pebble congl.	L. Pliocene/ U. Miocene
8	1	9/29	1500	3218-3223	5	0.5	344	349	halite, anhydrite	
9	CC	9/29	1705	3224-3233	9	0.02	350	359	foram sand	U. Miocene
10	2	9/29	2110	3233-3238	5	2.5	359	364	halite, marl oozes, anhydrite	U. Miocene
Hole 134A										
A1	2	9/30	0355	2904-2913	9	18	30	39	marl nannofossil oozes	Quaternary
A2	CC	9/30	0625	2921-2923	2	0.04	47	49	phyllite	Paleozoic
Hole 134B										
B1	CC	9/30	1045	2946-2951	5	0.2	67	72	marl ooze phyllite	Quaternary Paleozoic
Hole 134C										
C1	small vial	9/30	1530	3010-3010	0.1	Tr.	128	128	metagraywacke	Paleozoic
Hole 134D										
D1	1	9/30	2115	3056-3064	8	1	175	183	nodular dolomitic marl, gypsum	U. Miocene
D2	CC	9/30	2330	3088-3092	4	0.2	207	211	metagraywacke phyllite	Paleozoic
D3	CC	10/1	0215	3092-3095	3	0.1	211	214		
Hole 134E										
E1	CC	10/1	0630	3083-3092	9	00.1	203	213	marl ooze phyllite	Paleozoic
E2	0	10/1	1015	3095-3099	4	0	216	220		
E3	1	10/1	1157	3099-3101	2	0.2	220	222	phyllite	Paleozoic
134E SWC1		10/1	1300	at 3078 m	40 cm	20 cm	199		marl ooze, hardground	Quaternary/ Pliocene
134E SWC2		10/1	1420	at 2988 m	40 cm	40 cm	109		marl ooze	Quaternary

[a] Drill pipe measurements from derrick floor

sections were recovered from this core: Sections 1 to 4 consist of pelagic oozes, light olive gray in color, yielding rich assemblages belonging to the *Globorotalia margaritae margaritae* Lineage-zone of the Lower Pliocene.

Section 5 is a pelagic ooze of the same age, but it also contains pebbles, some of them flattened. An erosional contact between the Lower Pliocene calcareous ooze and the late Miocene evaporitic sequence is clearly visible at about 130 cm (Figure 14).

Three samples were examined from the topmost part of the evaporitic sequence (consisting of dolomitic and pyritic marls) in order to find some evidence of the stratigraphic age of this interval. They were from 132 cm, 144 cm, and the core catcher. The foraminiferal assemblages are

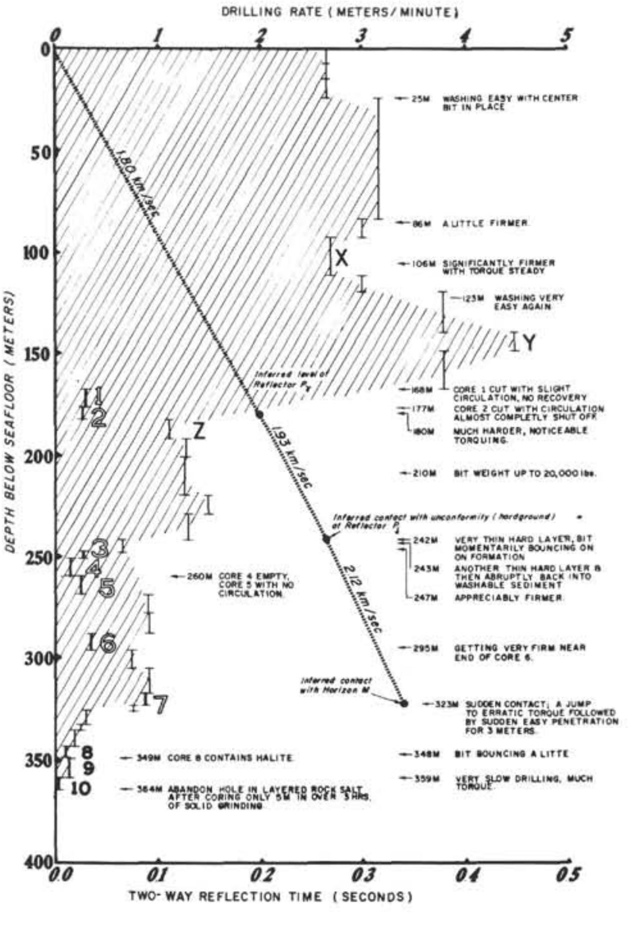

Figure 12. *Drilling rate curve for Hole 134. The interval compressional-wave velocities shown have been obtained by correlating observed drilling breaks with the prominent subbottom reflectors P_γ and P_δ and by assigning the top of the evaporite layer in Core 7 to the subsurface level of Horizon M.*

generally poor and not well preserved. Some of the specimens are smaller than normal.

Species recorded from the cited samples include:

Globigerina bulloides d'Orbigny
Globigerina bulbosa Leroy
Globigerina falconensis Blow
Globigerina microstoma Cita, Premoli and Rossi
Globigerina nepenthes Todd
Globigerina quinqueloba Natland
Globigerinoides obliquus Bolli
Globigerinoides quadrilobatus (d'Orbigny)
Globigerinoides trilobus (Reuss)
Globorotalia acostaensis Blow
Globorotalia merotumida Banner and Blow
Globorotalia obesa Bolli
Globorotalia scitula (Brady)
Orbulina universa d'Orbigny

This fauna indicates a late Miocene age. For instance, the occurrence of *Globigerina nepenthes* should be pointed out, because the range of this species is from Zone N.14 to Zone N.19 (pars), and its extinction above geomagnetic epoch 5 represents a datum plane related to paleomagnetic stratigraphy (datum VII of Saito in Hays *et al.*, 1969). This species which has been known for a long time to occur in the Mediterranean Miocene, has seldom been recorded in the Pliocene there, a fact which has to be considered as one of the peculiarities of the Mediterranean Pliocene.

Also of interest is the core catcher sample of Core 9 (350-359 m) which contains a coarse sand fairly rich in foraminifera, mainly planktonic, also including *Globorotalia acostaensis, G. humerosa, G. aff. margaritae* (primitive), *G. merotumida, G. plesiotumida, Globigerinoides bollii, G. quadrilobatus,* and *G. trilobus.*

The additional finding of this fauna assignable to Zone N.17 tends to support the interpretation of equivalence of the evaporite deposition in the Balearic Basin with the Messinian evaporites of Sicily (Catalano and Sprovieri, 1971).

Core 10 (349-364 m below bottom), the lowermost of this site, also contains rare planktonic foraminifera, as well as radiolaria, silicoflagellates, diatoms, and sponge spicules, all of them indicating an open marine environment. The foraminiferal fauna, however, is not so diverse and age diagnostic as that in Cores 7 and 9.

The Miocene/Pliocene boundary, as cored in Section 5, Core 7 of Hole 134, may be compared with the same boundary as is present in Section 2, Core 21, of Site 132 in the Tyrrhenian Basin. The main difference is that a significant biostratigraphic gap is present at Site 134, unlike Site 132, where a practically continuous biostratigraphic record is believed to have been found. Apparently the sedimentary record of a time span of some 800,000 years is missing at Site 134. This could be estimated by comparison with Site 132, where the Pliocene is considered to be complete in its lower part (see Chapters 47.1 and 47.2). The missing interval corresponds to Cores 19, 20, and 21 (pars) of Site 132, with a thickness of about 25 meters.

The change to open marine pelagic sedimentation appears to be as sudden here in the Balearic Basin as in the Tyrrhenian Basin. Shallow-water benthonic foraminifera and other fossil remains usually found in the basal part of a transgressive cycle are totally lacking.

Hole 134E

Sidewall Core 2 (109 meters) yielded an assemblage rich in pteropods and planktonic foraminifera characteristic of the glacial Pleistocene and indicating a temperate climate (typical "intermediate fauna" of Todd, 1958). The assemblage is dominated by *Globorotalia inflata*. Recorded taxa include:

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg)
Globigerina quinqueloba Natland
Globigerinita glutinata (Egger)
Globigerinoides helicinus (d'Orbigny)
Globigerinoides pyramidalis (d'Orbigny)
Globigerinoides ruber (d'Orbigny)
Globorotalia acostaensis Blow
Globorotalia inflata (d'Orbigny)
Globorotalia oscitans Todd
Globorotalia scitula (Brady)
Globorotalia truncatulinoides (d'Orbigny), very rare
Hastigerina siphonifera (d'Orbigny)
Orbulina universa d'Orbigny.

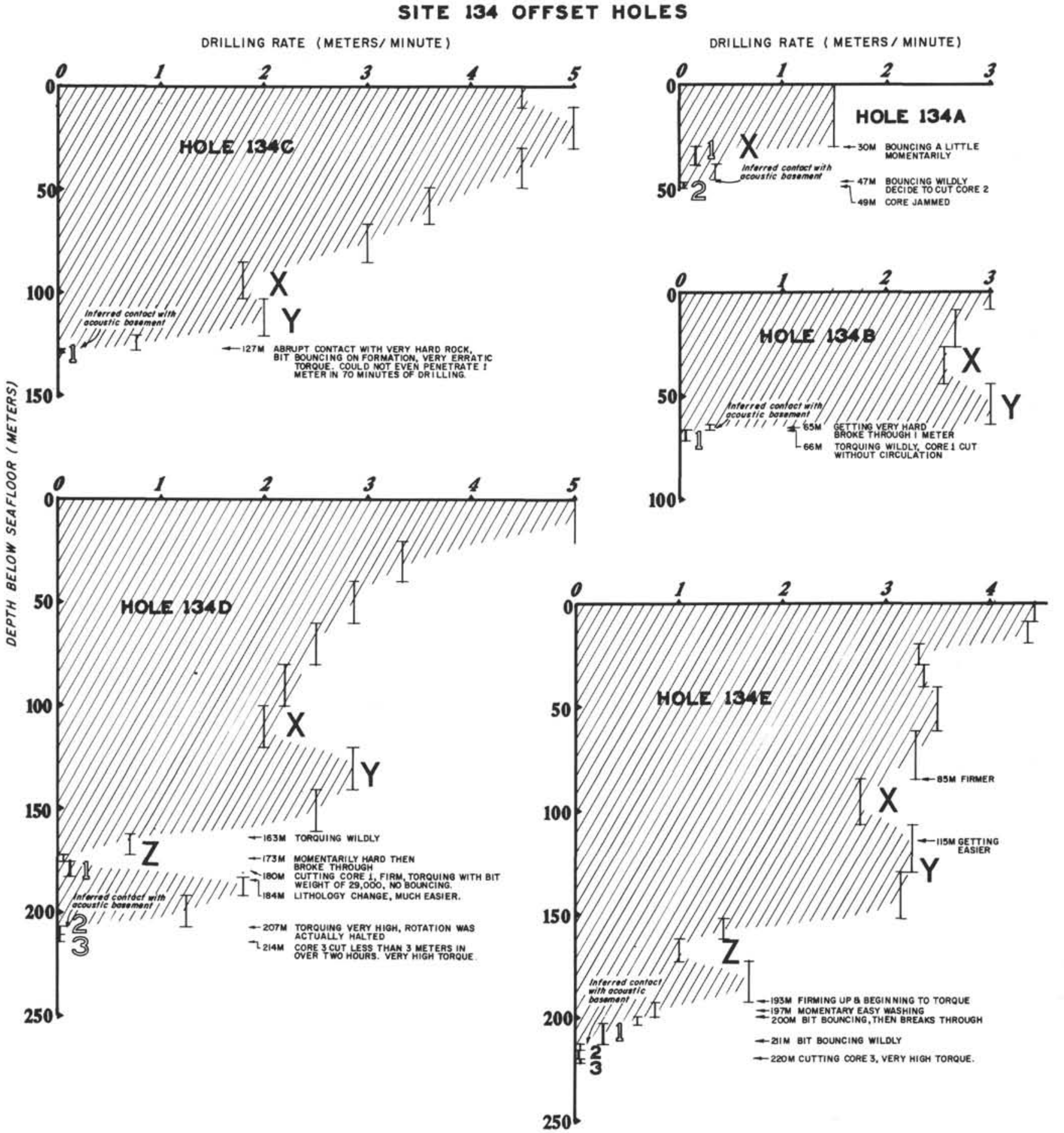

Figure 13. *Drilling rate curves for the offset holes of Site 134. Note the peaks and troughs marked* X, Y *and* Z *which correlate from hole to hole, and apparently record the onlap dips of the Pliocene-Pleistocene abyssal plain strata.*

Sidewall Core 1 (199 meters) was particularly interesting, because it yielded two different fossil assemblages, both of them excellently preserved and well diversified, yet containing species which are generally mutually exclusive, at least as far as the Mediterranean is concerned.

The bulk of the fauna is of Upper Pliocene age (*Globigerinoides obliquus extremus* Interval-zone) and is dominated by a population of *Globorotalia crassaformis* (including the variants *crassula* and *viola*) which in the Mediterranean Pliocene characterizes the interval immediately prior to the first occurrence of *Globorotalia inflata.*

Also present in abundance are typical Quaternary species, such as *Globorotalia truncatulinoides, G. inflata* (highly evoluted). *Globigerina pachyderma, G. praedigitata, Pulleniatina obliquiloculata*, etc.

TABLE 3
Range Distribution of 41 Species of Planktonic Foraminifera in the Pleistocene and Pliocene Sequence of Hole 134 Balearic Abyssal Plain

Depth Below Sea Floor (m)	Recovery (m)	Core Number	Section Number	Sample Interval (cm from top)	Planktonic Foraminifera																																									Various Other Components							Age	Zone
					Globigerina								*Globigerinoides*												*Globorotalia*														Other Genera															
					apertura	*bulbosa*	*bulloides*	*eggeri*	*falconensis*	*microstoma*	*pachyderma*	*quinqueloba*	*bollii*	*conglobatus*	*elongatus*	cf. *fistulosus*	*helicinus*	*obliquus*	*obliquus extremus*	*pyramidalis*	*quadrilobatus*	*ruber*	*sacculifer*	*trilobus*	*acostaensis*	*acostaensis humerosa*	*aemiliana*	*crassaformis crassaformis*	*crassaformis crassula*	*crassaformis viola*	*dutertrei*	*inflata*	*margaritae evoluta*	*margaritae margaritae*	*margaritae primitiva*	*obesa*	*puncticulata*	*scitula*	*Globigerinita glutinata*	*Globoquadrina altispira*	*Hastigerina siphonifera*	*Orbulina bilobata*	*Orbulina universa*	*Sphaeroidinellopsis seminulina*	*S. subdehiscens*	detritus	pyrite	organic matter	ostracods	echinoid spines	fish teeth	pteropods		
168 177		1		CC			●				●	●			●							●	●	●	●							●						●	●				●										Pleist.	*Globoratalia truncatulinoides* Total-range-zone
177 183	0.04	2		CC			●	●	●		●				●		●				●	●		●	●						●	●						●	●							●						●		
248	3	3	1	33-36	●	●	●		●			●			●		●		●	●	●	●	●	●	●			●		●							●	●	●		●		●	●	●		○	○	○				Upper Pliocene	*Sphaeroidinellopsis subdehiscens* Interval-zone
				113-116	●	●	●		●						●				●	●	●	●	●	●	●			●		●							●	●	●		●		●	●	●			○	○	○				
			2	35-37	●	●	●		●			●			●		●		●		●	●	●	●	●			●									●	●		●	●		●	●	●			○	○	○				
				115-117	●	●	●		●	●					●	●			●		●	●	●	●			●	●	●	●								●	●		●		●						○	○				
251				CC	●		●		●	●		●	●		●	●	●		●		●	●	●	●			●										●		●	●	●		●	●	●				○					
260	1.8	5	1	125-127	●	●	●						●		●			●	●	●	●	●	●	●	●												●						●	●	●				○					
			2	35-37	●		●					●			●				●		●	●	●	●	●												●	●	●				●			○		○						
				108-110		●	●		●	●				●	●		●				●	●		●													●			●			●	●	●	●								
269				CC	●		●		●			●			●				●		●		●	●	●												●	●	●	●			●		●	●	●							
288	7.7	6	1	40-42	●	●	●		●										●		●		●	●	●								●	●			●	●	●	●	●		●	●						○	○		Lower Pliocene	*Globoratalia margaritae evoluta* Lineage-zone
			2	77-80	●		●		●									●	●		●		●	●									●	●	●	●	●			●		●	●	●		○								
			3	35-37		●	●		●									●	●		●		●	●									●	●	●			●		●	●	●	●	●	●	○				○	○			
			4	35-37	●				●	●									●		●		●		●								●	●	●				●		●		●			○								
			5	35-37	●		●		●	●		●						●	●		●		●		●								●	●	●	●		●	●		●		●	●	●	○								
296				CC			●		●			●							●		●			●	●									●	●			●	●				●	●		○								
317	7.8	7	1	110-112			●		●										●		●		●	●										●	●			●	●			●	●	●	●									*Globoratalia margaritae margaritae* Lineage-zone
			2	0-2	●	●	●		●	●		●						●	●		●	●	●	●	●	●								●	●			●	●			●	●											
			3	115-117	●	●	●		●										●		●		●	●										●	●			●	●		●	●	●							○				
			4	115-117	●	●	●		●			●							●		●		●	●										●	●			●	●				●	●						○				
326			5	123-125	●		●		●										●		●		●	●	●									●	●			●				●	●	●				○		○				

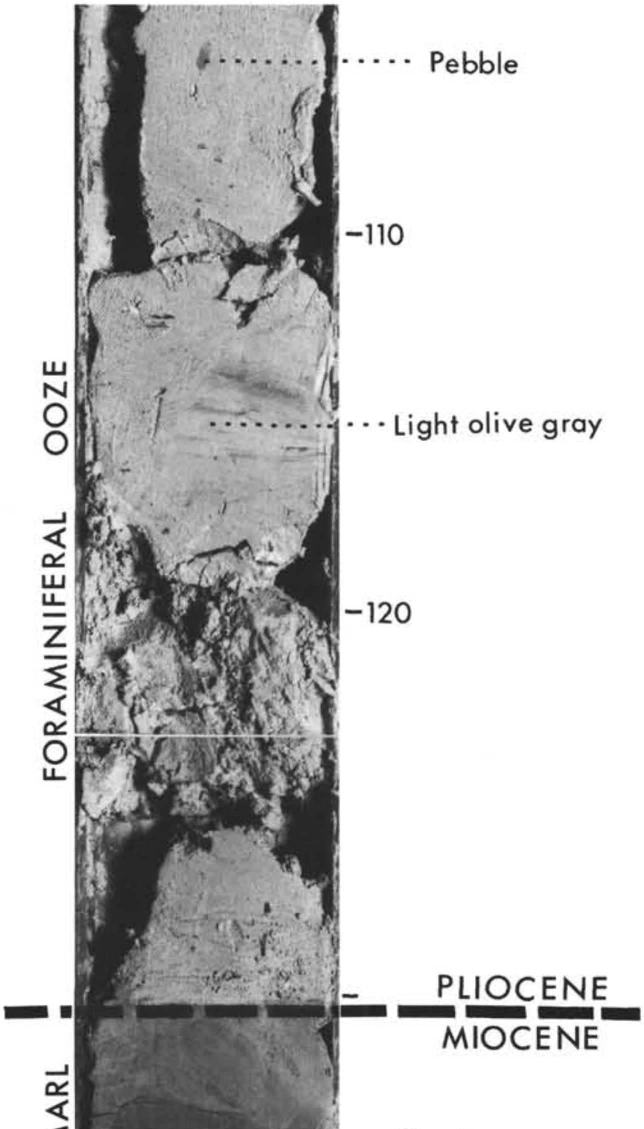

Figure 14. *The Miocene-Pliocene boundary in Section 5 of Core 7 of Hole 134 at a subbottom depth of 323 meters. Sediments of lowermost Pliocene age (the* Sphaeroidinellopsis *Acme-zone and part the* Globorotalia margaritae margaritae *Lineage-zone) are missing above the razor sharp contact at 130 cm in this core section, and this hiatus is estimated to be on the order of 0.8 my. Above the contact, the oozes are rich in calcareous nannoplankton and foraminifera ($CaCO_3$ = 63%) and contain specimens of deep-water psychrospheric ostracods (see Chapter 36.2). Below the contact foraminifera assemblages are generally poor and not well preserved (calcified), with some specimens under their normal size*

The two samples investigated from this core[8] also contain some flattened, well-rounded pebbles, quartz fragments, displaced shallow-water benthonic foraminifera, and fragments of bryozoa, probably accumulated by current action. But the most interesting finding is a number of thin mineralized crusts, which are interpreted as representing hardgrounds and indicate periods of nondeposition and/or submarine erosion. These mineral crusts are formed by iron hydroxydes (see Chapter 40) and contain a number of planktonic foraminifera (Figure 15), some of them still keeping their calcitic test when embedded in the mineralized crusts, others being substituted for by iron hydroxydes, and still others being entirely destroyed and only present as casts. Oxidized tests (iron-spots) of *Globorotalia truncatulinoides, G. inflata, Orbulina universa, Pulleniatina obliquiloculata*, etc., were observed.

The biostratigraphic interval missing at Site 134 (*Globorotalia inflata* Interval-zone of the Upper Pliocene and lower part of the *Globorotalia truncatulinoides* Total-range-zone of the lower Pleistocene) is represented at Site 132, in the Tyrrhenian Basin, by a thickness of about 36 meters. With a sedimentation rate of 3.5 cm/10^3y, Cores 6 to 9 at Site 132 are the sedimentary expression of some 1,000,000 years of deposition. It seems, therefore, reasonable to assume that this was the time during which nondeposition occurred at the eastern edge of the Balearic Abyssal Plain, as documented by Sidewall Core 1, Site 134E. It is suggested that a deep, oceanic type geostrophic current is responsible for the formation of the hardground under discussion.

This interpretation seems in good agreement with the evidence on the seismic profile of Figure 5 of a significant angular unconformity at Reflector Pδ.

The documentation of the presence of the *Globigerinoides obliquus extremus* Interval-zone of the Upper Pliocene below the hiatus comes from a smear of sediment in the core catcher sample of Core 2 (216-220 m below bottom in Hole 134E) which yielded an assemblage with *Globorotalia puncticulata.*

No pelagic sediments were encountered in the offset Holes 134C and 134D, where only cores of barren Miocene evaporites with gypsum and *in situ* metamorphic basement were obtained.

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[8] One from the top of the core, which is the farthest from the hole, another one from its base (which is the nearest to the hole). The entire core, from top to bottom, is cut perpendicular to the drill string and supposedly parallel to the bedding.

Figure 15. *Example of a foraminiferal test imbedded in a mineralized crust of the manganese hardground recovered in Side Wall Core 1 of Hole 134E. This core (only 40 cm in length) from 199 meters below bottom recorded a gap at the metaliferous crust of perhaps 1 million years between the* Globigerinoides obliquus extremus *Interval-zone of the Upper Pliocene and the middle of the* Truncatulinoides *Total-range-zone of the Pleistocene.*

Hole 134B

Core 1 (67-72 m below bottom) contains an unconformable contact between the basement rock and a pelagic ooze rich in planktonic foraminifera indicating a middle to late Quaternary age. The sediment reveals an important terrigenous influx. Recorded taxa include:

Globigerina bulloides d'Orbigny
Globigerina eggeri Rhumbler
Globigerina falconensis Blow
Globigerina pachyderma (Ehrenberg)
Globigerina quinqueloba Natland
Globigerinita glutinata (Egger)
Globigerinoides pyramidalis (d'Orbigny)
Globigerinoides ruber (d'Orbigny)
Globigerinoides sacculifer (Brady)
Globorotalia inflata (d'Orbigny)
Globorotalia scitula (Brady)
Globorotalia truncatulinoides (d'Orbigny).

Also present are otoliths, pteropods, fragments of thin-shelled pelecypods, ostracods, and pyrite crystals.

Hole 134A

Core 1 (30-39 m below bottom) yields a fauna similar to the one previously recorded, with a similar chronological significance. The terrigenous influx is even more evident and pteropods along with thin-shelled pelecypods are present in abundance.

Hole 133

Core 1 (45-54 m below bottom) is comprised of a rich assemblage of planktonic foraminifera, also of Quaternary age. The recorded taxa include:

Orbulina bilobata d'Orbigny
Orbulina universa d'Orbigny
Globorotalia inflata (d'Orbigny)
Globorotalia obesa Bolli
Globorotalia oscitans Todd
Globorotalia truncatulinoides (d'Orbigny)
Globigerina bulloides d'Orbigny
Globigerina eggeri Rhumbler
Globigerina pachyderma (Ehrenberg)
Globigerina quinqueloba Natland
Globigerinita glutinata (Egger)
Globigerinita uvula (Ehrenberg)
Globigerinoides ruber (d'Orbigny)

The occurrence of *Globorotalia truncatulinoides* suggests a Middle Quaternary age for the lowest sediments above the unconformity since this species is absent in the lower part of the Pleistocene in most of the deep-sea successions investigated from the Mediterranean during Leg 13.

The Quaternary assemblages found in Cores 4 and 6 of Hole 133 are considered as downhole contaminants and include a small number of species. The few specimens present show empty tests, very fresh, completely different from the sediment in which they are actually contained.

Benthonic Foraminifera (W. M.)

Benthonic foraminifera were recorded in all the cores with rich assemblages of planktonic foraminifera. Their occurrences in the cores of Pleistocene age are tabulated below, hole by hole. In general, the assemblages of benthonic foraminifera indicate a moderate by deep to deep environment of deposition, although occasional shallow-water neritic species (e.q. *Elphidium*) have apparently been displaced into some of the redeposited sandy horizons.

Hole 133 (Core 1):

Spiroloculina excavata d'Orb.
Nodophtalmidium cf. *tibia* (J. & P.)
Articulina tubulosa (Seg.)
Lagena bradyana Forn.
Lagena orbignyana (Seg.)
Bolivina alata Seg.
Bolivina pseudoplicata Herr. All. & Earl.
Hopkinsina sp.
Cibicides ungerianus-pseudoungerianus

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[9] The argument regarding existence of deep circulation in the western Mediterranean during Pliocene and lower Pleistocene times is treated in Chapter 47.5.

- *Robertinoides bradyi* Cush. & Parker
- *Karreriella bradyi* (Cush.)
- *Pyrgo depressa* (d'Orb.)
- *Bulimina aculeata basispinosa* Ted. & Zanm.
- *Cassidulina carinata* Silv.

Hole 134A (Core 1):

- *Lagena bradyana* Forn.
- *Bolivina alata* Seg.
- *Bolivina catanensis* Seg.
- *Bolivina dilatata* Reuss
- *Bolivina pseudoplicata* Herr. All. & Earl.
- *Bulimina costata* d'Orb.
- *Uvigerina proboscidea* Schwager
- *Elphidium* spp.
- *Cassidulina carinata* Silv.
- *Cassidulina subglobosa* Brady
- *Pyrgo depressa* (d'Orb.)
- *Lagena orbignyana* (Seg.)
- *Karreriella bradyi* (Cush.)
- *Marginulina obesa* Cush.
- *Buliminella elegantissima-basicostata*
- *Bolivina* cf. *punctata* d'Orb.
- *Hopkinsina* sp.
- *Spirillina vivipara* Ehrenbg.
- *Planulina ariminensis* (d'Orb.)
- *Cibicides ungerianus-pseudoungerianus*
- *Pullenia salisburyi* Stew.

Hole 134B (Core 1):

- *Karreriella bradyi* (Cush.)
- *Articulina tubulosa* (Seg.)
- *Lagena bradyana* Forn.
- *Bolivina catanensis* Seg.
- *Bolivina subspinescens* Cush.
- *Globobulimina*? sp.
- *Angulogerina angulosa* (Will.)
- *Spirillina vivipara* Ehrenbg.
- *Elphidium* spp.
- *Cibicides ungerianus-pseudoungerianus*
- *Cassidulina carinata* Silv.
- *Robertina subteres* (Brady)

Hole 134E (Core 1 and Sidewall Core 1):

- *Bolivina subspinescens* Cush.
- *Bolivina pseudoplicata* Herr. All. & Earl.
- *Cibicides bradyi* (Trauth)
- *Cibicides ungerianus-pseudoungerianus*
- *Cassidulina carinata* Silv.
- *Cassidulina subglobosa* Brady
- *Pullenia bulloides* (d'Orb.)
- *Karreriella bradyi* (Cush.)
- *Lagena bradyana* Forn.
- *Siphonina reticulata* (Czjzek)
- *Eponides umbonatus* (Reuss)
- *Eponides umbonatus stellatus* (Silv.)
- *Planulina wuellerstorfi* (Schwager)
- *Cibicides boueanus* (d'Orb.)
- *Cibicides robertsonianus* (Brady)
- *Nonion padanum* Perconig

The Pliocene and Miocene assemblages recovered in Hole 134 are much more extensive and are listed in Table 4.

The Miocene age of the section cored below Core 7, Section 5 (144 cm) is demonstrated by species like *Bolivinoides miocenicus* Gianotti, *Bolivina antiqua* d'Orb., *Bolivina scalprata miocenica* MacFadyen, *Cibicides cicatricosus maioricensis* Colom, etc., as well as by the presence of the planktonic foraminifer *Globorotalia merotumida-plesiotumida* Blow & Banner.

Calcareous Nannofossils (H.S.)

Five of the holes drilled at Site 133 and 134 contained nannofossils. Quaternary assemblages representing Zones NN 19 to NN 20 and containing *Gephyrocapsa oceanica, Pseudoemiliania lacunosa* and, *Helicosphaera carteri* have been recorded in Hole 133 (Core 1); Hole 134 (Cores 1 and 2), Hole 134A (Core 1), Hole 134B (Core 1CC), and Hole 134E (SWC 2).

Of the seven nannofossil zones which generally represent the Pliocene in the Mediterranean, only four have been detected here, two from the Upper Pliocene and two from the lower Pliocene. As was also inferred to be the case for the planktonic foraminifera, both the youngest and oldest parts of the Pliocene are considered to be missing at unconformities. From top to bottom, the first nannofossil zone recorded is NN 16 (*Discoaster surculus* Zone), which is represented in Holes 134 (Core 3) and 134E (Core 2CC and SWC 1) with assemblages of calcareous nannofossils containing *Discoaster brouweri, Discoaster surculus,* and *Ceratolithus rugosus.* The next lower zone NN 15, *Reticulofenestra pseudoumbilica* Zone) occurs in Core 5 of Hole 134 with an assemblage of *Discoaster asymmetricus, Discoaster variabilis, Discoaster surculus,* and *Reticulofenestra pseudoumbilica.*

The *Discoaster asymmetricus* Zone – NN 14 of the upper part of the Lower Pliocene – has been recognized in Core 6 of the same hole with assemblages containing *Ceratolithus tricorniculatus* and *Discoaster assymetricus.* The latter species is not found in Core 7, nor is *Ceratolithus rugosus,* suggesting a level somewhere in the *Ceratolithus tricorniculatis* Zone, NN 12.

Within the evaporite below 130 cm in Section 5 of Core 7, all the ceratoliths are missing, as was the case for Site 132 in the Tyrrhenian Basin. Cores 9 and 10 of Core 134 contain an ooze interbedded in halite comprising large, robust, and slightly overcalcified specimens of *Discoaster challengeri* and *Discoaster variabilis.* The number of taxa in the Miocene assemblage is small.

Reworked nannofossils from the Eocene (*Discoaster barbadiensis, D. deflandrei, D. lodoensis*) and also from the Cretaceous (*Nannoconus sp. Cretarhabdus crenulatus*) were found after careful examination of the variegated silts of Hole 133 (Core 1 and 4) on the western Sardinia Slope, along with a few minor occurrences of downhole contaminants of Quaternary age.

The age-diagnostic nannofossil assemblages are shown below.

TABLE 4
Range Distribution of Benthonic Foraminifera in Hole 134 – Balearic Abyssal Plain

Age	Depth Below Sea Floor (m)	Cores	*Sigmoilina schlumbergeri* (Silv.)	*Siphonina reticulata* (Czjzek)	*Eponides umbonatus stellatus* (Silv.)	*Cibicides* cf. *boueanus* (d'Orb.)	*Cibicides ungerianus-pseudoungerianus*	*Karreriella bradyi* (Cush.)	*Martinottiella communis* (d'Orb.)	*Spiroloculina tenuiseptata-tenuis*	*Lagena acuticosta* Reuss	*Lagena bradyana* Forn.	*Lagena longirostris* (Seg.)	*Lagena quadricostulata* Reuss	*Robulus cultratus* Montf.	*Bolivina catanensis* Seg.	*Bolivina pseudoplicata* Herr. All. & Earl.	*Bolivina subspinescens* Cush.
	Sea Floor 2864 m																	
Pleistocene	168-177	1 ▮																
	177-183	2 ▮	▮	▮	▮	▮	▮											
Pliocene Upper	248-251	3 ▮	▮	▮			▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮
	251-260	4 ▮																
	260-269	5 ▮			▮							▮						
Pliocene Lower	288-296	6 ▮	▮	▮	▮	▮	▮	▮	▮	▮		▮						▮
	317-326	7 ▮	▮	▮	▮		▮	▮	▮	▮		▮						▮
Messinian U. Miocene Evaporite Section	344-349	8 ▮																
	350-359	9 ▮					▮											
	359-364	10 ▮																

Age	Depth Below Sea Floor (m)	Cores	*Bulimina aculeata basispinosa* Ted. & Zanm.	*Bulimina costata* d'Orb.	*Siphonodosaria monilis* (Silv.)	*Uvigerina* cf. *longistriata* Perconig	*Uvigerina proboscidea* Schwager	*Eponides* cf. *schreibersii* (d'Orb.)	*Eponides umbonatus* (Reuss)	*Planulina ariminensis* (d'Orb.)	*Pleurostomella alternans* Schwager	*Cassidulina subglobosa* Brady	*Nonion padanum* Perconig	*Nonion pompilioides* (F. & M.)	*Pullenia bulloides* (d'Orb.)	*Gyroidina* cf. *laevigata* d'Orb.	*Bigenerina nodosaria* d'Orb.	*Vulvulina pennatula* (Batsch)
	Sea Floor 2864 m																	
Pleistocene	168-177	1 ▮																
	177-183	2 ▮																
Pliocene Upper	248-251	3 ▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮		
	251-260	4 ▮																
	260-269	5 ▮						▮	▮									
Pliocene Lower	288-296	6 ▮			▮			▮	▮	▮	▮	▮	▮		▮		▮	▮
	317-326	7 ▮		▮	▮	▮		▮		▮	▮	▮	▮		▮	▮	▮	
Messinian U. Miocene Evaporite Section	344-349	8 ▮																
	350-359	9 ▮									▮		▮					
	359-364	10 ▮																

Age	Depth Below Sea Floor (m)	Cores	*Liebusella soldanii* (Jones & Parker)	*Dentalina leguminiformis* (Batsch)	*Orthomorphina* cf. *jedlitschkai* (Thalm.)	*Orthomorphina* cf. *tenuicostata* (Costa)	*Planularia auris cymba* (d'Orb.)	*Vaginulinopsis* cf. *sublegumen* Parr	*Bolivina dilatata* Reuss	*Bolivina* cf. *punctata* d'Orb.	*Siphonodosaria consobrina* (d'Orb.)	*Uvigerina peregrina-mediterranea*	*Cibicides robertsonianus* (Brady)	*Lagena lacunata* Burr. & Holland	*Gyroidina neosoldanii* Brotzen	*Anomalina helicina* (Costa)	*Pullenia salisburyi* Stew.	*Lagena laevis* (Montagu)
	Sea Floor 2864 m																	
Pleistocene	168-177	1 ▮																
	177-183	2 ▮																
Pliocene Upper	248-251	3 ▮																
	251-260	4 ▮																
	260-269	5 ▮																
Pliocene Lower	288-296	6 ▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮	▮		
	317-326	7 ▮		▮				▮	▮	▮		▮			▮	▮	▮	▮
Messinian U. Miocene Evaporite Section	344-349	8 ▮																
	350-359	9 ▮																
	359-364	10 ▮																

Age	Depth Below Sea Floor (m)	Cores	*Cancris oblongus* (d'Orb.)	*Cibicides bradyi* (Trauth)	*Asterigerina planorbis* (d'Orb.)	*Bolivina scalarata miocenica* MacFadyen	*Uvigerina rutila* Cush.	*Astrononion stelligerum* (d'Orb.)	*Hanzawaia* n. sp.	*Bolivina antiqua* d'Orb.	*Bolivinoides miocenicus* Gianotti	*Angulogerina angulosa* (Will.)	*Trifarina bradyi* Cush.	*Planulina* aff. *renzi* Cush. & Stainforth	*Cibicides cicatricosus maioricensis* Colom	*Cibicides* cf. *floridanus* (Cush.)	*Gyroidina girardana* (Reuss)	*Hanzawaia* cf. *boueana* (d'Orb.)
	Sea Floor 2864 m																	
Pleistocene	168-177	1 ▮																
	177-183	2 ▮																
Pliocene Upper	248-251	3 ▮																
	251-260	4 ▮																
	260-269	5 ▮																
Pliocene Lower	288-296	6 ▮																
	317-326	7 ▮	▮	▮	▮	▮	▮	▮	▮									
Messinian U. Miocene Evaporite Section	344-349	8 ▮																
	350-359	9 ▮				▮				▮	▮	▮	▮	▮	▮	▮	▮	▮
	359-364	10 ▮																

Quaternary

Samples: 13-133-1; 13-134-1; 13-134-2, CC; 13-134A-1, CC; 13-134B-1, CC; 13-134E, SWC 2:

Braarudosphaera bigelowi
Ceratolithus telesmus
Coccolithus pelagicus
Cyclococcolithus leptoporus s.l.
Gephyrocapsa oceanica
Helicosphaera carteri
Micrascidites sp.
Pontosphaera japonica
Pontosphaera scutellum
Pseudoemiliania lacunosa
Rhabdosphaera clavigera
Rhabdosphaera stylifera
Scyphosphaera apsteini
Sphenolithus abies
Syracosphaera pulchra
Thoracosphaera heimi

Zone: NN 19 – NN 20
Age: Quaternary

Pliocene

Samples: 13-134-3-1, 25 cm; 134-3-2, 72 cm; 134-3, CC; 13-134E-2, CC:

Ceratolithus rugosus
Coccolithus pelagicus
Cyclococcolithus leptoporus s.l.
Discoaster asymmetricus
Discoaster brouweri
Discoaster surculus
Discolithina macropora
Helicosphaera carteri
Lithostromation perdurum
Pontosphaera japonica
Pontosphaera scutellum
Rhabdosphaera stylifera
Scyphosphaera apsteini
Scyphosphaera intermedia
Thoracosphaera imperforata

Zone: NN 16 *Discoaster surculus* Zone
Age: Upper Pliocene

Samples: 13-134-5-1, 140 cm; 134-5-2, 90 cm; 134-5, CC:

Braarudosphaera bigelowi
Ceratolithus rugosus
Coccolithus pelagicus
Cyclococcolithus leptoporus s.l.
Discoaster asymmetricus
Discoaster brouweri
Discoaster variabilis
Discolithina macropora
Helicosphaera carteri
Lithostromation perdurum
Pontosphaera japonica
Reticulofenestra pseudoumbilica
Scyphosphaera apsteini
Scyphosphaera intermedia
Sphenolithus abies

Zone: NN 15 *Reticulofenestra pseudoumbilica* Zone
Age: Upper Pliocene

Samples: 13-134-6-1, 75 cm; 134-6-1, 125 cm; 134-6-2, 114 cm; 134-6-3, 125 cm; 134-6-4, 25 cm; 134-6-5, 125 cm; 134-6, CC:

Ceratolithus tricorniculatus
Coccolithus pelagicus
Cyclococcolithus leptoporus s.l.
Discoaster asymmetricus
Discoaster brouweri
Discoaster pentaradiatus
Discoaster challengeri
Discoaster variabilis
Reticulofenestra pseudoumbilica
Scyphosphaera apsteini
Scyphosphaera intermedia

Zone: NN 14 *Discoaster asymmetricus* Zone
Age: Lower Pliocene

Samples: 13-134-7-1, 105 cm; 134-7-1, 145 cm; 134-7-2, 1 cm; 134-7-2, 129 cm; 134-7-3, 125 cm; 134-7-4, 124 cm; 134-7-5, 95 cm; 134-7-5, 120 cm:

Ceratolithus tricorniculatus
Coccolithus pelagicus
Cyclococcolithus leptoporus s.l.
Discoaster brouweri
Discoaster challengeri
Discoaster pentaradiatus
Discoaster surculus
Lithostromation perdurum
Pontosphaera japonica
Pontosphaera scutellum
Reticulofenestra pseudoumbilica
Scyphosphaera apsteini
Scyphosphaera intermedia

Zone: NN 12 *Ceratolithus tricorniculatus* Zone
Age: Lower Pliocene

Miocene

Samples: 13-134-7-5, 136 cm; 134-7, CC, 134-9, CC; 134-10, CC:

Coccolithus pelagicus
Cyclococcolithus rotula
Discoaster challengeri
Discoaster variabilis
Lithostromation perdurum
Pontosphaera multipora
Pontosphaera scutellum
Reticulofenestra pseudoumbilica
Sphenolithus abies

Zone: NN 11 Zone *Discoaster quinqueramus* lacking
Age: Upper Miocene

Siliceous Microfossils (P.D.)

A poor assemblage of siliceous microfossils was recorded within the bedded salt layer of Core 10 of Hole 134 on the Balearic Abyssal Plain. It contains radiolarian fragments, rare specimens of *Mesocena elliptica, Dictyocha fibula, Distephanus crux, Distephanus speculum, Actiniscus pentasterias, Actiniscus elongatus, Melosira granulata, Coscinodiscus* sp., and particularly frequent sponge spicules. This assemblage, rather similar to that encountered in Site 124, Core 10, suggests that an open marine environment existed intermittently for short periods of time during the Late Miocene "crisis of salinity".

LITHOSTRATIGRAPHY

The sections of sediment and rock recovered from the seven holes drilled at Sites 133 and 134 are broadly grouped into three basic lithologic units. We recognize that such a classification is somewhat restrictive, but it serves the purpose of concentrating our attention on the principal findings resulting from our preliminary observations. The lithologic units are identified in Table 5, which also includes a listing of the various holes and core numbers where each unit was recovered. As discussed earlier, major unconformities and stratigraphic gaps have been found separating the units one from another, as well as subdividing the units themselves.

TABLE 5
Lithologic Units of Sites 133 and 134

Unit	Lithology	Age
1	Foraminiferal marl oozes with sand layers, pebbles, and hardgrounds (133-1, 134-1 to 7, 134A-1, 134E-SWC 2)	Quaternary and Pliocene
2a	Variegated silts and shales (barren) with rounded cobbles of metamorphic rock (133-1 through 8)	Upper Miocene (Messinian)
2b	Dolomitic and pyritic marls, bedded gypsum, laminated anhydrite, and halite (134-7, 8 and 10, 134D-1)	Upper Miocene (Messinian)
3	Metamorphic basement consisting of Phyllites and metagraywackes (134A-2, 134B-1, 134C-1, 134D-2 and 3, 134E-3)	Paleozoic (inferred)

Unit 1 – Foraminiferal Marl Oozes with Sand Layers, Pebbles, and Hardgrounds

The lithologies represented in Unit 1 are selected to include those which everywhere lie on and above Horizon M. In the case of Site 133, they occur in a thin veil over the crest and landward flank of the buried basement ridge. At Site 134, they are generally horizontally stratified beneath the surface of the Balearic Abyssal Plain and only gently uplap onto the seaward flank of the basement ridge.

In Hole 133, more than 250 meters above the level of the abyssal plain, the oozes are highly calcareous, with carbonate contents ranging to 70 per cent. They are comprised almost entirely of the tests of foraminifera and coccoliths, with only minor contributions of fine-grained terrigenous clay minerals. Their color is pale brown with common dark streaks of hydrotriolite. Burrowing is extensive and parts of the section are sandy as the result of winnowing during the core recovery operations. The washed sand fraction includes grains of quartz, mica, and pyrite, with numerous fragments of feldspathic schist. Two large rounded pebbles of metagraywacke were found floating in a marl ooze layer.

In Holes 134, 134A, and 134E on the abyssal plain the marl oozes are somewhat more terrigenous and have lower carbonate contents, ranging from 13 to 63 per cent. More of the rounded pebbles and cobbles of metamorphic rock are also present. The youngest sediments, of Quaternary age, such as those found in Core 1 of Hole 134A at 30 to 39 meters below bottom, are thinly bedded and olive to olive gray in color; perhaps reflecting a greater influx of hemipelagic materials. A relatively high content of terrigenous debris (e.g. $CaCO_3$ = 22 to 29%) is accompanied by displaced faunas and thin-shelled pelecypods and ostracods.

Unconformities are present between the Pleistocene and Pliocene as represented in Sidewall Core 1 of Hole 134E at 199 meters and by the observed drilling break at 242 meters in Hole 134. It is here that the hardground was found which has been previously discussed in the section on Biostratigraphy (see Figure 15).

Cores 3, 6, and 7 of Hole 134, in the underlying Pliocene, display penecontemporaneous deformational structures including folding and overturned strata. Core 5, however, is not folded and is composed of horizontal strata of different colors with sharp or gradational boundaries, layers of size-sorted foraminifera, and other bedding structures characteristic of current-controlled deposition.

Well-rounded gravels, some of them very flattened (Figure 16), are scattered all through Core 7. They range in size up to 1 cm on the long axis and are composed of the same matagraywacke as the larger pebbles and cobbles previously described. Neither size grading nor preferred grain-imbrication were observed.

The Pliocene oozes, particularly those of the lower Pliocene, are much more "pelagic" looking than those of the Quaternary, except for the fragments of rock. In the seismic reflection profiles made with an airgun sound source (Figure 2), the Quaternary sequence reveals much more acoustic stratification. Its horizontal bedding suggests gravity transport in sediment suspensions (i.e. turbidity currents) as a major process in the sediment distribution.

Unit 2a – Variegated Silts and Shales

Variegated detrital silts and shales with well-rounded cobbles of metamorphic rock were recovered only in Hole 133 on the Sardinia Slope in Cores 1 (pars) through 8, between ~ 50 and 192 meters. Their upper surface is correlated to Horizon M and they have been given an inferred age of Upper Miocene.

The rocks in the silts are metagraywackes and phyllites similar to those found in Unit 1, and their petrology is described in some detail in Chapter 29.

The variegated sediments are loose to semi-consolidated with colors ranging from rusty red to aquamarine. Their sedimentology is presented in Chapter 25.1.

The sand and silt-size particles include detrital quartz with some feldspar, micas, dolomite, and rounded and flattened sandstone, and schist fragments (Figure 17) embedded in a clayey matrix. Bedding with sharp contacts separates layers of different granulometric composition. A thick bed of clay, almost free of sand and silt, is present in Core 5.

As discussed in Chapter 25.1, these clastics, which are totally barren of microfossils, are probably continental in

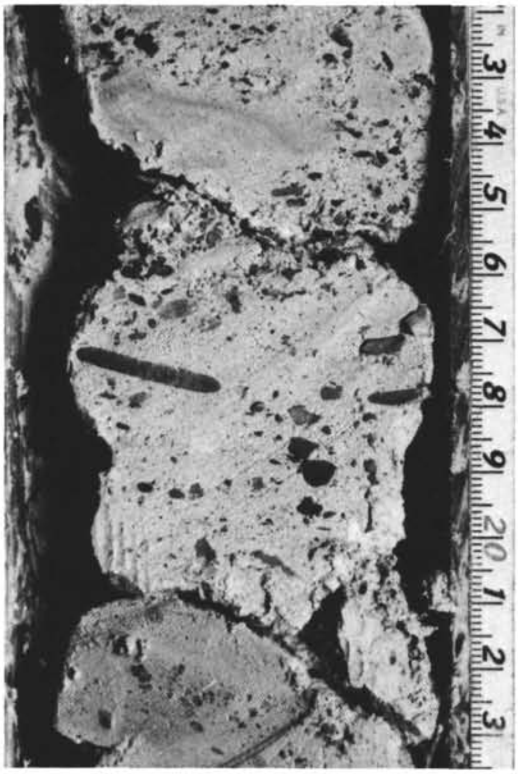

Figure 16. *Randomly oriented flattened pebbles of metamorphic rock in a matrix of foraminifera ooze in Section 5, Core 7 of Hole 134. This layer of sediment lies a meter above Horizon M and may possibly be a slump deposit from the nearby basement ridge. The pebbles are believed to be derived from former Upper Miocene fan conglomerates on the Sardinia Slope which were cored there in Hole 133. Scale is in centimeters.*

origin and have a lithology similar to that of variegated clastics often deposited in an arid environment.

Unit 2b – Dolomitic and Pyritic Marls with Anhydrite and Halite

The sediments below Horizon M beneath the abyssal plain at Site 134 are entirely different from those just described from the eastward flank of the basement ridge under the Sardinia slope. Their shallowest occurrence is in Core 1, Hole 134D (175-183 m), where dark gray dolomitic marls occur with white nodules of gypsum. The marls are bedded and partly indurated with secondary growth of selenite. The white nodules (see Figure 18) and large individual white crystals are saccharoidal in texture. Fine anhedral gypsum, quartz, feldspar, and calcite are observed in smear slides. These sediments are most similar to those in Cores 6 and 7 of Site 124 on the Balearic Rise which were interpreted to belong to an intertidal evaporite facies (see Chapter 6).

Where Horizon M occurs at a great depth below the surface of the abyssal plain, such as at the location of the most westward hole (134), the evaporites consist of dolomitic and pyritic marls, this time intercalated with laminated anhydrite and halite. The boundary between Unit 1 and 2b beneath the Balearic Abyssal Plain here has been placed at ~ 323 meters, coincident with an observed drilling break when cutting Core 7.

The cored contact is sharp and suggests an erosion surface (Figure 14). Lithologically, light-colored pelagic oozes overlie dark dolomitic marls. According to the fauna, a hiatus of approximately one million years occurs between the two lithologies.

The top of the evaporitic series, recovered at 130 cm in Section 5 of Core 7, is composed of pyritic marl and dolomitic marl oozes. They are laminated and display alternate lighter and darker hues of olive to dark gray. Oblique bedding, characteristic of bottom current action, microfractures and microdeformations are present. X-ray analysis shows that the laminated horizons are interbedded pyritic marl oozes (calcite only) and dolomitic marl oozes (calcite and dolomite). In addition, the oozes comprise quartz, feldspar, halite, clays, and, in one sample, anhydrite. Clay minerals are dominantly montmorillonite together with illite and chlorite.

A slightly overcalicified nannoplankton fauna together with a poor, small-sized foraminiferal assemblage indicate a Messinian age for the marls of the top of the evaporitic series.

The following 18-meter interval was washed out and the next core (134-8) recovered a 30-cm layer of solid

Figure 17. *Flattened pebbles in the variegated silts and shales from Core 5, Section 1 of Hole 133 which have been interpreted to be detrital alluvium deposited on a former exposed flood plain during a late Miocene desiccation of the Balearic Basin.*

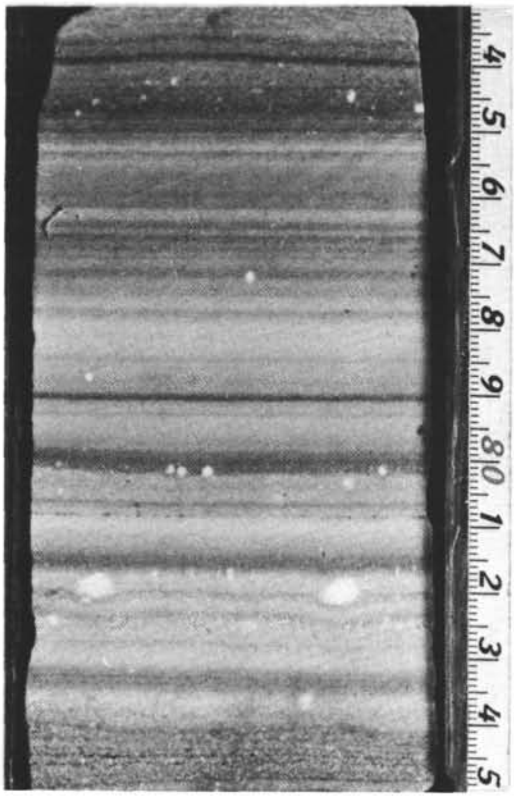

Figure 18. *An example of nodular gypsum in a host matrix of dark gray dolomitic marl and silt. The enterolithic structures observed here in Core 1 of Hole 134D are formed by early diagenetic sulfate growth. This type of displacement origin is common in present-day* sabkhas *and sometimes produces convolutions and flowage between undisturbed confining layers through the lateral relief of growth pressure. Some mechanical deformation from the coring process is also recognized.*

anhydrite above 30 cm of halite. The anhydrite is a finely laminated rock of white and gray millimetric laminae. A 5-cm layer composed of white nodules embedded in a gray matrix occurs in the middle of the laminations (see Figure 19). X-ray analysis indicates pure anhydrite in the light-colored bands. The penecontemporaneous bedding structures suggest a diagenetic replacement of marls through displacement growth of anhydrite spherules and micronodules. The halite has a schistose fabric and contains much dark organic matter.

Core 9 recovered only a small piece of unconsolidated foraminiferal ooze of Messinian age. The rock is composed of abundant foraminifera together with quartz, mica, and a scanty nannoplankton fauna.

The last cored series (Core 10) consists of anhydrite overlying dolomitic marls, which in turn overlie a thick (1.6 m) bed of rock salt (halite). The laminated (*balatino*) anhydrite is similar to the rock of Core 8. The dolomitic marls are plastic, bedded, and dark gray in color. They comprise quartz, dolomite, anhydrite, clays, and trace amounts of halite and gypsum. The clay minerals are illite, mixed layers clays, montmorillonite, and chlorite. The fauna is poor and composed of rare planktonic foraminifera and nannoplankton together with ostracods, radiolarian debris, and sponge spicules. This assemblage suggests deposition in a marine environment. When the core was opened, the dolomitic marl ooze layer emitted a strong methane-like odor. Shore laboratory analysis identified the presence of gasoline-range hydrocarbons (see Chapter 32 this volume).

The drilling terminated in a massive bed of halite of which 1.6 meters were penetrated. The halite is translucent and banded (see Figure 20). Intercalated within are more layers of laminated anhydrite 1 to 5 cm thick, with detrital silts similar to the rocks of Core 8. Desiccation cracks and erosional surfaces were noted and many of the bedding planes are undulatory.

Unit 3 – Metamorphic Basement

Hard rocks forming the edge of the Sardinian continental margin were reached in Holes 134A, B, C, D, and E.

Coring brought back both angular fragments and well-rounded cobbles of dark olive gray phyllite and metagraywacke. They are composed of quartz, plagioclase, sericitized plagioclase, hornblende, epidote, etc., in a micaceous

Figure 19. *Laminated* (balatino) *facies of Core 10, Hole 134. The tiny white anhydrite spherules tend to form along the slightly coarser textured, darker dolomitic partings, and their penecontemporaneous growth often deforms the bedding interfaces.*

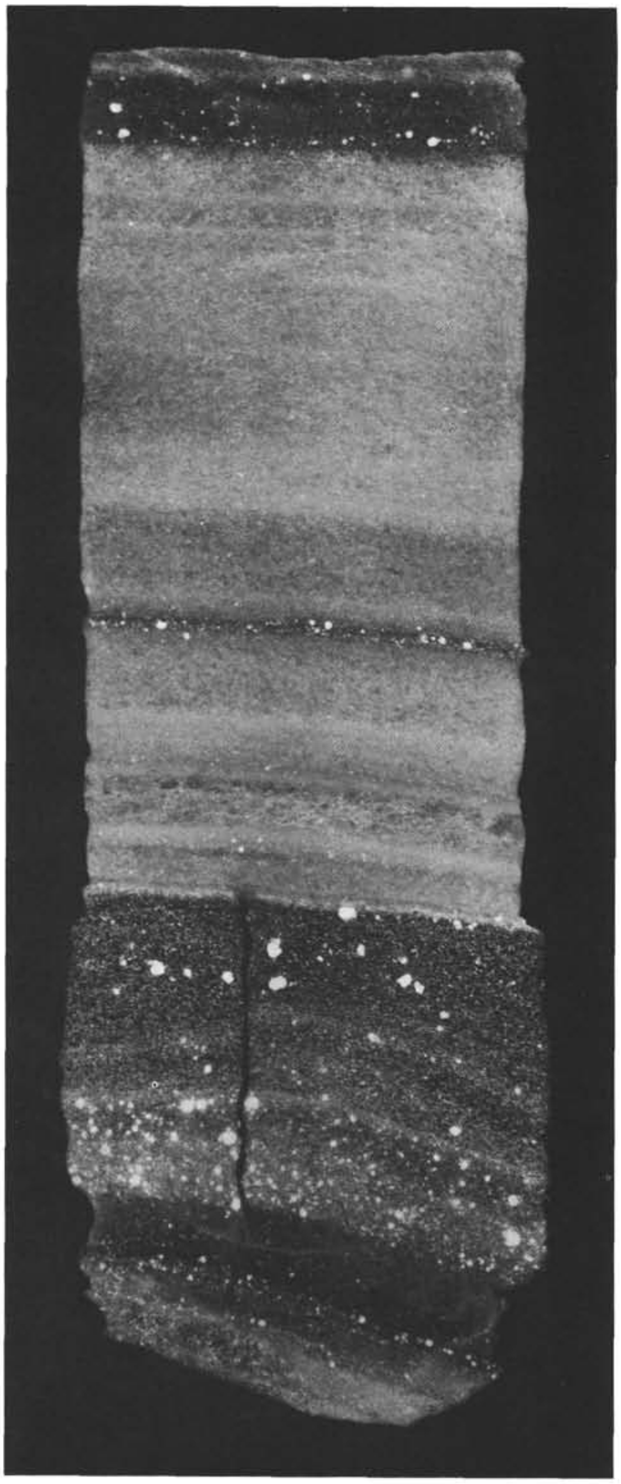

Figure 20. *Polished section (life size) of an interval of interbedded salt and detrital silt (with anhydrite) in in Core 10, Section 2 of Hole 134. The halite is banded with alternating translucent and cloudly laminae. Note the desiccation crack through the upper part of the detrital layer. See Chapter 22.2 for a more detailed petrographic description of this rock sample.*

matrix, their petrologic makeup and age determination are presented in Chapter 29.

PHYSICAL PROPERTIES

Because the recovery was very poor in most of the cores from the various drill holes at Sites 133 and 134, physical property measurements were only conducted on the cores from the single hole which penetrated the deepest (i.e., Hole 134). The recovered materials which were investigated include the foraminiferal marl oozes of lithologic Unit 1 and the dolomitic marl, anhydrite, and halite of lithologic Unit 2b.

Very few penetrometer measurements were made, and values lie in the range 22.7×10^{-1} to 7.3×10^{-1} mm, showing the relatively indurated state of the sediments. Maximum values occur in the marl oozes of Core 5, where intercalated beds of sand and silt also occur. Bulk density varies between 1.62 and 1.96 gm/cc; grain density varies between 1.93 and 2.87 gm/cc, measured in Core 6. Water content decreases from 22.2 to 20.5 per cent and porosity from 41.0 per cent to 32.9 per cent downward.

Natural gamma radiation is remarkably uniform and low in Cores 3, 6, and 7, with readings falling in the range of 1900 to 2400 counts, and increasing with depth. Fluctuations may result from variation in calcium carbonate content, as foram-rich horizons and rock fragments produce low counts of 1900, while coarser-grained beds seem to correspond to the higher values at 2200 counts or more. Higher count rates of about 2800 or 2900 correspond to sand horizons in Core 5. Pure halite produces a count rate of 1400, while laminated anhydrite and dolomitic marl gives a peak count of 3100. These values agree rather well with the results of the gamma radiation investigations carried out on evaporitic sediments at other Mediterranean sites.

DISCUSSION AND CONCLUSIONS

Facies Distribution Along Horizon M

The principal objectives at Sites 133 and 134 of exploring the composition and facies of the M-Reflectors on either side of the basement ridge along the western margin of Sardinia were successfully accomplished by drilling several holes along the east-west traverse. As discussed in previous sections of this chapter, the variegated materials recovered from below Horizon M at Site 133 on the landward flank of the ridge are considered to be flood plain deposits of a terrestrial origin. They contain no autochthonous marine microfossils nor, in fact, any kind of carbonate (either as detritus or cement), and they are relatively enriched in fresh-looking grains of potassium feldspars and plagioclase. The rounded cobbles and occasional flattened pebbles of schist are believed to be debris of the basement ridge itself, eroded and abraded at times during the Late Miocene when the flanks of this feature were near wave base or subaerially exposed.

The interpreted alluvial fanglomerates of the western Sardinia margin were found only on the continental slope (Figure 21), where Horizon M was encountered at 2623 meters below present-day sea level. As predicted by the desiccation model of Figure 1C, an entirely different facies

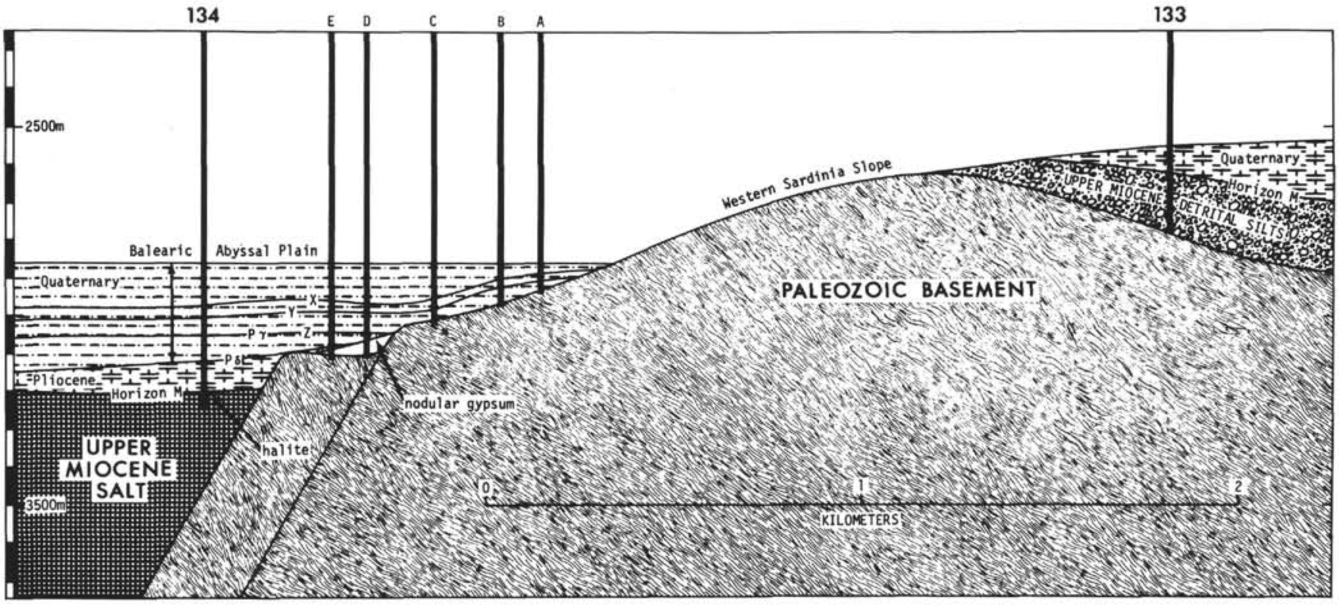

Figure 21. *Cross-section of the basement ridge beneath the foot of the western Sardinia Slope (drawn with no exaggeration) illustrating the evaporite facies distribution at Sites 133 and 134. Flood plain gravels were first encountered in Hole 133 on the landward side of the ridge at a depth of 2623 meters below present sea level. Subsequently playa salts were reached beneath the abyssal plain in Hole 134 on the seaward side at 3218 meters below sea level; and, finally, at the margin of the plain, intertidal and supratidal nodular gypsum was penetrated at 3056 meters in Hole 134D. Metamorphic basement consisting of metagraywackes and phyllites were encountered in offset Holes 134A, B, C, D, and E. Also depicted are various reflecting interfaces and the drilling breaks* X, Y, *and* Z *noted in Figures 12 and 13.*

is developed beneath the floor of the contemporary abyssal plain where Horizon M was penetrated at a level some 574 meters deeper. Here, in Hole 134, cores of banded halite alternating with laminae of anhydrite laths and detrital sand (Chapter 22.2), and interbedded with finely laminated anhydrite, reflect a depositional environment beneath a shallow brine pool on a playa surface, itself sometimes emergent (Shearman, 1970).

We believe that it is no coincidence that a nodular gypsum facies is represented at the very margin of this ancient playa where Horizon M is observed to onlap at a somewhat shallower elevation against the seaward flank of the basement ridge (i.e., Hole 134D). Contemporary sediments with a comparable nodular texture form only in the supratidal environment of coastal sabkhas such as those along the Trucial Coast of the Persian Gulf (Shearman, 1966; Kinsman, 1969). Beneath the sabkha surface at a small distance above the groundwater table, perhaps less than one meter, the nodules grow by displacement processes (See Chapter 6) from capillary brines carried in from either upslope or from the salina.

According to modern counterparts, the facies distribution detected at Sites 133 and 134 and portrayed in Figure 21 is completely compatible with the concept of a desiccated Late Miocene deep basin. Upon drying up, the floor of the basin would then have been transferred into a shallow playa in which the brine layer could be trapped and layered halite would be precipitated. The landward extremity of the brine pool would have provided a temporary strandline above which sabkha terrains developed. In such a scheme, the accumulation of a thick succession of halite and gypsum would not necessarily have had to involve sympathetic tectonic subsidence, since the floor of the deep basin could have gradually filled up, instead. Because the westward flank of the basement ridge descends steeply beneath the abyssal plain, the creation of a thick salt layer here might not have involved a great lateral retreat of the sabkhas, provided they could have received enough host sediment themselves to support the diagenetic growth of the sulfates. Obviously, the location of any strandline would be likely to be very temporary since the level of the surface of the brine pool on the playa floor would be controlled by relative rates of evaporation versus precipitation and runoff. As a consequence, we might expect to find an appreciable interfingering of both the nodular and layered sequences, as is the case so often in ancient evaporites (Fuller and Porter, 1969).

Post-Evaporite Environment

Because of the apparent gap in sedimentation between the top of the pyritic and dolomitic marls of the Messinian evaporites and the first permanently deposited marine ooze of Pliocene age, as documented in Section 5, Core 7 of Hole 134, we cannot offer any concrete facts as to how the evaporite epoch ended at this particular location in the Balearic Basin. However, the presence of randomly oriented pebbles of schists in the ooze of this core and contorted bedding in the next core above seems to indicate that this particular sediment interval was probably emplaced as a slump of some kind from the basement ridge.

The post-Horizon-M, pre-Reflector-Pδ sediment layer of Pliocene age is observed on the reflection profile of

Figure 4 to be both transgressive across Horizon M and truncated by Horizon Pδ, whereas the overlying blanket of acoustically stratified sediment of Pleistocene age is generally flatlying or slightly uplifted across the seaward field of diapirs.

The differential thickness of the Pliocene interval and its unconformable bedding surfaces are characteristic of drifting and erosion through current activity (Heezen *et al.*, 1966). The manganese crust encountered at the level of the Pδ Reflector corroborates this opinion. The horizontal bedding of the younger Quaternary sediment, on the other hand, indicates a greater influence of gravity on the depositional process. The sandy nature of these sediments and their much higher net rate of accumulation points to a significant contribution from suspension flows (i.e., turbidity currents). Unfortunately, recovery of these sequences was too sparse to permit the identification of a turbidite facies on the basis of primary bedding structures alone. Nevertheless, displaced tests of shallow-water benthonic foraminifera were detected.

As to the depth of water in the basin during the deposition of the Pliocene ooze, we can refer to the study of Benson reported in Chapter 36.2, which describes the occurrence of a psychrospheric ostracod assemblage in Core 7 of Hole 134, not to mention the previously discussed presence of thin-shelled deep-water benthonic foraminifera.

Nature of the Basement Ridge

The basement ridge, first identified on the reflection profiles, was subsequently penetrated in five of the drill holes. Based on the subbottom depth of the initial encounter with hard rocks, the inferred configuration of subcropping relief of this ridge is sketched in Figure 21. The faults depicted are interpretive, based on the knowledge from the reflection profile that the salt layer probably exceeds one kilometer in thickness beneath the Hole 134 position on the east-to-west traverse (that is, by assigning a compressional-wave velocity of > 4.0 km/sec to this facies as documented in Chapter 18). The crustal layer beneath the salt is inferred to be oceanic bedrock as determined from the interpreted seismic structure of Refraction Profile No. 194 some 45 km further to the west (Fahlquist and Hersey, 1969).

Offsets in the metamorphic basement were diagnosed by finding equivalent strata for correlatable drilling breaks in Hole 134D at a slightly greater depth than in Hole 134E. Note that in the interpreted section of Figure 21 the younger sediments on the abyssal plain abut against the western flank of the ridge, whereas the older Pliocene oozes onlap and progressively pinch out. As of now, we do not know if the part of this western flank of the ridge which lies above the surface of the abyssal plain actually outcrops, or whether it is buried under a thin veneer of sediment; however, we can point out that coherent echo returns in the profile of Figure 8 would suggest the latter case to be more likely.

Metamorphic rocks were recovered in all samples from the basement ridge. Since their petrology is described and discussed in Chapter 29, there is no need to repeat it here. What is startling is that the composition, grain size, textures, and metamorphic fabric of these rocks from the western margin of Sardinia are incredibly similar to those which are observed in the rock samples from basement Cores 2 and 3 of the *Mistral* exploratory hole in the Gulf of Lyon on the other side of the basin (Figure 22). Perhaps this similarity is fortuitous; yet, as mentioned previously, when the Sardinia microplate is rotated back against France these two drilling areas lie at conjugate points of the reconstruction at a separation of only 55 km. Additional points of matching identical types of rocks and formations (namely the Permian rhyolites of Esterel and Monte Cinto, Corsica, and the Silurian metamorphics of Toulon and Cape Falcon, Sardinia) have previously been pointed out by Narin and Westphal (1968) and Alvarez (1972).

Examining the Paleo-Reconstruction of the Balearic Basin

Many details of the proposed Corsica and Sardinia fit remain to be worked out in the future, provided, of course, that it represents any kind of geological reality. The tentative reconstruction of Figure 6 first suggested by Walter Alvarez and which involves a separate motion of both Corsica and Sardinia, seems not only to more accurately align the three conjugate features but also appears to satisfy the paleomagnetic results somewhat better than other previous reconstructions treating both islands as a single unit. For example, the most up-to-date paleomagnetic pole positions show a rotation relative to stable Europe of 25 degrees to 30 degrees for Corsica (Narin and Westphal, 1968) and about 50 degrees for Sardinia (De Jong *et al.*, 1969; Zijderveld *et al.*, 1970) which can be compared to 32 degrees and 65 degrees, respectively, in the proposed fit (Alvarez, in press).

Unfortunately, considering the provisional nature of the reconstruction and the lack of deep drilling in the center of the abyssal plain, we can only speculate as to the age of the initial rotation of microplates and the opening of the Liguian Trough and Balearic Basin. In an attempt to put some constraints on a possible age, we have depicted in Figure 23 the proposed reconstruction with the addition of contoured marine magnetic anomalies (Vogt *et al.*, 1971) which have been rotated back with the particular margin on which they reside (see hachuring).

At first glance, two significant overlaps are apparent which would tend to refute the reconstruction altogether – one on the northwestern corner of the island of Sardinia and the other in the Gulf of Lyon just to the west of Sites 133 and 134. If these anomalies represent the magnetic expression of intrusive bodies which predate the extension, the fit is obviously wrong. However, if these anomalies reflect intrusions which took place during, or after, the early phases of distension, then the conflict would disappear.

The Possibility of Postdistension Intrusions

Considering this latter hypothesis, we note that the marine magnetic anomalies of the western Sardinia margin continue on the mainland into a belt of andesitic volcanics (the Alghero trachyandesites) where the magnetic declination differences with respect to Europe are some 15 degrees less than the angle inferred for the snug fit of Figure 23. If this discrepancy of 15 degrees is indeed real, it may be that the paleopole positions recorded for Sardinia

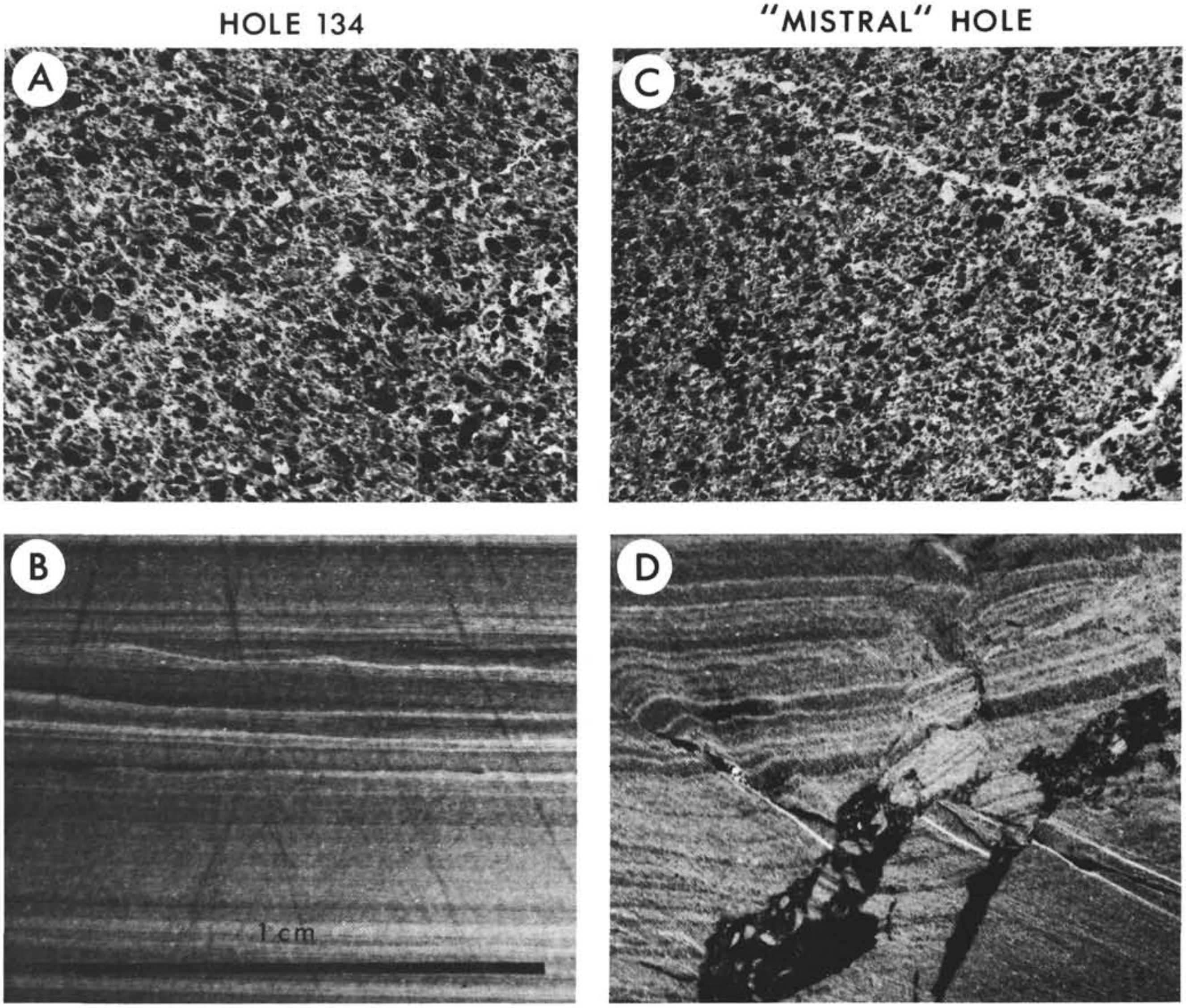

Figure 22. *Comparison of the Site 134 graywacke and phyllite from the basement ridge of the western Sardinia Slope with almost identical rocks from beneath the Gulf of Lyon south of France in the* Mistral *exploratory hole of the Compagnie Francaise des Pétroles. These illustrations are reverse print enlargements of thin sections.* A = *Sample 134D*-3, CC; B = *Sample 134B*-1, CC; C = *Sample from* Mistral *Core 2; and* D = *Sample from* Mistral *Core 3.*

were locked into the Alghero volcanics during eruptive phases that followed the initial rifting.

All the magnetic anomalies shown in Figure 23 are positive, and according to model studies they represent the magnetic signature of bodies magnetized during a period of normal goemagnetic field polarity (see discussion in Chapter 5). Perhaps, as suggested by Alvarez (in press), the anomalies represent a single intrusive phase which took place sometime after the separation of Sardinia from the mainland, yet before the departure of Corsica. It is curious indeed, that a 15 degree counterclockwise rotation of Sardinia not only removes the previously mentioned overlap by opening the Strait of Bonifacio sphenochasm and carrying Sites 133 and 134 south of the Gulf of Lyon anomaly, but that this rotation then aligns the whole anomaly pattern into a single northeast-southwest belt.

Several age dates are available which shed some light on the timing of the volcanic outpouring.[10] The andesites recovered from the basement ridge at Site 123 in the Valencia Trough have been dated by both potassium-argon and fission track techniques at ≈ 19 to 22 my (see Chapter 28.4) while those further north on the sea coast of the Cote d'Azur of southern France have been recorded at 26.2 my (Bellon and Brousse, 1971). This interval spans the Burdigalian stage of the Lower Miocene and coincides with the first deposition of marine sediment over the now buried basement ridge at the *Mistral* drill hole. The sediment there

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[10] Most recent estimates of the age of the Balearic Basin put it somewhere in the Cenozoic (e.g. Le Pichon *et al.*, 1971).

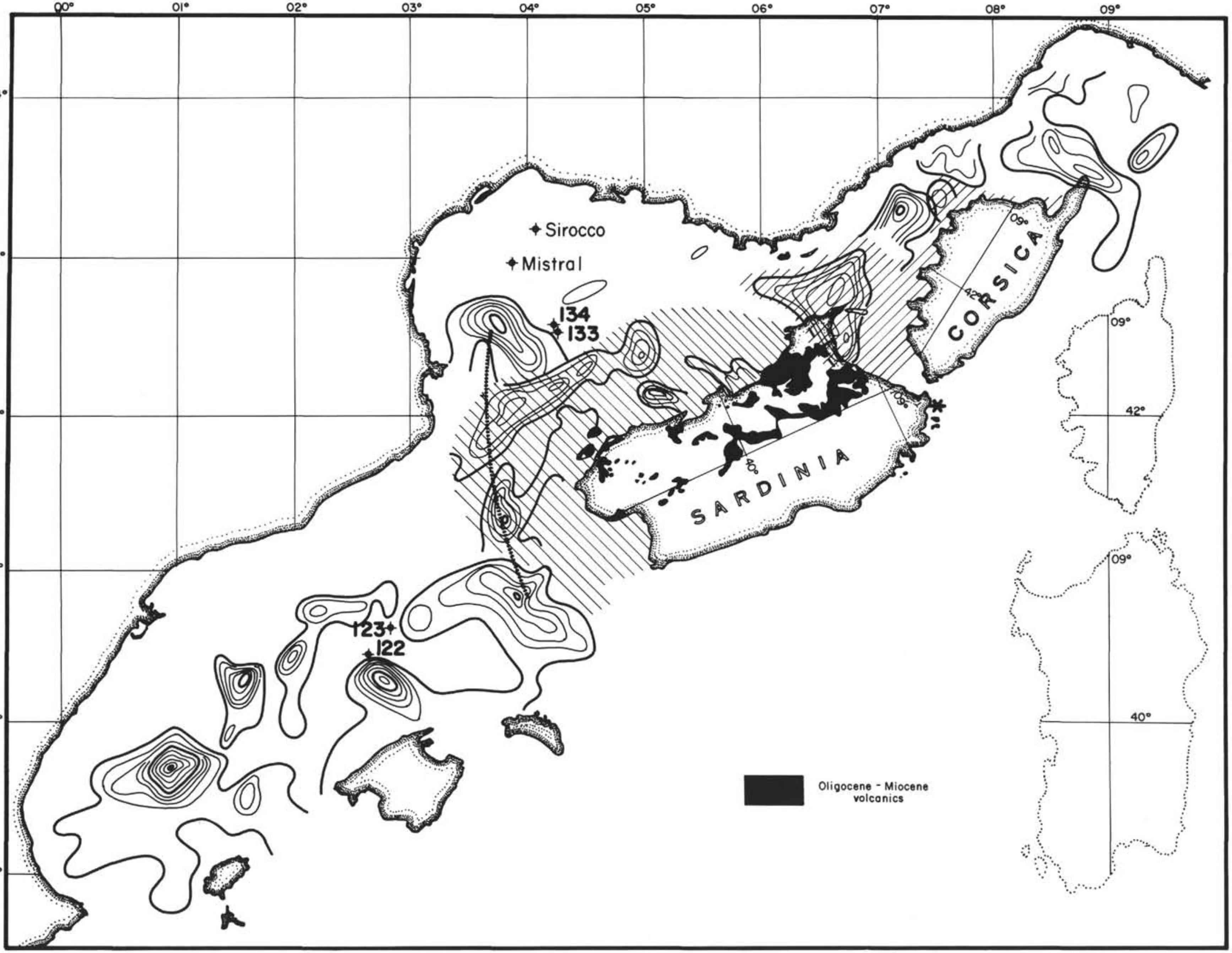

Figure 23. *Reconstruction of the Sardinia and Corsica microplates. The magnetic anomalies (all positive) are from Vogt* et al. *(1971) and have been rotated with each plate. Note the overlap of Sites 133 and 134 with a large oval anomaly in the Gulf of Lyon.*

appears to be a transgressive deposit[11] because the basal layers at a present depth of 3455 meters below sea level are rich in detrital silt, organic matter, and glauconite, thought to be an indicator of shallow shelf environments.

Other suggestions of a Neogene age include another body of andesites at the southwestern extremity of the magnetic anomaly belt in the Almeria Province of Spain,[12] and previously mentioned Alghero trachyandesites of Sardinia, which have been given an age as young as early Miocene by M. Deriu in De Jong *et al.* (1969), although this formation has also been considered to be of possible Oligocene age.

Minimum Age of the Basin

Regardless, however, of the exact age of the hypothetical opening, the rotation of the microplates must somehow have been completed prior to the Messinian Stage of the Upper Miocene since the salt layer can be detected in seismic profiles across the entire width of the basin, with the best-developed piercement structures actually occupying the axial region (Zone A of Glangeaud *et al.*, 1966). A much more precise timetable will undoubtedly be available when future drilling programs are able to penetrate through the salt layer and effect considerable sub-bottom penetration near the center of the abyssal plain.

In retrospect, the sampling of metagraywackes and phyllites from the buried basement ridge west of Sardinia does not in itself prove the concept of extension and continental drift in order to explain the origin of the western Mediterranean. It does, nevertheless, supply one more geological observation compatible with, and explainable by, this type of oceanization process. That subsidence has played a significant role is not ruled out by any means. The Paleozoic (?) metagraywackes and phyllites of the *Mistral* hole and Sites 133 and 134 were encountered more than 3 km below present-day sea level, and their occurrence here must have involved not only an unroofing of this unit but a considerable foundering as well.

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[11] Oral communication of P. F. Burollet at the VIIIth International Sedimentological Congress in Heidelberg, 1971.

[12] Sedimentary rocks of an established Tortonian age directly overlying pyroclastics (an orthopyroxene-labradorite pheno-andesite) in the western part of La Serrata Nijar (Zeck and Soediono, 1970).

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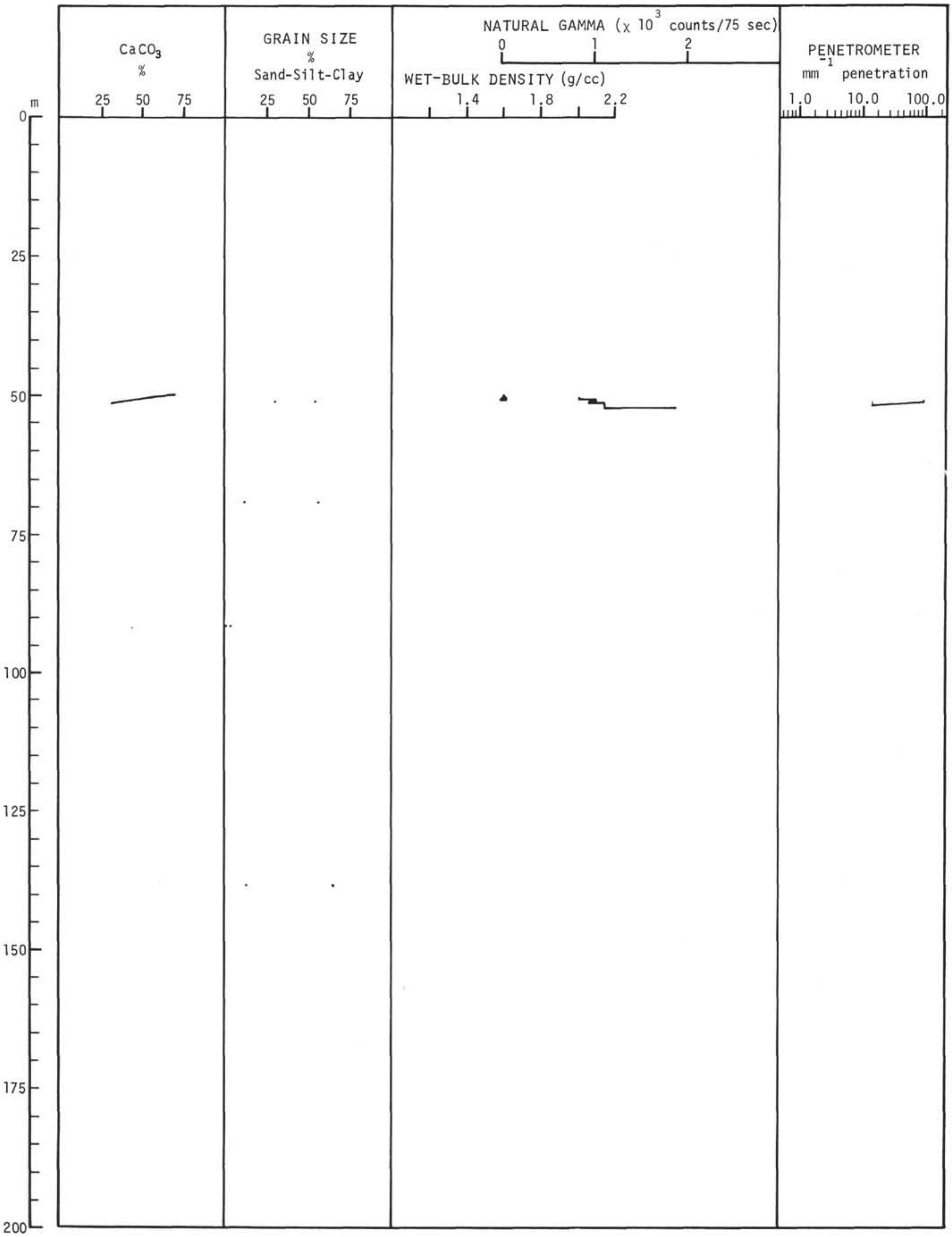
Site Summary 133



AGE

LITHOLOGY AND BIOSTRATIGRAPHY

LITHOLOGY

PLEISTOCENE

Foraminiferal MARL OOZES, SANDS and PEBBLES (pelagics with coarse terrigenous influxes)

marl oozes: very pale brown, plastic, bedded, mottled, with abundant forams

Sands and gravels:

loose sand and rolled pebbles of semi-schist

rich planktonic assemblages with *Globorotalia truncatulinoides* and *Gephyrocapsa oceanica*

60m lower part of the Quaternary is missing

LATE MIOCENE (Messinian) ?

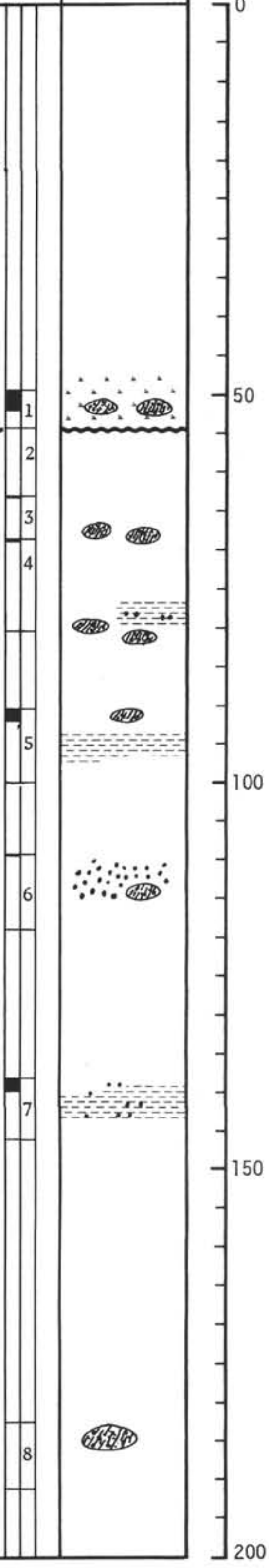
PEBBLES, ARENITES and CLAYS (continental deposits)

interbedded semi-schist pebbles, coarse clayey sands and silts, and clays.

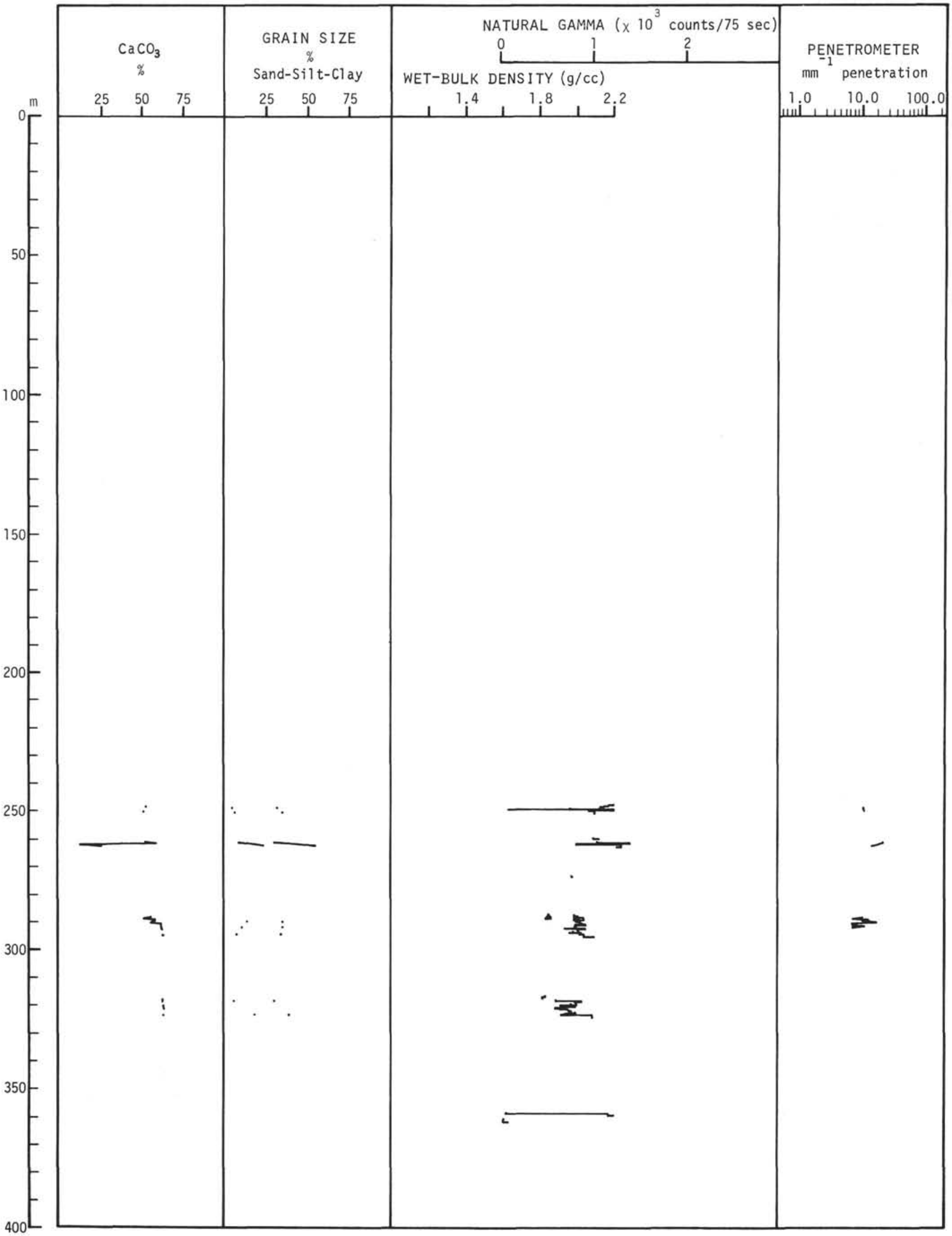
barren

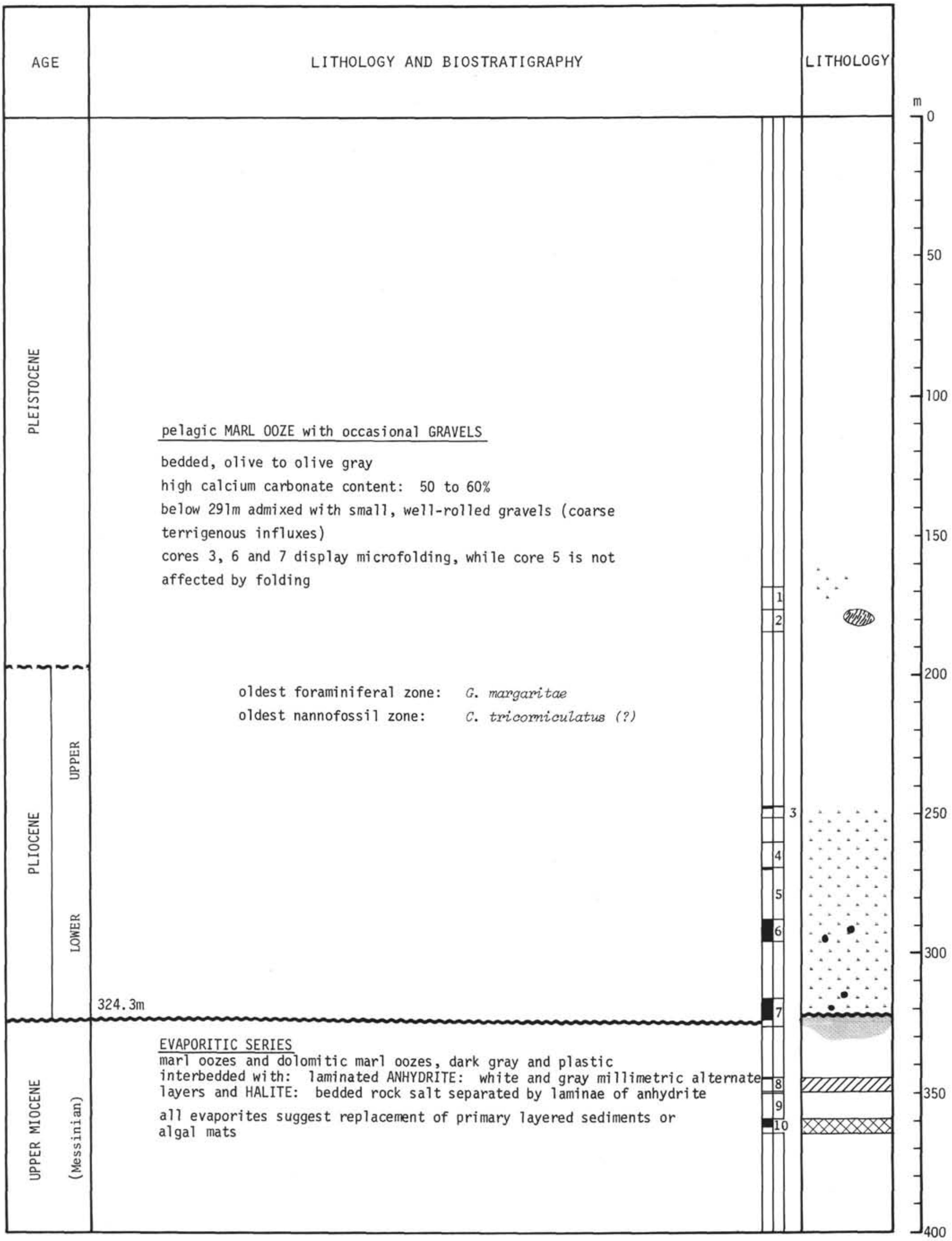
varicolored: red and green hues

(schist pebbles similar petrologically to basement rocks of Site 134 holes, and also to lower Paleozoic of western Sardinia)



Hole Summary 134





pelagic MARL OOZE with occasional GRAVELS

bedded, olive to olive gray

high calcium carbonate content: 50 to 60%

below 291m admixed with small, well-rolled gravels (coarse terrigenous influxes)

cores 3, 6 and 7 display microfolding, while core 5 is not affected by folding

oldest foraminiferal zone: *G. margaritae*

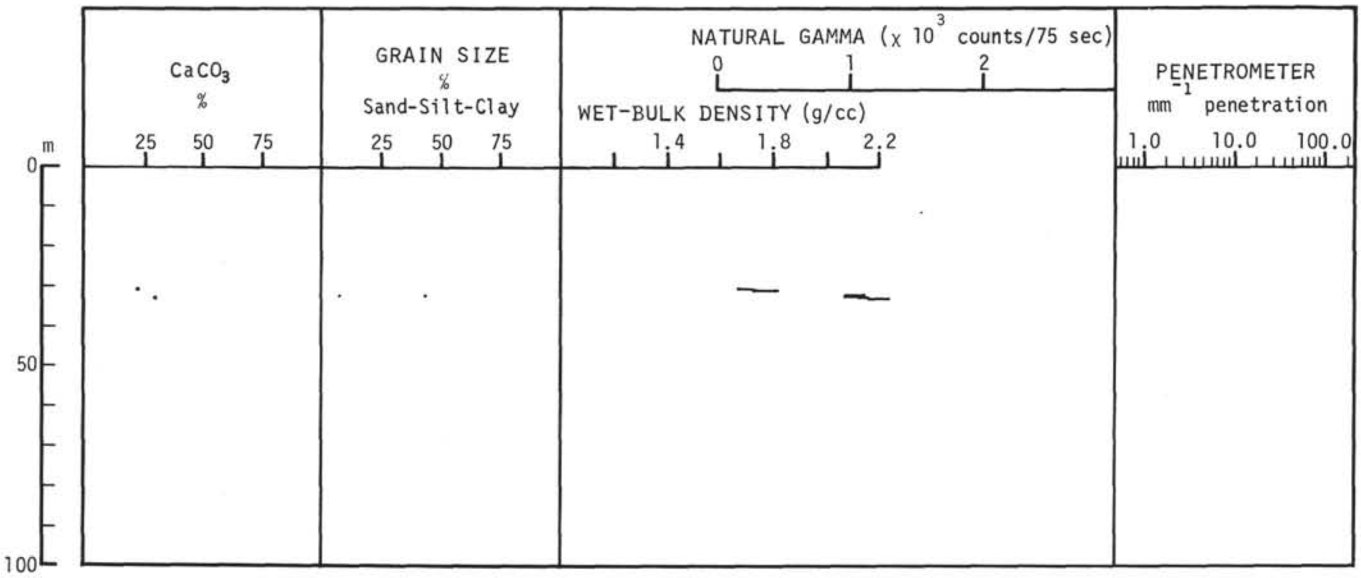
oldest nannofossil zone: *C. tricorniculatus (?)*

EVAPORITIC SERIES

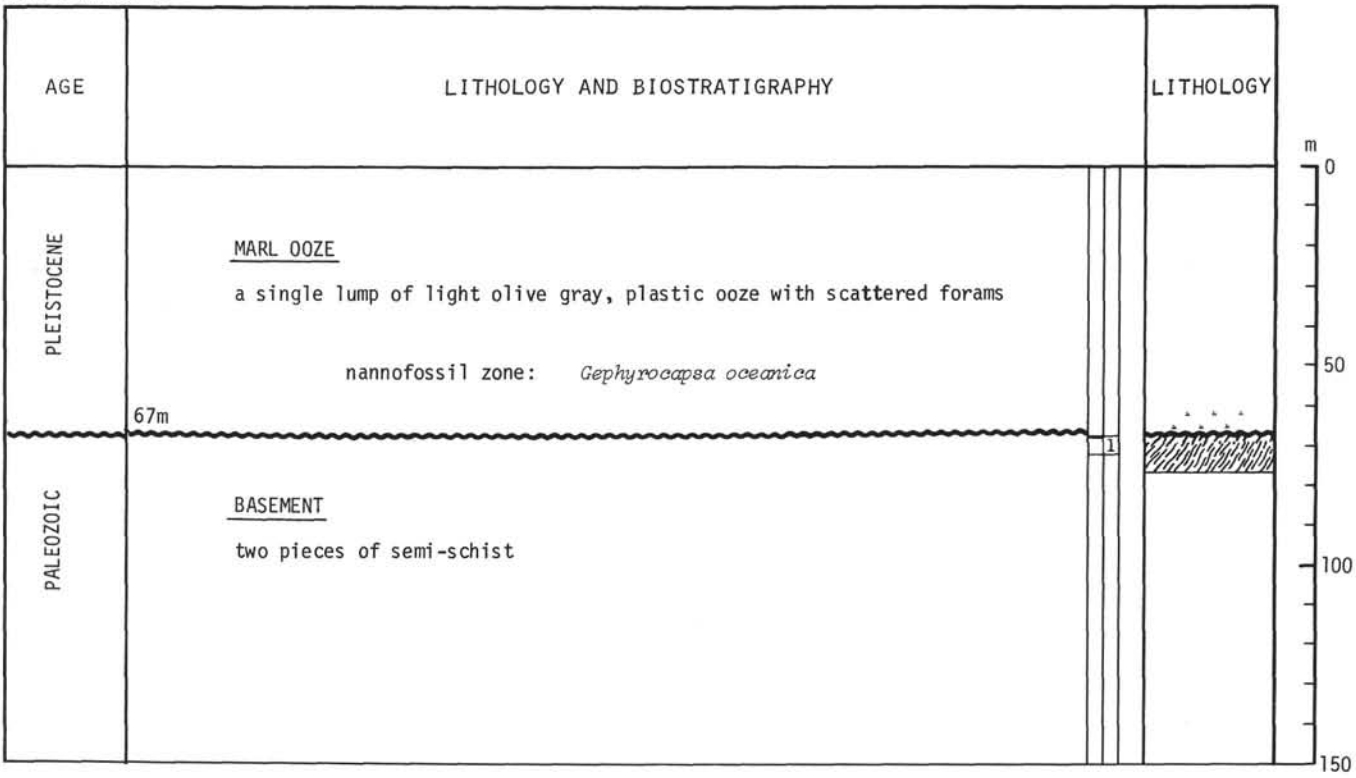
marl oozes and dolomitic marl oozes, dark gray and plastic interbedded with: laminated ANHYDRITE: white and gray millimetric alternate layers and HALITE: bedded rock salt separated by laminae of anhydrite

all evaporites suggest replacement of primary layered sediments or algal mats

Hole Summary 134A



Hole Summary 134B



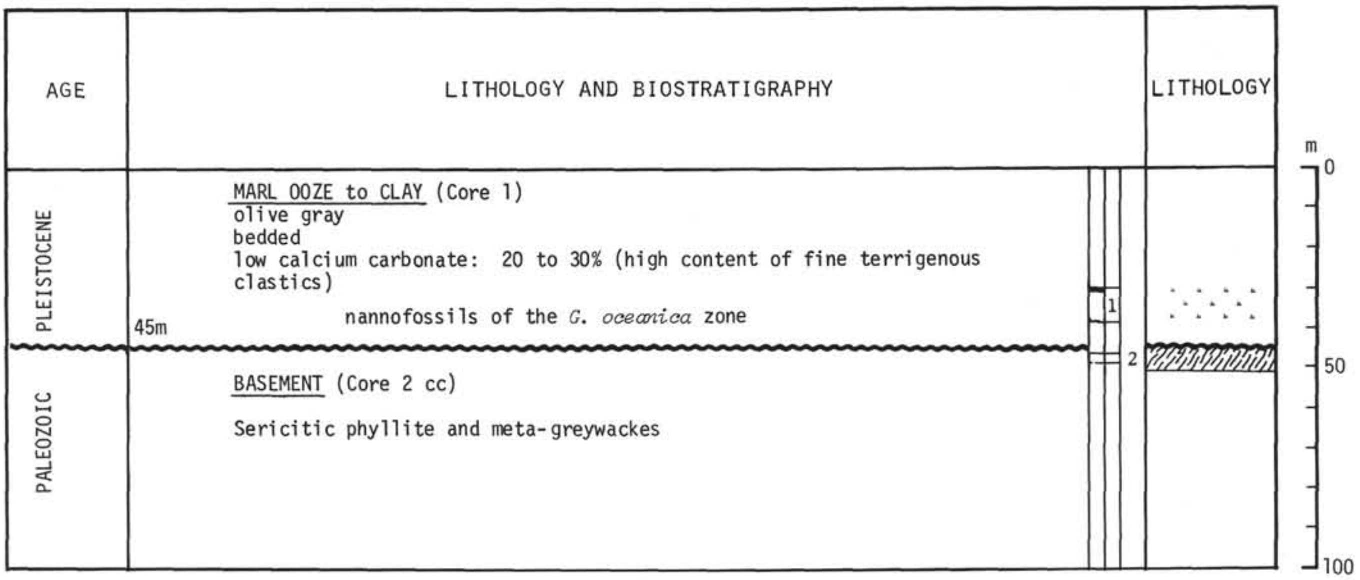
MARL OOZE

a single lump of light olive gray, plastic ooze with scattered forams

nannofossil zone: *Gephyrocapsa oceanica*

BASEMENT

two pieces of semi-schist



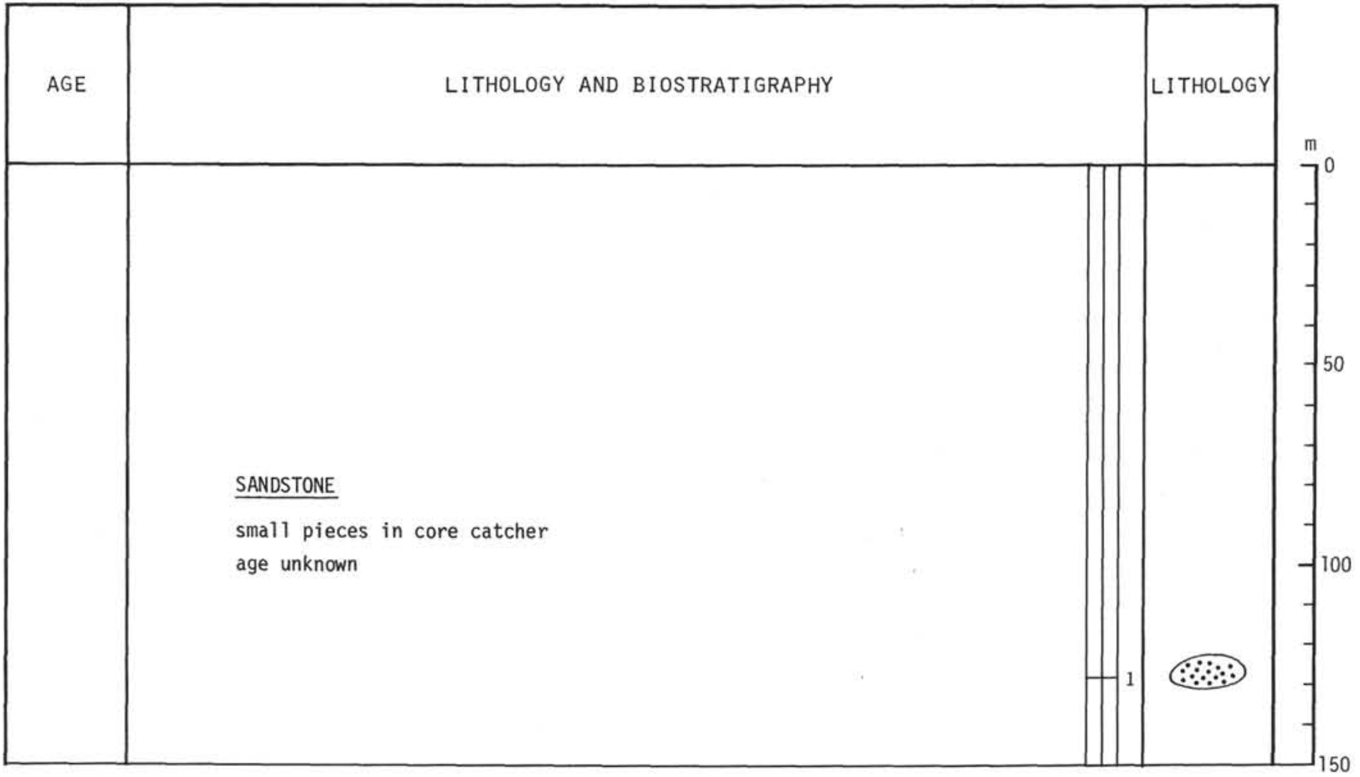
MARL OOZE to CLAY (Core 1)
olive gray
bedded
low calcium carbonate: 20 to 30% (high content of fine terrigenous clastics)

nannofossils of the *G. oceanica* zone

BASEMENT (Core 2 cc)

Sericitic phyllite and meta-greywackes

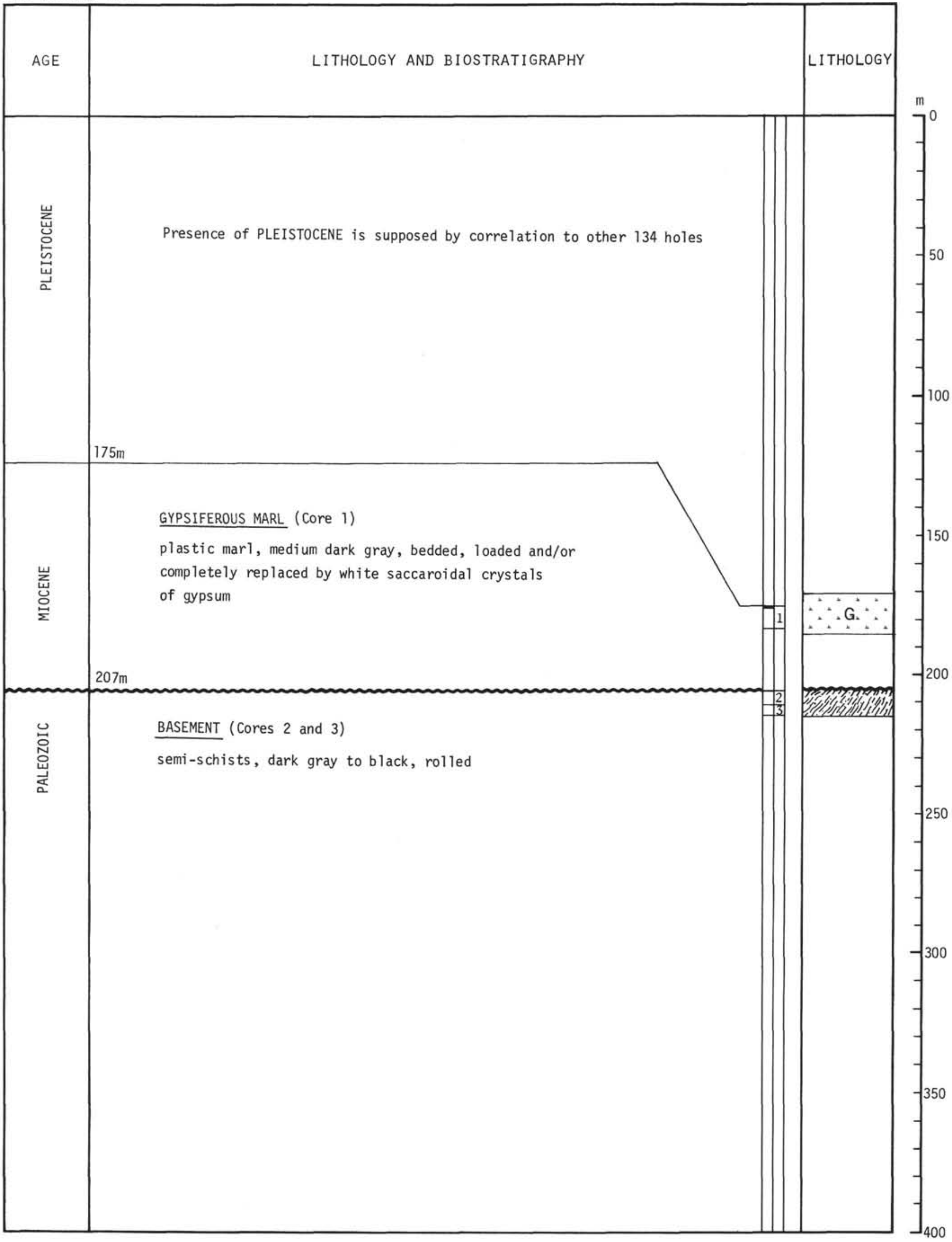
Hole Summary 134C



SANDSTONE

small pieces in core catcher
age unknown

Hole Summary 134D



Presence of PLEISTOCENE is supposed by correlation to other 134 holes

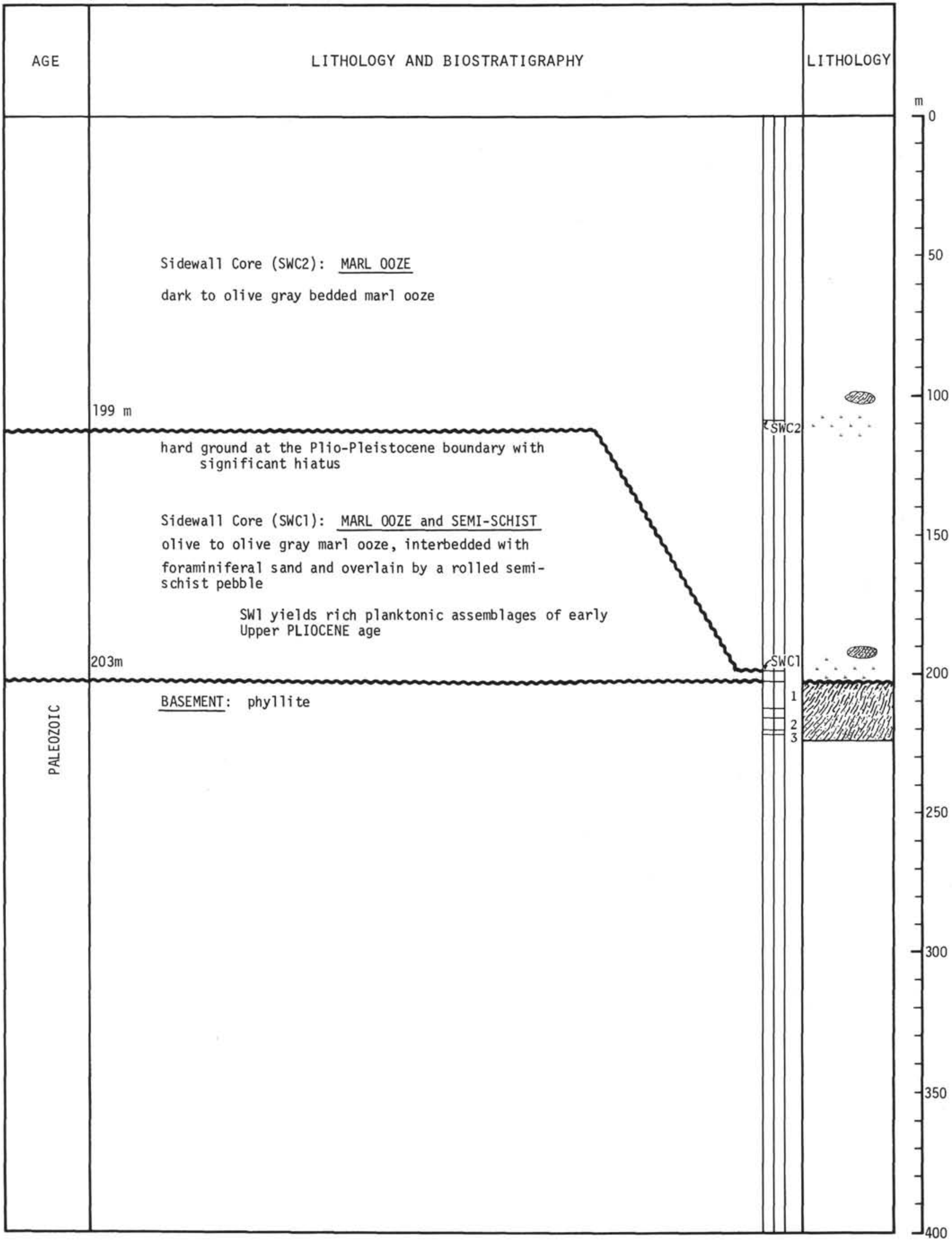
GYPSIFEROUS MARL (Core 1)

plastic marl, medium dark gray, bedded, loaded and/or completely replaced by white saccaroidal crystals of gypsum

BASEMENT (Cores 2 and 3)

semi-schists, dark gray to black, rolled

Hole Summary 134E



Sidewall Core (SWC2): MARL OOZE

dark to olive gray bedded marl ooze

hard ground at the Plio-Pleistocene boundary with significant hiatus

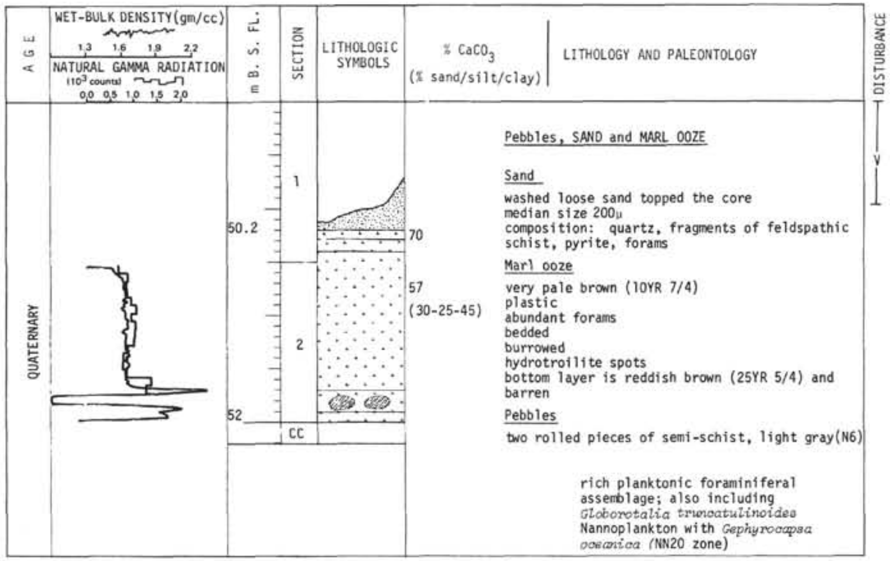
Sidewall Core (SWC1): MARL OOZE and SEMI-SCHIST

olive to olive gray marl ooze, interbedded with foraminiferal sand and overlain by a rolled semi-schist pebble

SW1 yields rich planktonic assemblages of early Upper PLIOCENE age

BASEMENT: phyllite

SITE 133 CORE 1 Cored Interval 49-54 m



Pebbles, SAND and MARL OOZE

Sand

washed loose sand topped the core
median size 200μ
composition: quartz, fragments of feldspathic schist, pyrite, forams

Marl ooze

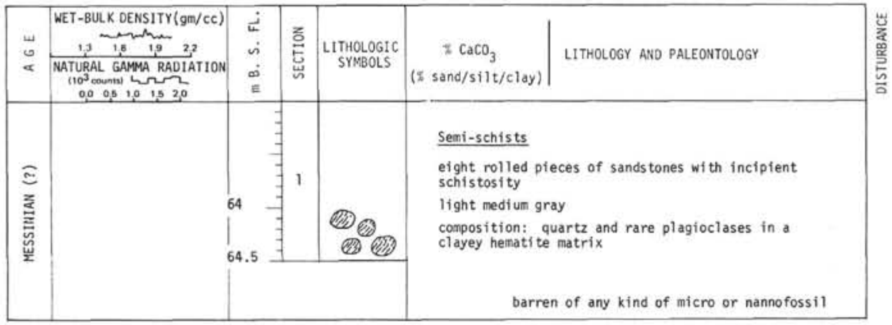
very pale brown (10YR 7/4)
plastic
abundant forams
bedded
burrowed
hydrotroilite spots
bottom layer is reddish brown (25YR 5/4) and barren

Pebbles

two rolled pieces of semi-schist, light gray(N6)

rich planktonic foraminiferal assemblage; also including *Globorotalia truncatulinoides*
Nannoplankton with *Gephyrocapsa oceanica* (NN20 zone)

SITE 133 CORE 3 Cored Interval 63-68 m



Semi-schists

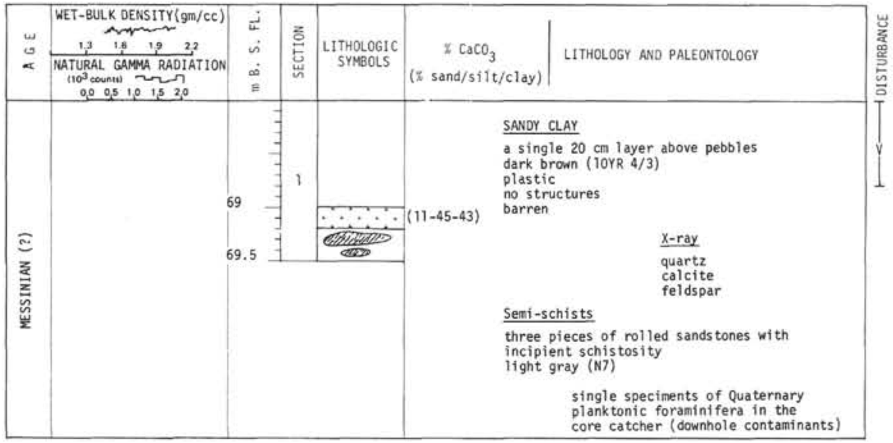
eight rolled pieces of sandstones with incipient schistosity

light medium gray

composition: quartz and rare plagioclases in a clayey hematite matrix

barren of any kind of micro or nannofossil

SITE 133 CORE 4 Cored Interval 68-81 m



SANDY CLAY

a single 20 cm layer above pebbles
dark brown (10YR 4/3)
plastic
no structures
barren

X-ray

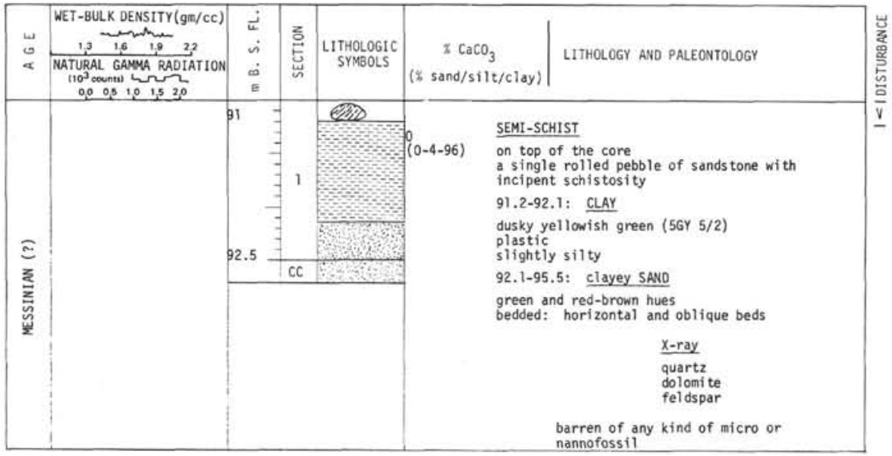
quartz
calcite
feldspar

Semi-schists

three pieces of rolled sandstones with incipient schistosity
light gray (N7)

single speciments of Quaternary planktonic foraminifera in the core catcher (downhole contaminants)

SITE 133 CORE 5 Cored Interval 91-100 m



SEMI-SCHIST

on top of the core
a single rolled pebble of sandstone with incipient schistosity

91.2-92.1: CLAY

dusky yellowish green (5GY 5/2)
plastic
slightly silty

92.1-95.5: clayey SAND

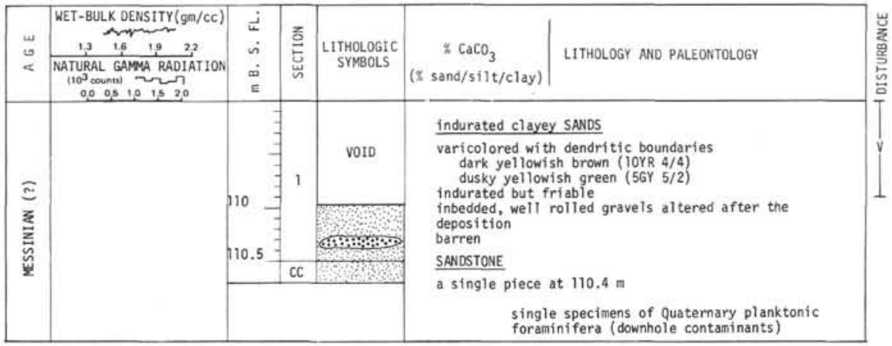
green and red-brown hues
bedded: horizontal and oblique beds

X-ray

quartz
dolomite
feldspar

barren of any kind of micro or nannofossil

SITE 133 CORE 6 Cored Interval 109-118 m



indurated clayey SANDS

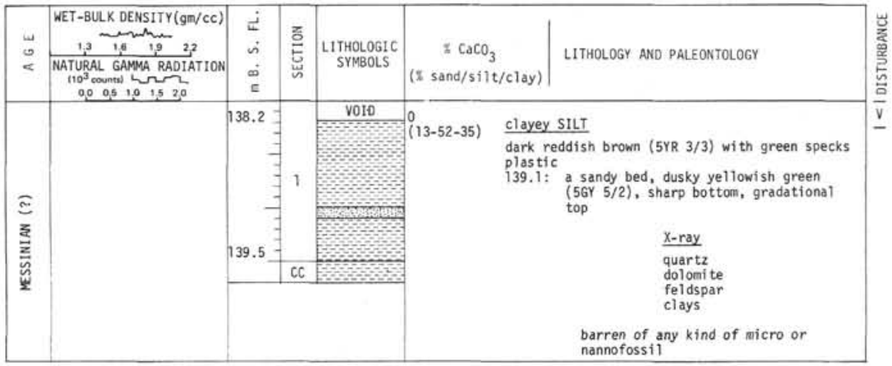
varicolored with dendritic boundaries
dark yellowish brown (10YR 4/4)
dusky yellowish green (5GY 5/2)
indurated but friable
inbedded, well rolled gravels altered after the deposition
barren

SANDSTONE

a single piece at 110.4 m

single specimens of Quaternary planktonic foraminifera (downhole contaminants)

SITE 133 CORE 7 Cored Interval 138-147 m



0
(13-52-35)

clayey SILT

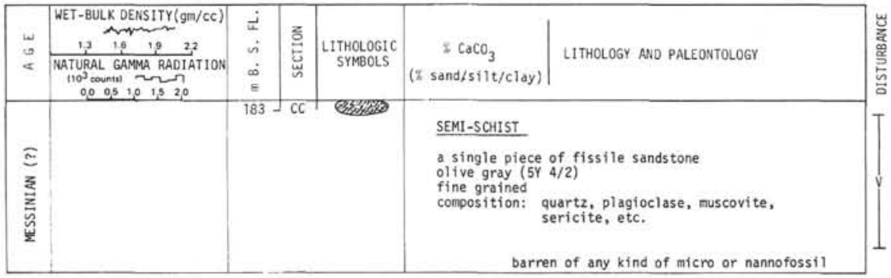
dark reddish brown (5YR 3/3) with green specks
plastic
139.1: a sandy bed, dusky yellowish green (5GY 5/2), sharp bottom, gradational top

X-ray

quartz
dolomite
feldspar
clays

barren of any kind of micro or nannofossil

SITE 133 CORE 8 Cored Interval 183-192 m

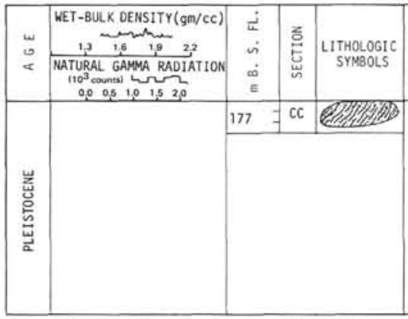


SEMI-SCHIST

a single piece of fissile sandstone
olive gray (5Y 4/2)
fine grained
composition: quartz, plagioclase, muscovite, sericite, etc.

barren of any kind of micro or nannofossil

SITE 134 CORE 2 Cored Interval 177-183 m (SITE 134, CORE 1: Cored interval, 168-177m; no recovery)



% CaCO$_3$ (% sand/silt/clay) | LITHOLOGY AND PALEONTOLOGY | DISTURBANCE

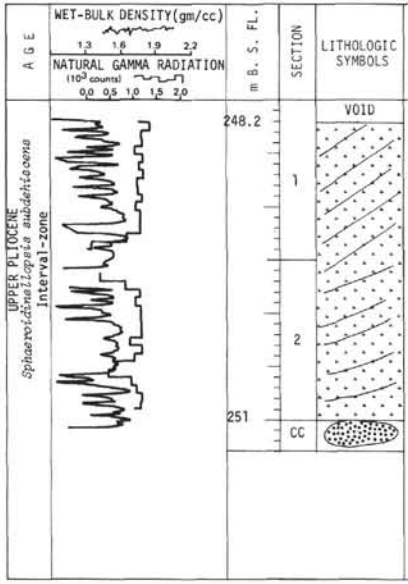
SEMI-SCHIST

four cm long pebble with gravel and coarse lithic sand gray (5Y 5/1)

planktonic foraminifera include *Globorotalia inflata, Globigerina pachyderma*, etc.

nannofossils with *Gephyrocapsa oceanica* and *Pseudoemiliania lacunosa*

SITE 134 CORE 3 Cored Interval 248-251 m



% CaCO$_3$ (% sand/silt/clay) | LITHOLOGY AND PALEONTOLOGY | DISTURBANCE

52
(5-28-67)

(6-29-65)
51

MARL OOZE

dark olive (5Y 4/2)
plastic to firm
oblique bedding
30° in section 1
10° to 20° in section 2

overlying SANDSTONE (in the core catcher)

composition: quartz, plagioclase, pyrite in a micaceous matrix
black (5Y 2/1)

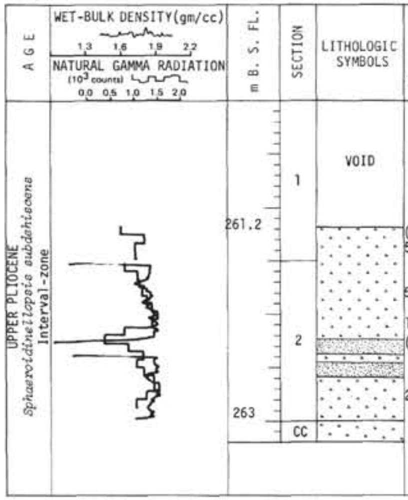
pelagic sedimentation

planktonic foraminifera very abundant and diversified
ostracodes, organic matter, echinoid spines

nannofossils of the *Discoaster surculus* zone

SITE 134, CORE 4: Cored interval, 251-260 m; no recovery.

SITE 134 CORE 5 Cored Interval 260-269 m



% CaCO$_3$ (% sand/silt/clay) | LITHOLOGY AND PALEONTOLOGY | DISTURBANCE

(9-22-69)
52
57
13
(24-32-44)
26

MARL OOZE

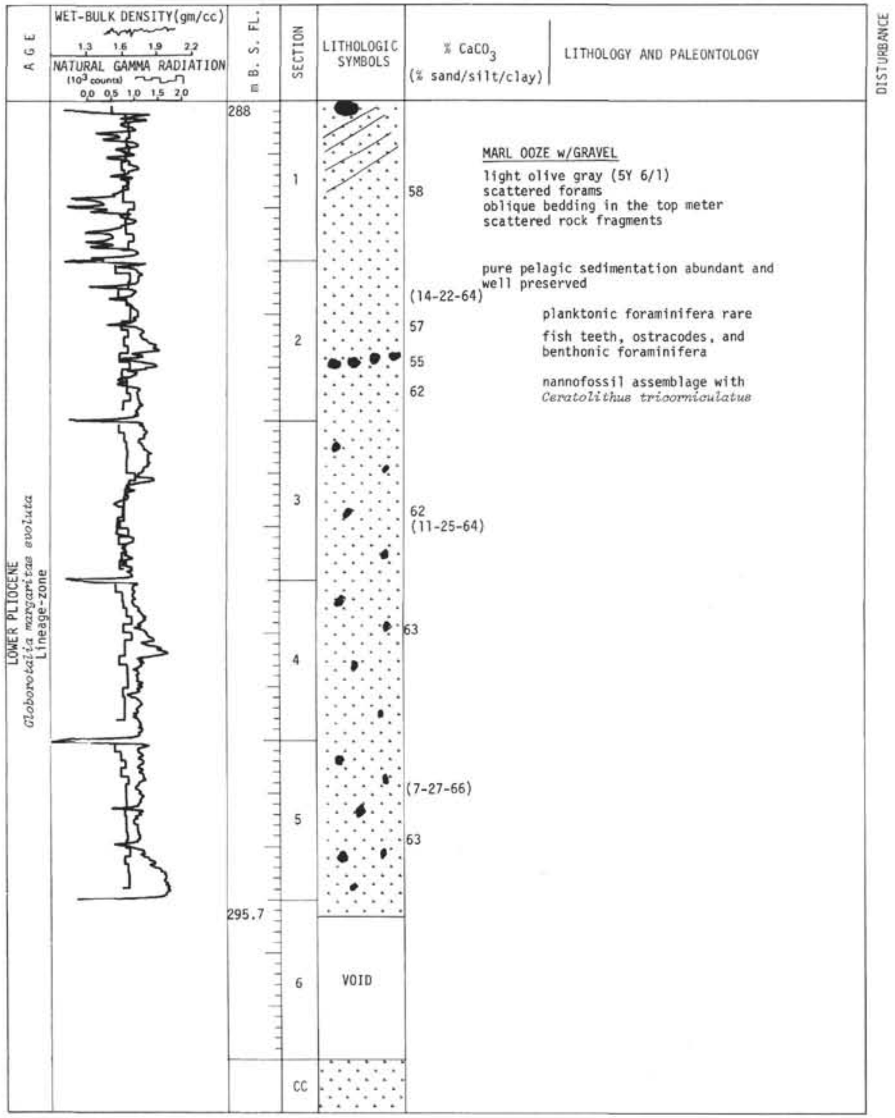
light gray (N7) to olive gray (5Y 5/1)
bedded
mottled
with beds of foraminiferal sand with sharp bottom and top contacts (contour current action)

Smear	
nannos	35
forams	25
quartz	15
mica	20
pyrite	5

pelagic sedimentation in the marl ooze, with rare ostracodes, some organic matter

nannofossils of the *Reticulofenestra pseudoumbilica* zone

SITE 134 CORE 6 Cored Interval 288-296 m



MARL OOZE w/GRAVEL

light olive gray (5Y 6/1)
scattered forams
oblique bedding in the top meter
scattered rock fragments

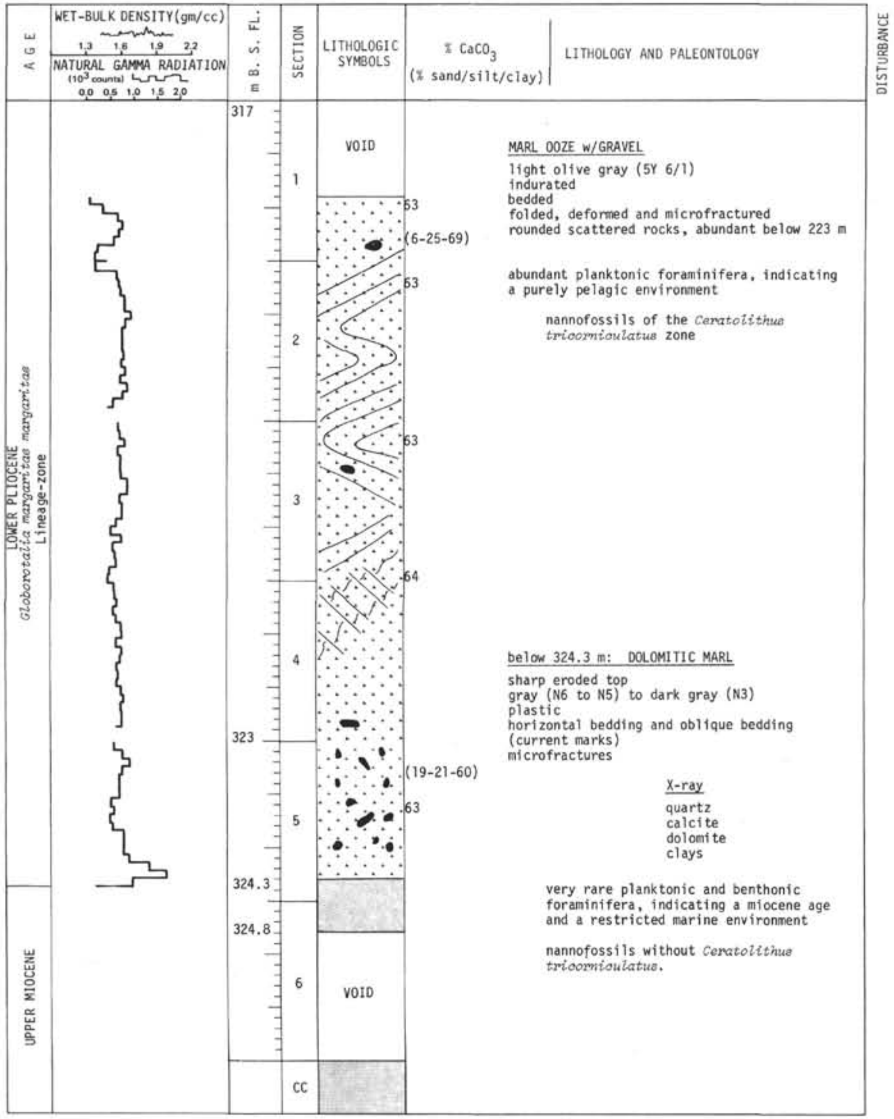
pure pelagic sedimentation abundant and well preserved

planktonic foraminifera rare

fish teeth, ostracodes, and benthonic foraminifera

nannofossil assemblage with *Ceratolithus tricorniculatus*

SITE 134 CORE 7 Cored Interval 317-326 m



MARL OOZE w/GRAVEL

light olive gray (5Y 6/1)
indurated
bedded
folded, deformed and microfractured
rounded scattered rocks, abundant below 223 m

abundant planktonic foraminifera, indicating a purely pelagic environment

nannofossils of the *Ceratolithus tricorniculatus* zone

below 324.3 m: DOLOMITIC MARL

sharp eroded top
gray (N6 to N5) to dark gray (N3)
plastic
horizontal bedding and oblique bedding (current marks)
microfractures

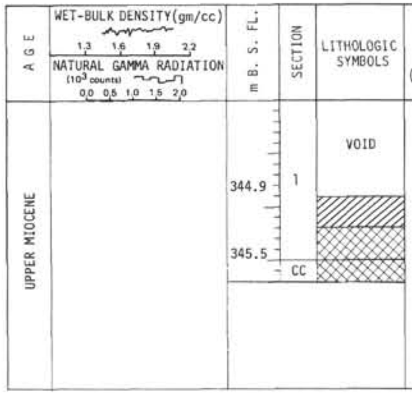
X-ray

quartz
calcite
dolomite
clays

very rare planktonic and benthonic foraminifera, indicating a miocene age and a restricted marine environment

nannofossils without *Ceratolithus tricorniculatus*.

SITE 134 CORE 8 Cored Interval 344-349 m



% $CaCO_3$ (% sand/silt/clay) | LITHOLOGY AND PALEONTOLOGY | DISTURBANCE

ANHYDRITE

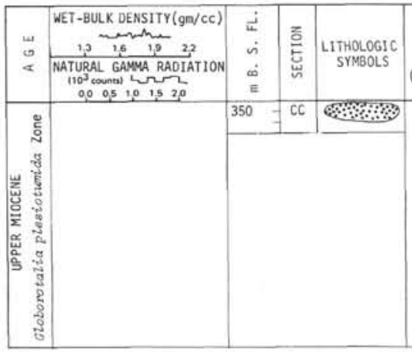
fine grained rock
light gray (N5)
millimetric bedding of alternating dark and light colored laminae with an interbedded horizon of nodular texture

overlying HALITE

transparent
faint bedding
thin, centimetric, beds of anhydrite, interbedded at 10 cm intervals

Barren

SITE 134 CORE 9 Cored Interval 350-359 m



% $CaCO_3$ (% sand/silt/clay) | LITHOLOGY AND PALEONTOLOGY | DISTURBANCE

foraminiferal SANDSTONE

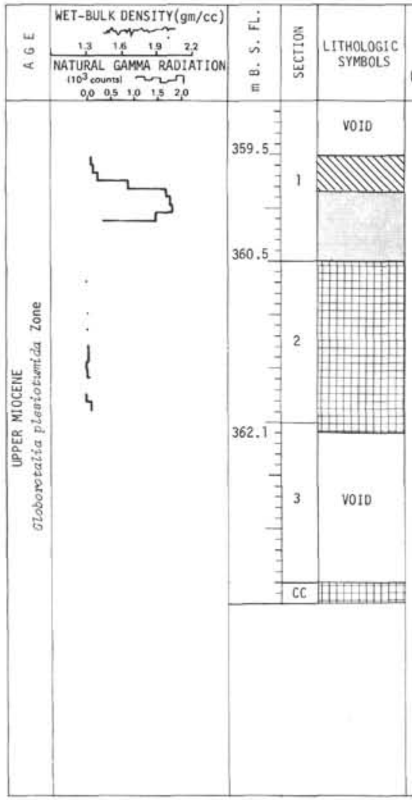
components: forams (dominant), quartz, rock fragments, glauconite, etc.

planktonic foraminifera fairly abundant and not dwarfed, also including keeled globorotalias

nannofossils without *Ceratolithus tricorniculatus*

some discoasters appear overcalcified

SITE 134 CORE 10 Cored Interval 359-364 m



% $CaCO_3$ (% sand/silt/clay) | LITHOLOGY AND PALEONTOLOGY | DISTURBANCE

interbedded:

ANHYDRITE

fine grained rock
light gray (N5)
millimetric bedding of lighter and darker laminae

DOLOMITIC OOZE

black (N#0)
plastic
bedded
gasoline odor (laboratory analysis show migrated hydrocarbons)

X-rays

quartz
dolomite
clays
anhydrite
halite

HALITE

transparent
faint bedding
thin (1 to 5 cm) regularly interbedded layers of anhydrite

planktonic foraminifera are present in the hydrocarbon-bearing layer;

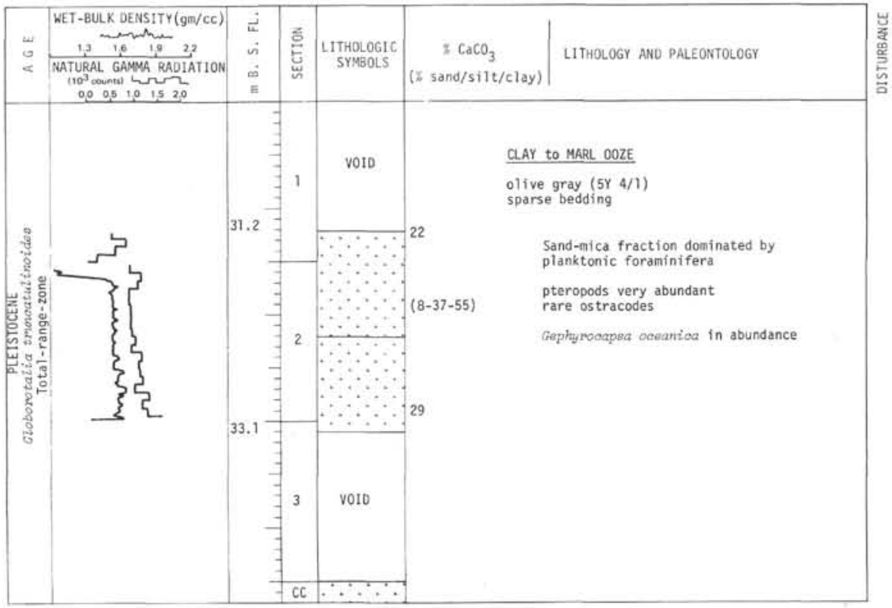
benthonic foraminifera including *Bolivina antiqua* and *Bolivinoides miocenicus*

siliceous microfossils including radiolaria, selicoflagellates, diatoms, and sponge spicules

calcareous nannofossils scanty

Total Drilling: 364 m in halite.

SITE 134A CORE 1 Cored Interval 30-39 m



CLAY to MARL OOZE

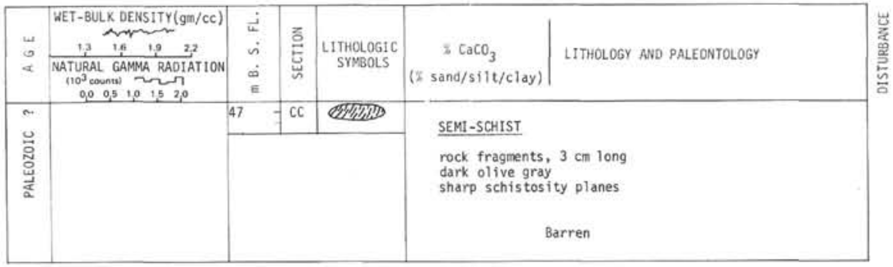
olive gray (5Y 4/1)
sparse bedding

Sand-mica fraction dominated by planktonic foraminifera

pteropods very abundant
rare ostracodes

Gephyrocapsa oceanica in abundance

SITE 134A CORE 2 Cored Interval 47-49 m

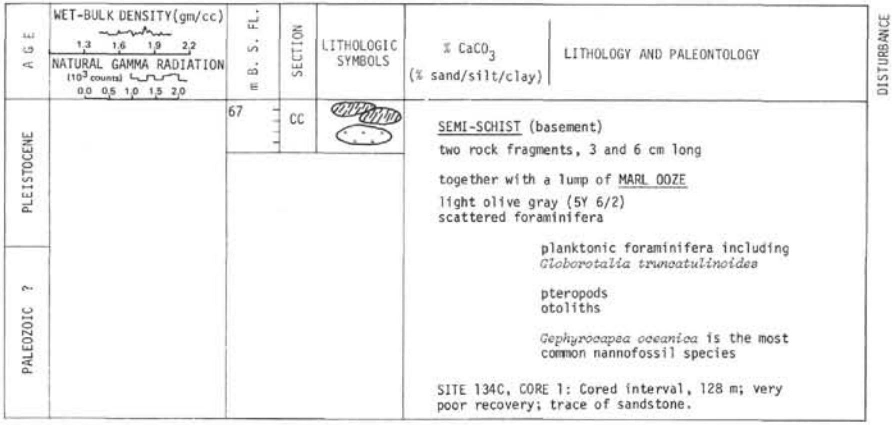


SEMI-SCHIST

rock fragments, 3 cm long
dark olive gray
sharp schistosity planes

Barren

SITE 134B CORE 1 Cored Interval 67-72 m



SEMI-SCHIST (basement)

two rock fragments, 3 and 6 cm long

together with a lump of MARL OOZE

light olive gray (5Y 6/2)
scattered foraminifera

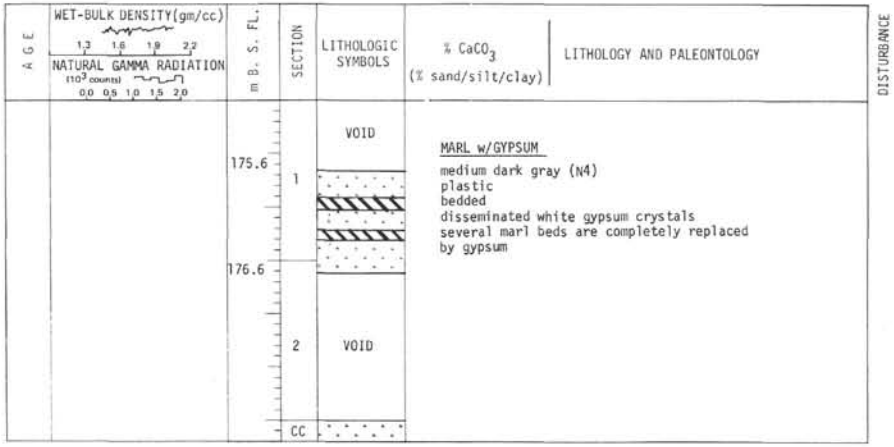
planktonic foraminifera including *Globorotalia truncatulinoides*

pteropods
otoliths

Gephyrocapsa oceanica is the most common nannofossil species

SITE 134C, CORE 1: Cored interval, 128 m; very poor recovery; trace of sandstone.

SITE 134D CORE 1 Cored Interval 175-183 m



MARL w/GYPSUM

medium dark gray (N4)
plastic
bedded
disseminated white gypsum crystals
several marl beds are completely replaced by gypsum

SITE 134D CORE 2 Cored Interval 207-211 m

AGE	WET-BULK DENSITY(gm/cc) 1.3 1.6 1.9 2.2 NATURAL GAMMA RADIATION (10^3 counts) 0.0 0.5 1.0 1.5 2.0	m B. S. FL.	SECTION	LITHOLOGIC SYMBOLS	% $CaCO_3$ (% sand/silt/clay)	LITHOLOGY AND PALEONTOLOGY	DISTURBANCE
		207	CC			SEMI-SCHIST (basement) three rock fragments gray to black	

SITE 134D CORE 3 Cored Interval 211-214 m

AGE	WET-BULK DENSITY(gm/cc) 1.3 1.6 1.9 2.2 NATURAL GAMMA RADIATION (10^3 counts) 0.0 0.5 1.0 1.5 2.0	m B. S. FL.	SECTION	LITHOLOGIC SYMBOLS	% $CaCO_3$ (% sand/silt/clay)	LITHOLOGY AND PALEONTOLOGY	DISTURBANCE
		211	CC			SEMI-SCHIST (basement) rock fragments dark gray (5Y 4/1)	

SITE 134E CORE 1 Cored Interval 203-213 m

AGE	WET-BULK DENSITY(gm/cc) 1.3 1.6 1.9 2.2 NATURAL GAMMA RADIATION (10^3 counts) 0.0 0.5 1.0 1.5 2.0	m B. S. FL.	SECTION	LITHOLOGIC SYMBOLS	% $CaCO_3$ (% sand/silt/clay)	LITHOLOGY AND PALEONTOLOGY	DISTURBANCE
PALEOZOIC ?		203	CC			SEMI-SCHIST (basement) a single rock fragment very dark gray (5Y 3/1) SITE 134E, CORE 2: Cored interval, 216-220 m; no recovery.	

SITE 134E CORE 3 Cored Interval 220-222 m

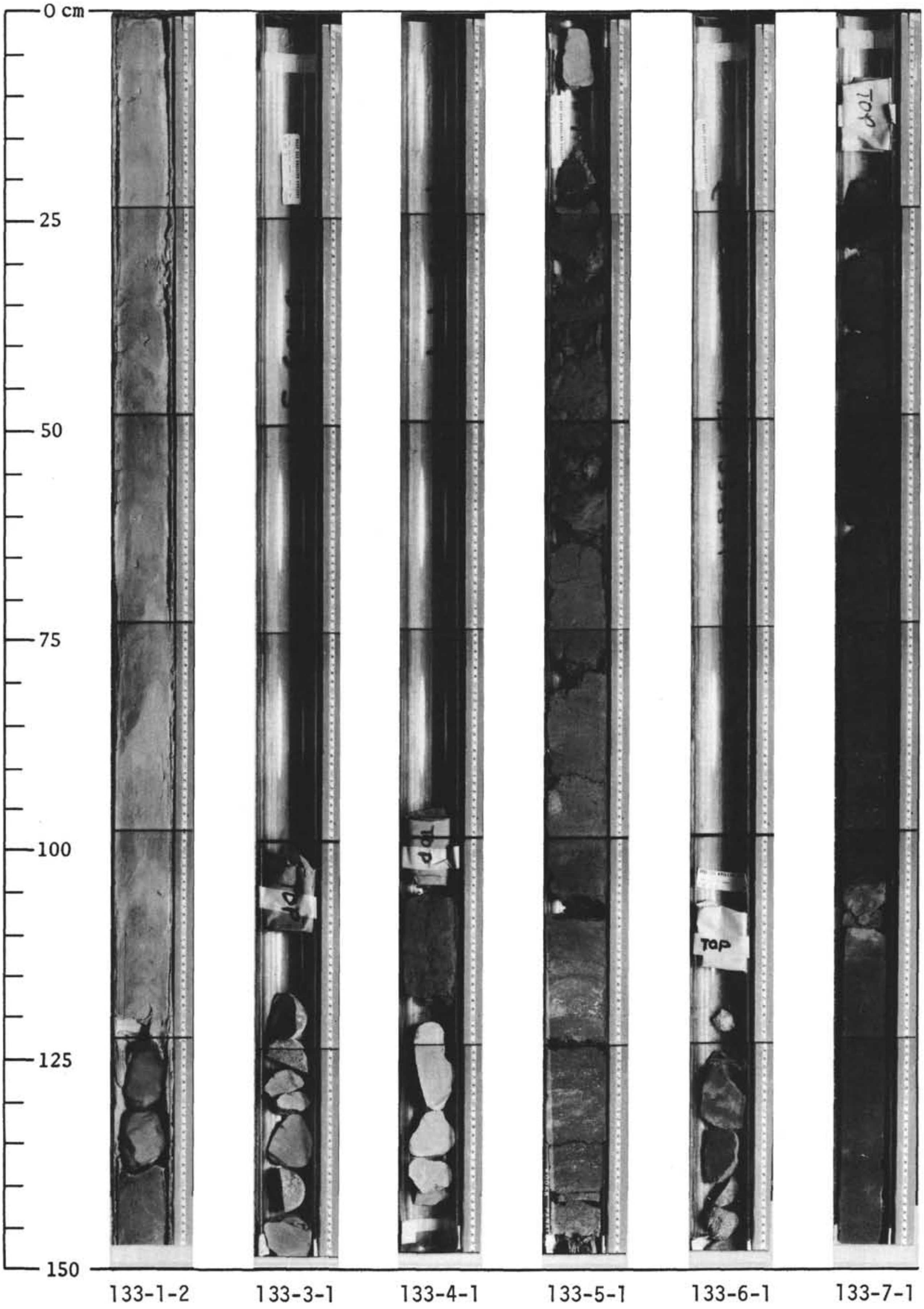
AGE	WET-BULK DENSITY(gm/cc) 1.3 1.6 1.9 2.2 NATURAL GAMMA RADIATION (10^3 counts) 0.0 0.5 1.0 1.5 2.0	m B. S. FL.	SECTION	LITHOLOGIC SYMBOLS	% $CaCO_3$ (% sand/silt/clay)	LITHOLOGY AND PALEONTOLOGY	DISTURBANCE
PALEOZOIC ?		220	CC			SEMI-SCHIST (basement) two rock fragments medium light gray	

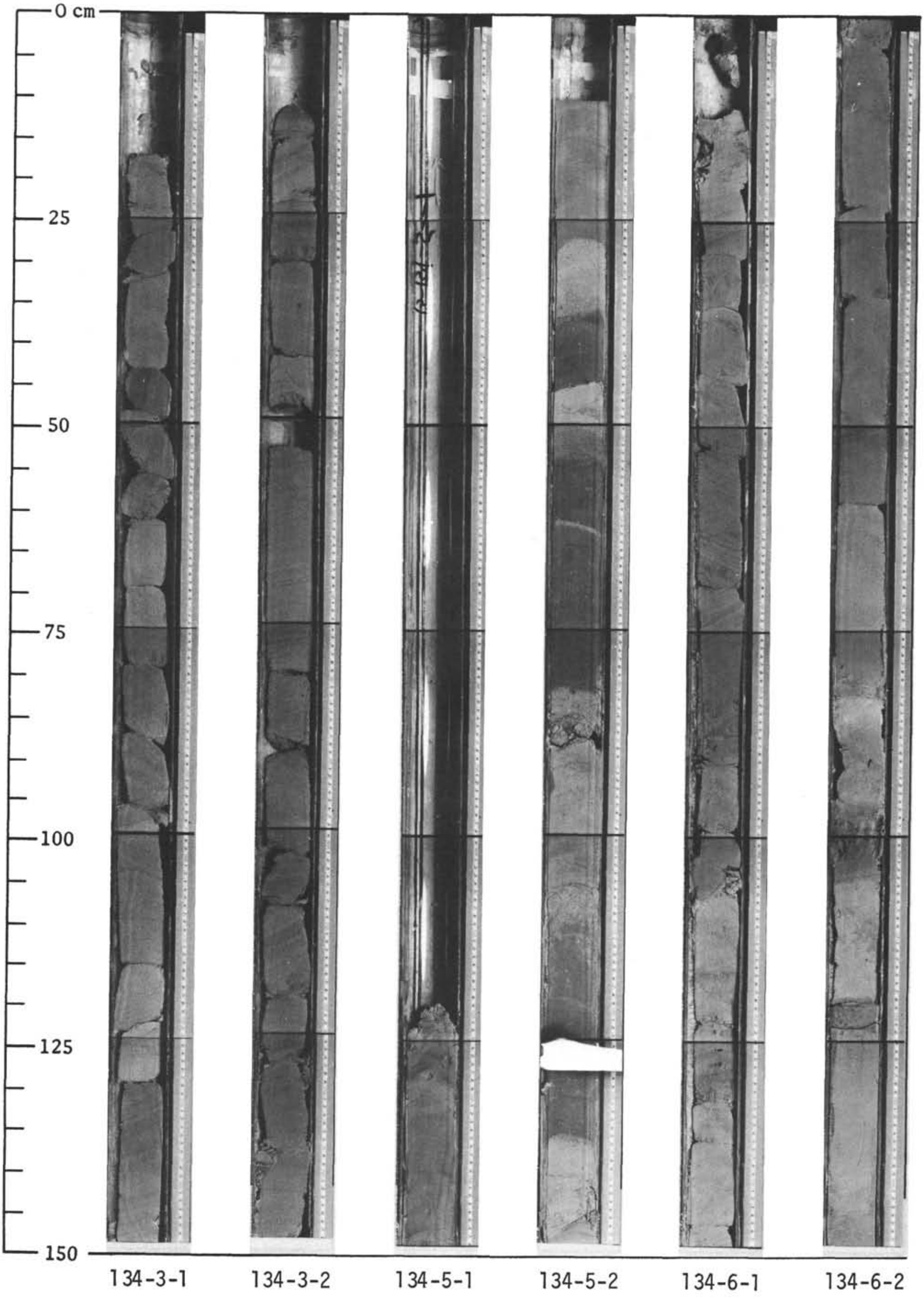
SITE 134E CORE SWC1 Cored Interval 199 m

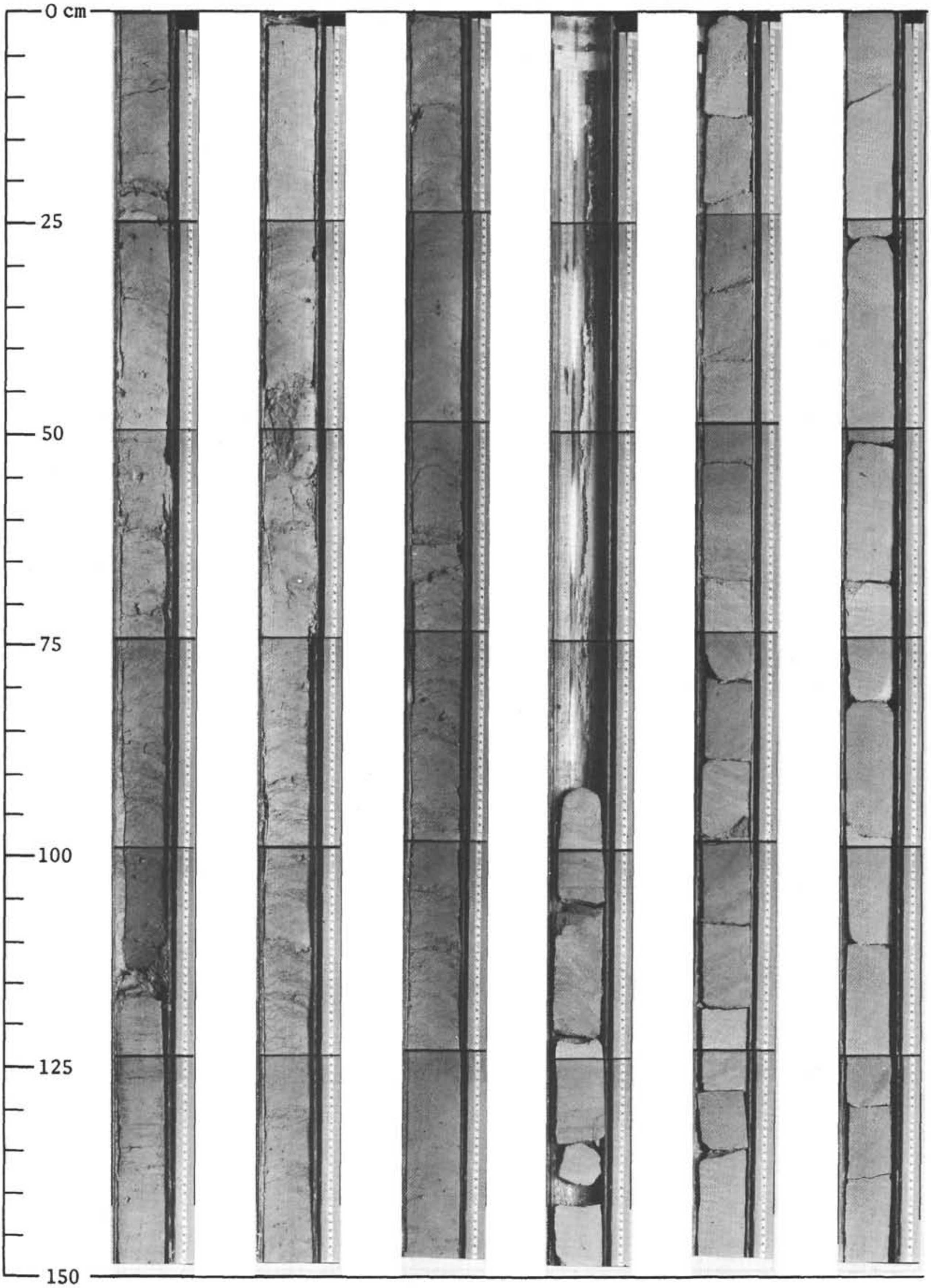
AGE	WET-BULK DENSITY(gm/cc) 1.3 1.6 1.9 2.2 NATURAL GAMMA RADIATION (10^3 counts) 0.0 0.5 1.0 1.5 2.0	m B. S. FL.	SECTION	LITHOLOGIC SYMBOLS	% $CaCO_3$ (% sand/silt/clay)	LITHOLOGY AND PALEONTOLOGY	DISTURBANCE
PLEIST.		199				MARL OOZE w/PEBBLE light olive gray (5Y 6/1) bedded and deformed patches of foraminaferal sand overlain by a rolled pebble	
UPPER PLIOCENE							

SITE 134E CORE SWC2 Cored Interval 109 m

AGE	WET-BULK DENSITY(gm/cc) 1.3 1.6 1.9 2.2 NATURAL GAMMA RADIATION (10^3 counts) 0.0 0.5 1.0 1.5 2.0	m B. S. FL.	SECTION	LITHOLOGIC SYMBOLS	% $CaCO_3$ (% sand/silt/clay)	LITHOLOGY AND PALEONTOLOGY	DISTURBANCE
PLEISTOCENE		109				MARL OOZE olive gray (5Y 5/2) to dark gray (10YR 4/1) plastic bedded semi-schist gravel embedded at 20 cm and rock fragments at the base planktonic foraminiferal fauna dominated by *Globorotalia inflata* Pteropods *Gephyrocapsa oceanica* and *Pseudoemiliania lacunosa*	


0 cm
25
50
75
100
125
150
TOP
TOP
TOP
TOP
133-1-2
133-3-1
133-4-1
133-5-1
133-6-1
133-7-1


0 cm
25
50
75
100
125
150
134-3-1
134-3-2
134-5-1
134-5-2
134-6-1
134-6-2


0 cm
25
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75
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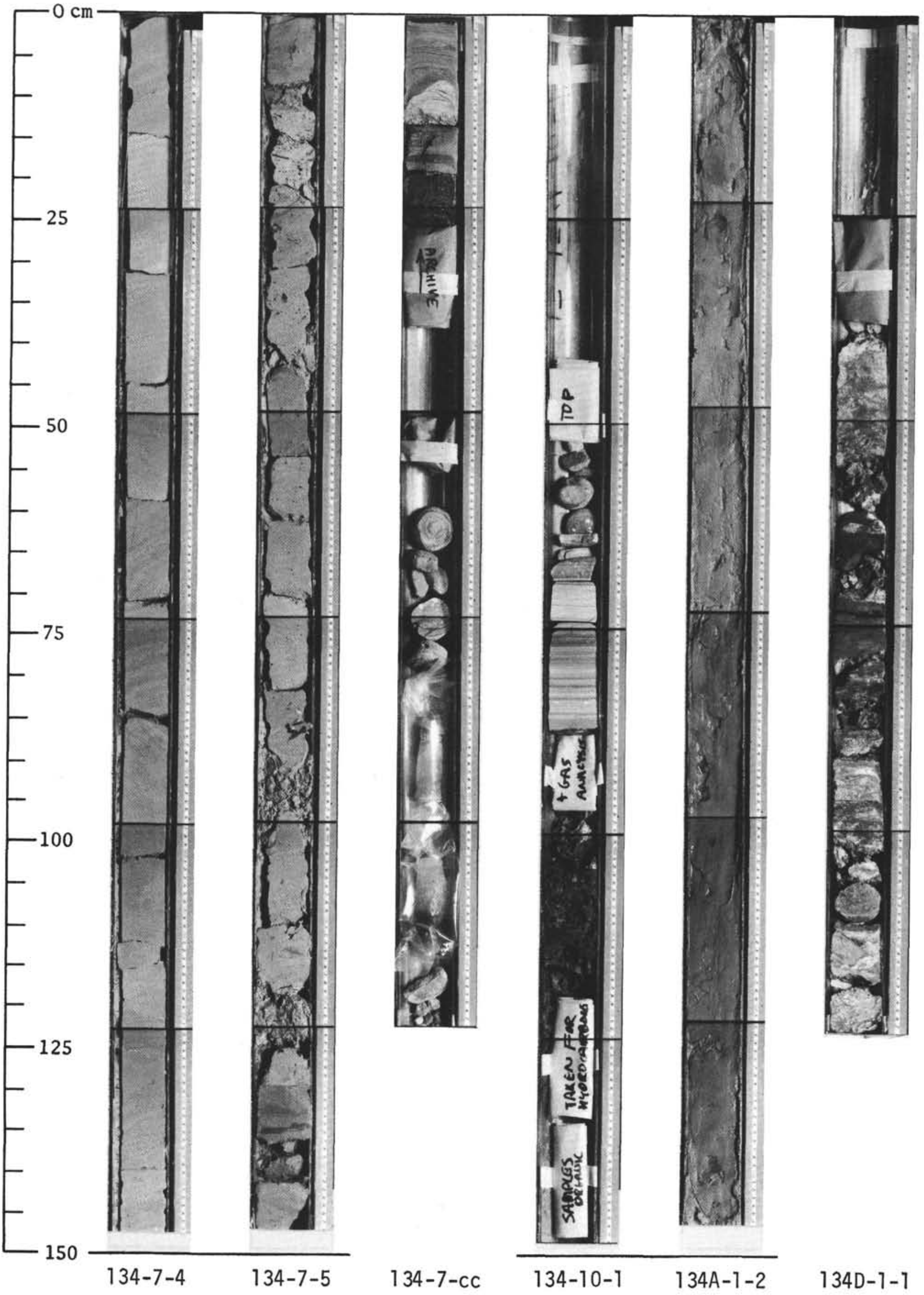
150
134-6-3
134-6-4
134-6-5
134-7-1
134-7-2
134-7-3


0 cm
25
50
75
100
125
150
ARCHIVE
TOP
+ GAS ANALYSIS
TAKEN FOR HYDROCARBONS
SAMPLES ORGANIC
134-7-4
134-7-5
134-7-cc
134-10-1
134A-1-2
134D-1-1