# 2. SITE 2[1]

The Shipboard Scientific Party[2]

## SITE REPORT

### Setting and Purpose

The Sigsbee Basin of the Gulf of Mexico lies between the Sigsbee Scarp to the north, about 200 miles off the Texas-Louisiana coast, and the Campeche Scarp to the south, about 150 miles off the Yucatan Peninsula, and between the West Florida Escarpment to the east, about 120 miles west of the Florida coast, and the Mexican coast to the west. The Sigsbee Basin includes the Mississippi Cone, to the east, and the Sigsbee Abyssal Plain to the west and south. The Sigsbee Abyssal Plain is interrupted only by the Sigsbee Knolls, the first three of which were discovered by M. Ewing in 1954 (Ewing, Ericson, and Heezen, 1958).

In 1961, with the introduction of seismic profiling in deep water, the Sigsbee Knolls were shown to be three diapiric structures of a group of 21; these three being the only ones of the group having a surface expression (Ewing, Worzel, and Ewing, 1962). At this time, it was concluded that these were probably salt domes because:

1. They were sub-circular in plan.
2. They were clearly intrusive.
3. They were 6 to 11 kilometers in diameter.
4. The reflecting horizons were unwarped along the flanks.
5. In many cases, there were rim synclines.
6. Gravity and magnetic data ruled out the possibility of igneous intrusion.
7. Gas at these depths would have inadequate volume to supply the effects of buoyancy or lubrication important in mud or shale domes.

It was also suggested that petroleum accumulations were likely to be associated with these structures. These data were fully substantiated and the number of knolls (those with surface expression) and domes (those without surface expression) was increased to 44, as reported by Ewing and Antoine (1966) and Talwani and Ewing (1966). This work also indicated a trend to the southwest and south of the original structures.

Bryant and Pyle (1965) took a sediment core on top of one of the knolls which contained Tertiary fossils. They attributed this discovery to the slumping of sediments off the knoll, uncovering older deposits.

Along the Mexican continental slope, long linear fold-type features were reported by Bryant, Antoine, Ewing, and Jones (1968). These could be attributed alternatively to: gravity sliding on a decollement surface; folding associated with compressional tectonic stresses; vertical movements of shale or salt masses related to static loading; or folding related to faulting. The authors gave the third alternative as their preference because of the apparent continuity with the Texas-Louisiana continental slope, and the salt features in the surrounding areas.

In the early part of 1967, *Vema* Cruise 24, outlined the zone in which knolls and domes were found and demonstrated that the zone joined the known salt dome fields of Tabasco-Campeche. Figure 1 shows the zone outlined (after Worzel, Leyden, and Ewing, 1968). The dome outlined in the circle was chosen as the one on which the drilling operation was to take place; because it had a surface expression, it was located by means of satellite navigation. The sediment cover was thin enough that no dangerous excess pressure was expected, and it was near to the route of *Glomar Challenger.* The profiler record made on *Vema* Cruise 24 is shown in Figure 2. It may be noted, particularly in the traverse of the two large domes that appear near the edges of the figure, that turbidite sediments abut a semi-transparent sheath that may well be cap rock. Challenger Knoll, so named after the successful drilling operation, is the one about a third of the way from the left hand margin of the figure. This record was made on a track from the southwest to the northeast which apparently passed over the northwestern flank of the dome that was to become Challenger Knoll.

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[1] Lamont-Doherty Geological Observatory of Columbia University contribution No. 1364.

[2] M. Ewing and J. L. Worzel, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York; A. O. Beall, Continental Oil Company, Ponca City, Oklahoma; W. A. Berggren, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts; D. Bukry, U. S. Geological Survey, La Jolla, California; C. A. Burk, Mobil Oil Company, Princeton, New Jersey; A. G. Fischer, Princeton University, Princeton, New Jersey; and, E. A. Pessagno, Jr., Southwest Center for Advanced Studies, Dallas, Texas.

Further work substantiating this zone of domes was reported by Uchupi and Emery (1968) and at the Mexico City meeting of the Geological Society of America (Ballard and Feden, 1968).

Nevertheless, there was still much doubt in the minds of a number of geologists and geophysicists, and, as is so frequently the case, drilling and direct examination promised the only means of final determination. So, Hole 2 was drilled at 23°27.3′N, 92°35.2′W. The depth was 3572 meters (11,720 feet) corrected for sound velocity and transponder depth. The hole was drilled to a depth of 144 meters (472 feet) subbottom.

More detailed information about the geological setting of Site 2 will be provided by the site survey conducted during *Vema* Cruise 26 in March 1969. The cores here have demonstrated beyond reasonable doubt that these diapirs are salt domes and that the phenomena found associated with Gulf Coast salt domes also occur here.

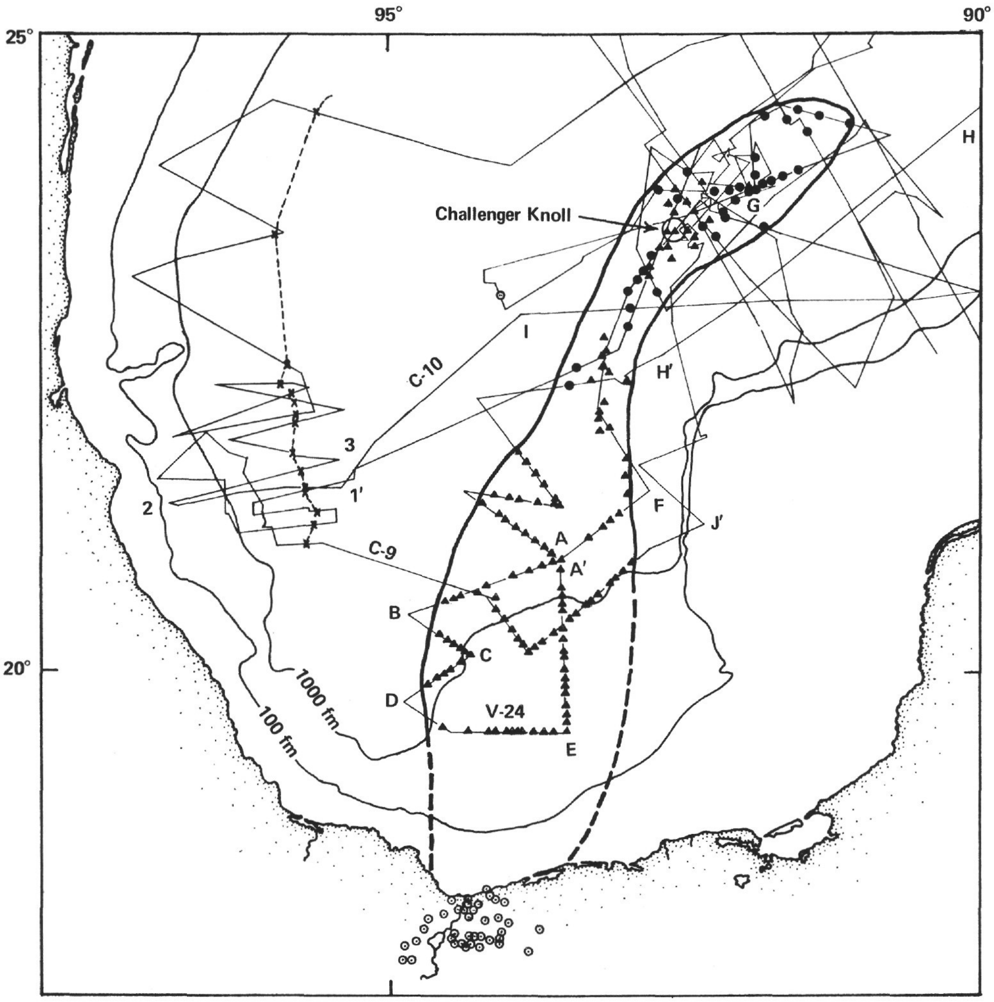


Figure 1. *Chart of the area of the Sigsbee Knolls and domes. Challenger Knoll is circled (after Worzel* et al., *1968).*

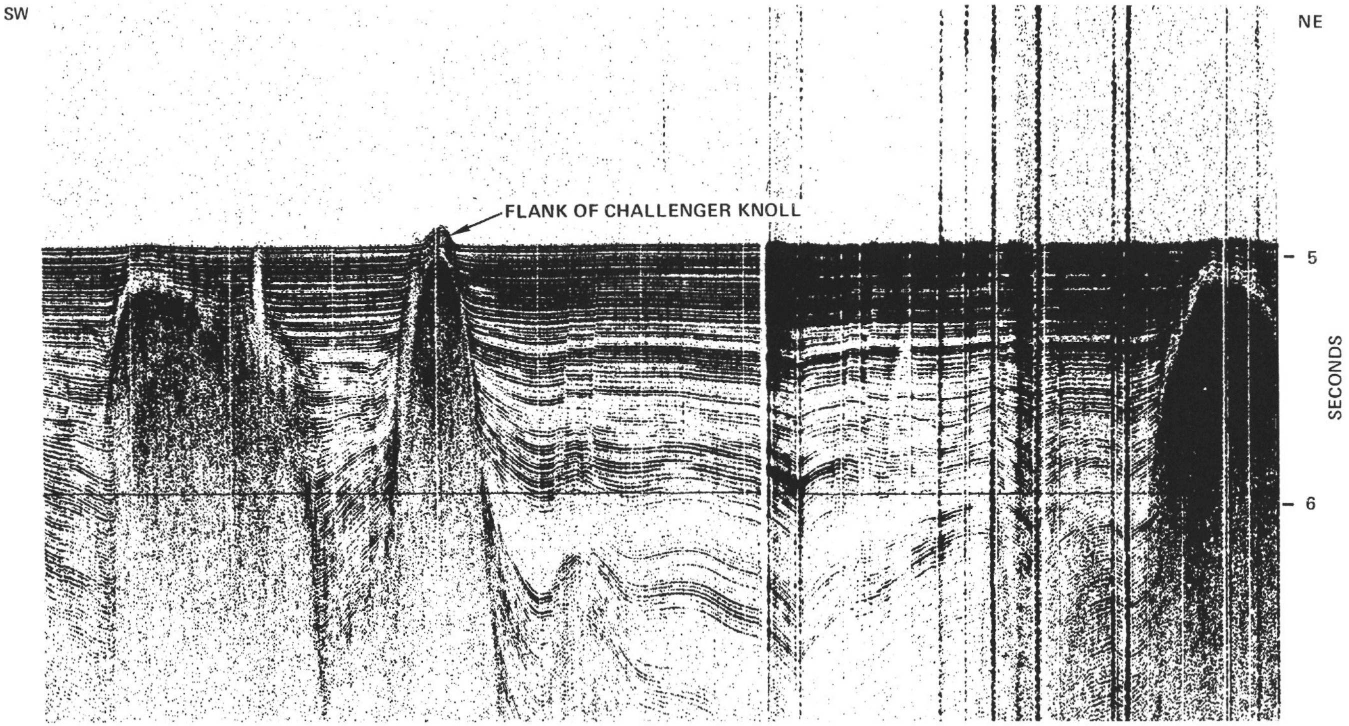


Figure 2. *Profiler traverse of Challenger Knoll area.*

## Summary of Drilling and Coring at Site 2

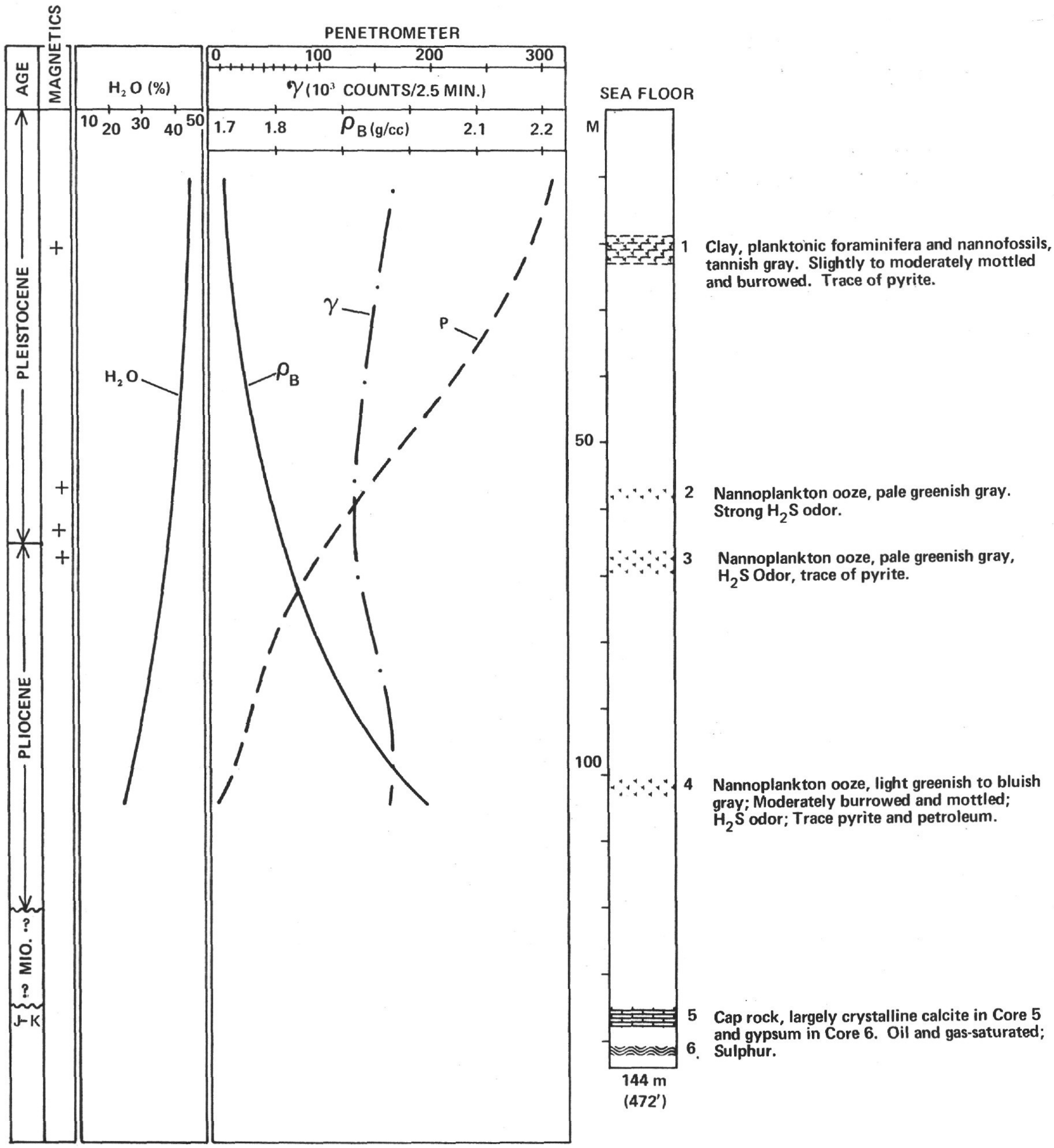


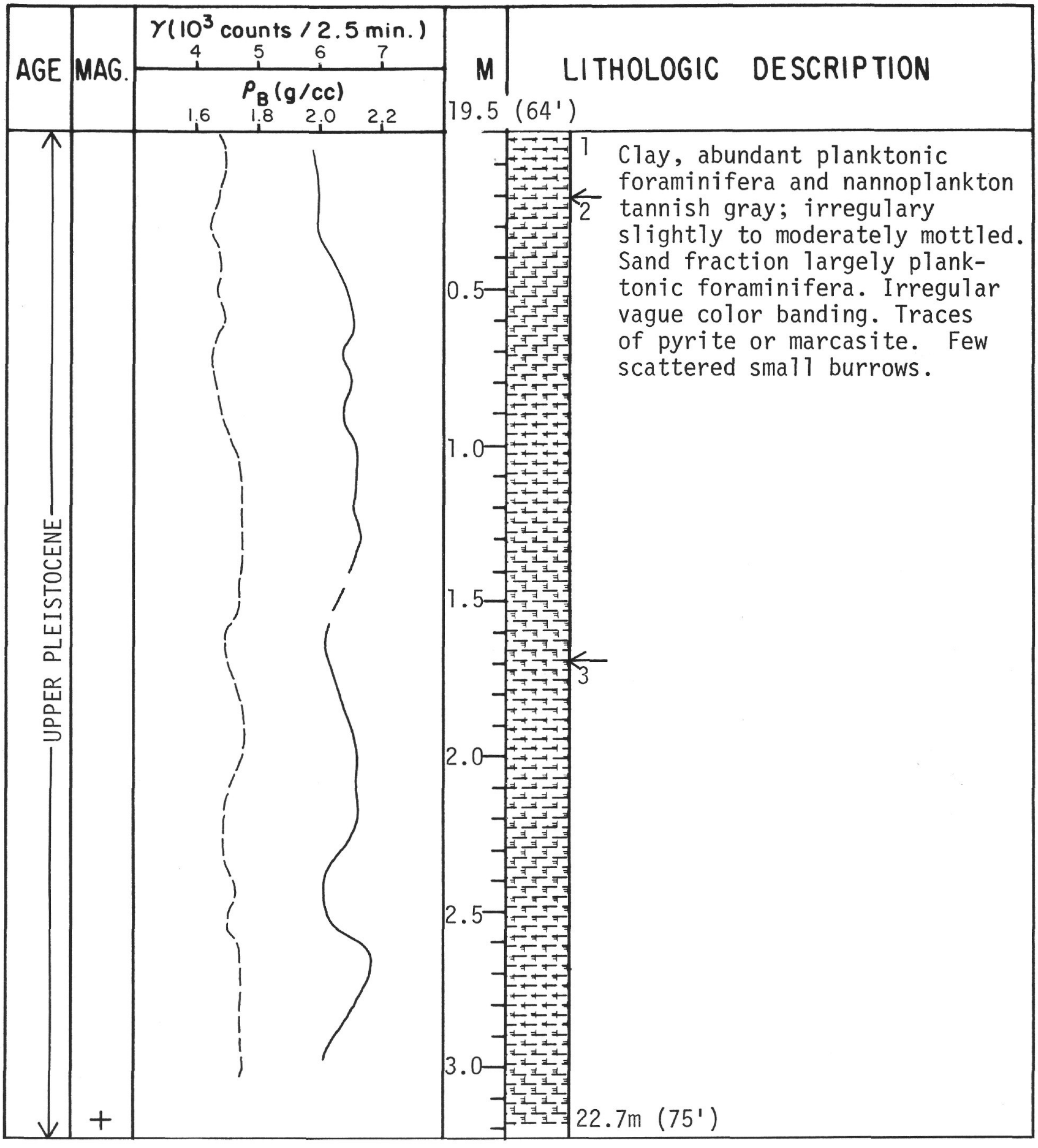
Figure 3. *Summary of drilling and coring at Site 2.*

**The Cores Recovered from Site 2**

Figures 4 through 9 are the graphic summaries of the cores recovered at Site 2.

These figures show for each core:

(1) The stratigraphic age.
(2) The paleomagnetic results—normal (+) or reversed (-).
(3) The natural gamma radiation (full line).
(4) The bulk density as determined by the GRAPE (Gamma Ray Attenuation Porosity Evaluator) equipment (broken line).
(5) The length of the core in meters measured from the top of the core and the subbottom depth of the top of the cored interval.
(6) The lithology (see key with Site 1 Report).
(7) The positions of the tops of each core section.
(8) Some notes on the lithology.



Clay, abundant planktonic foraminifera and nannoplankton tannish gray; irregulary slightly to moderately mottled. Sand fraction largely planktonic foraminifera. Irregular vague color banding. Traces of pyrite or marcasite. Few scattered small burrows.

Figure 4. *Hole 2, Core 1.*

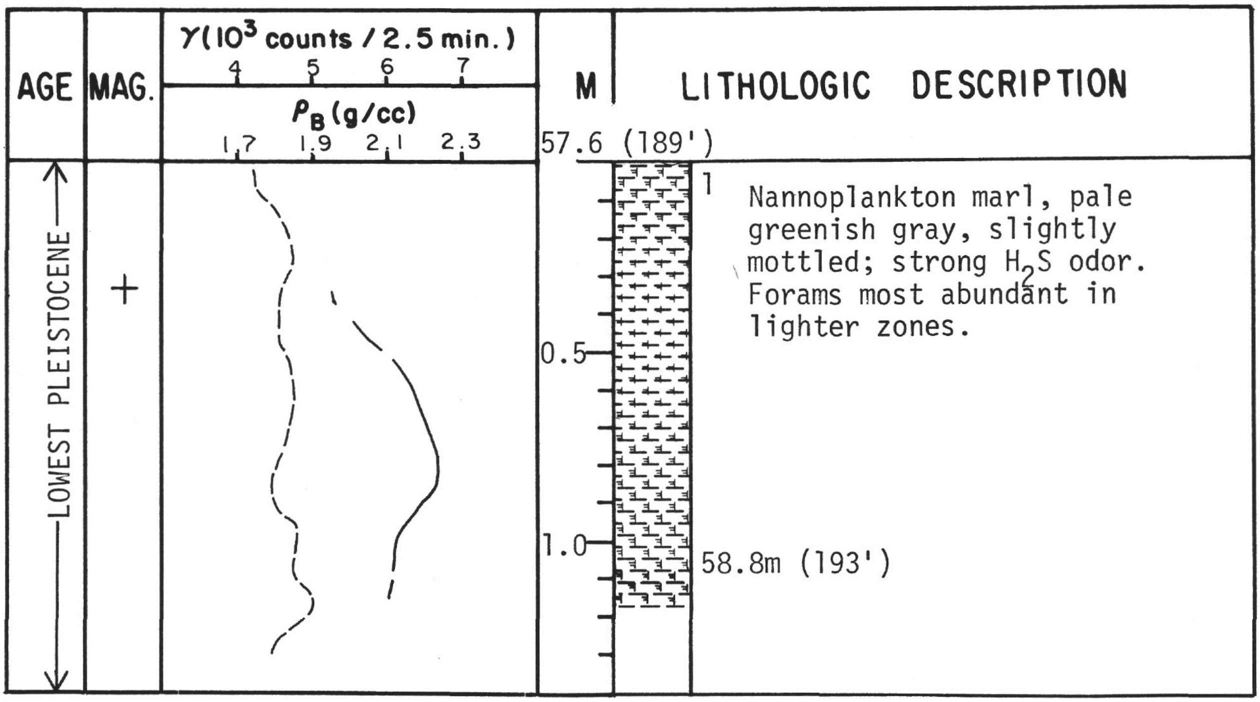
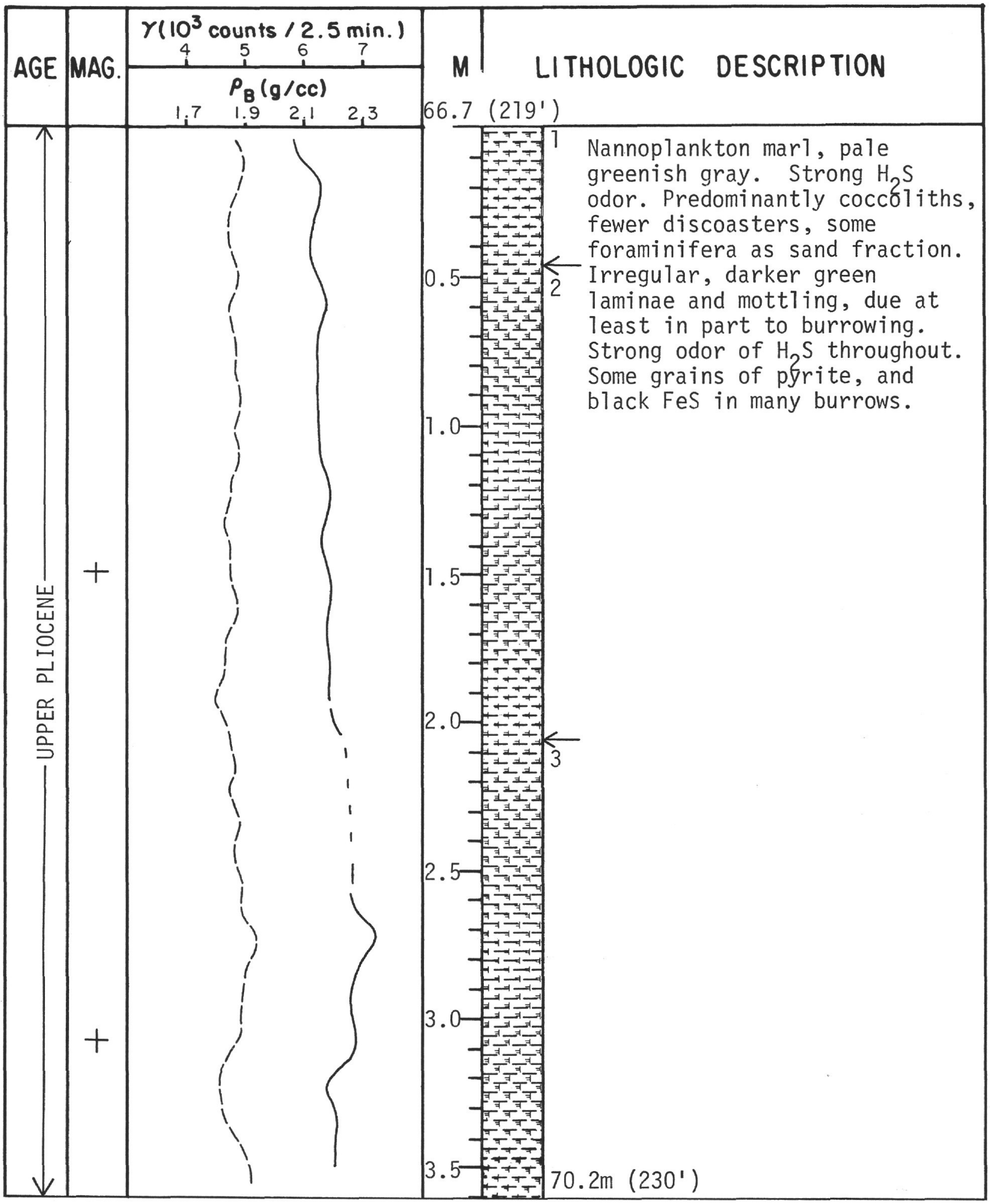
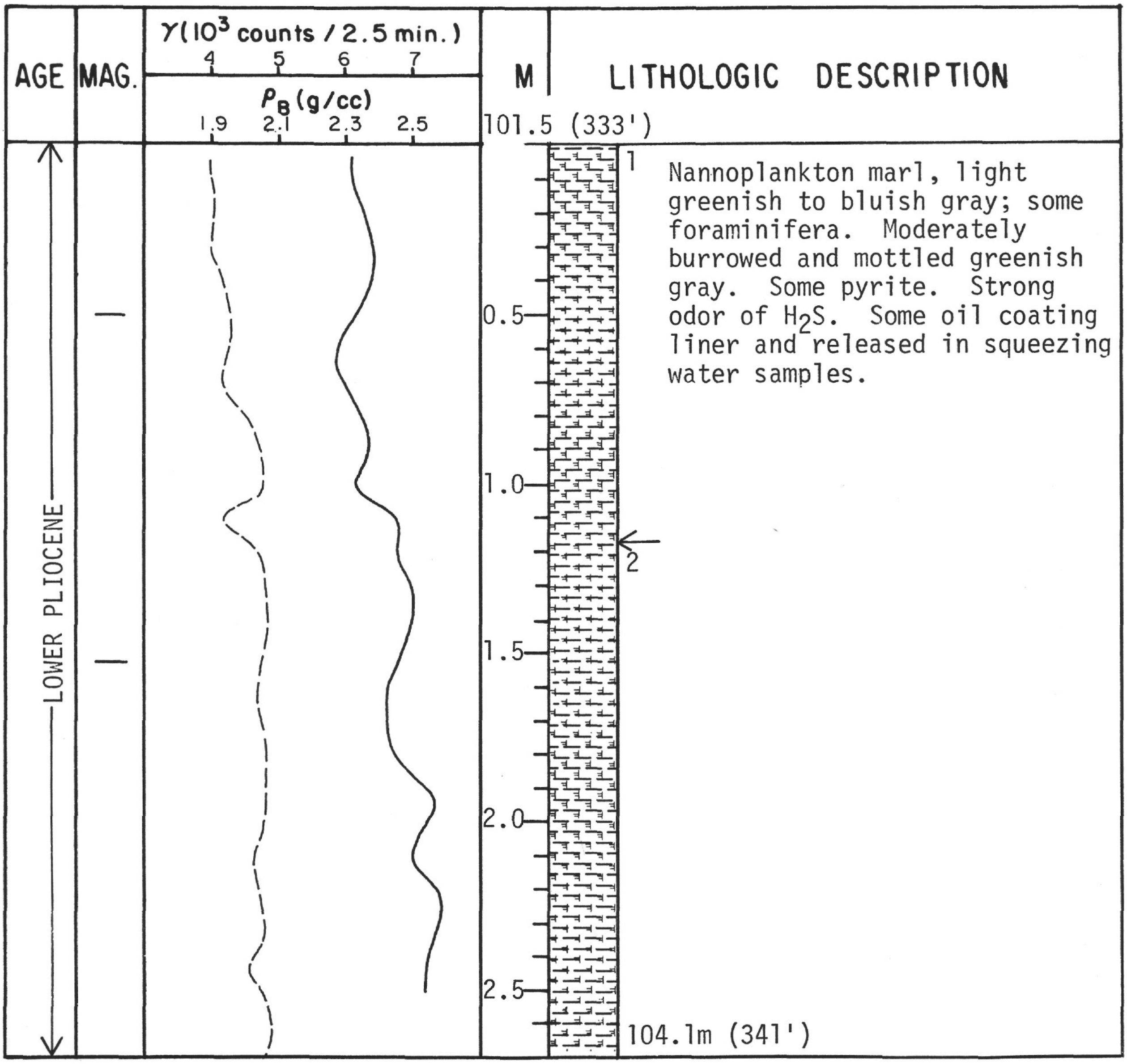


Figure 5. *Hole 2, Core 2.*



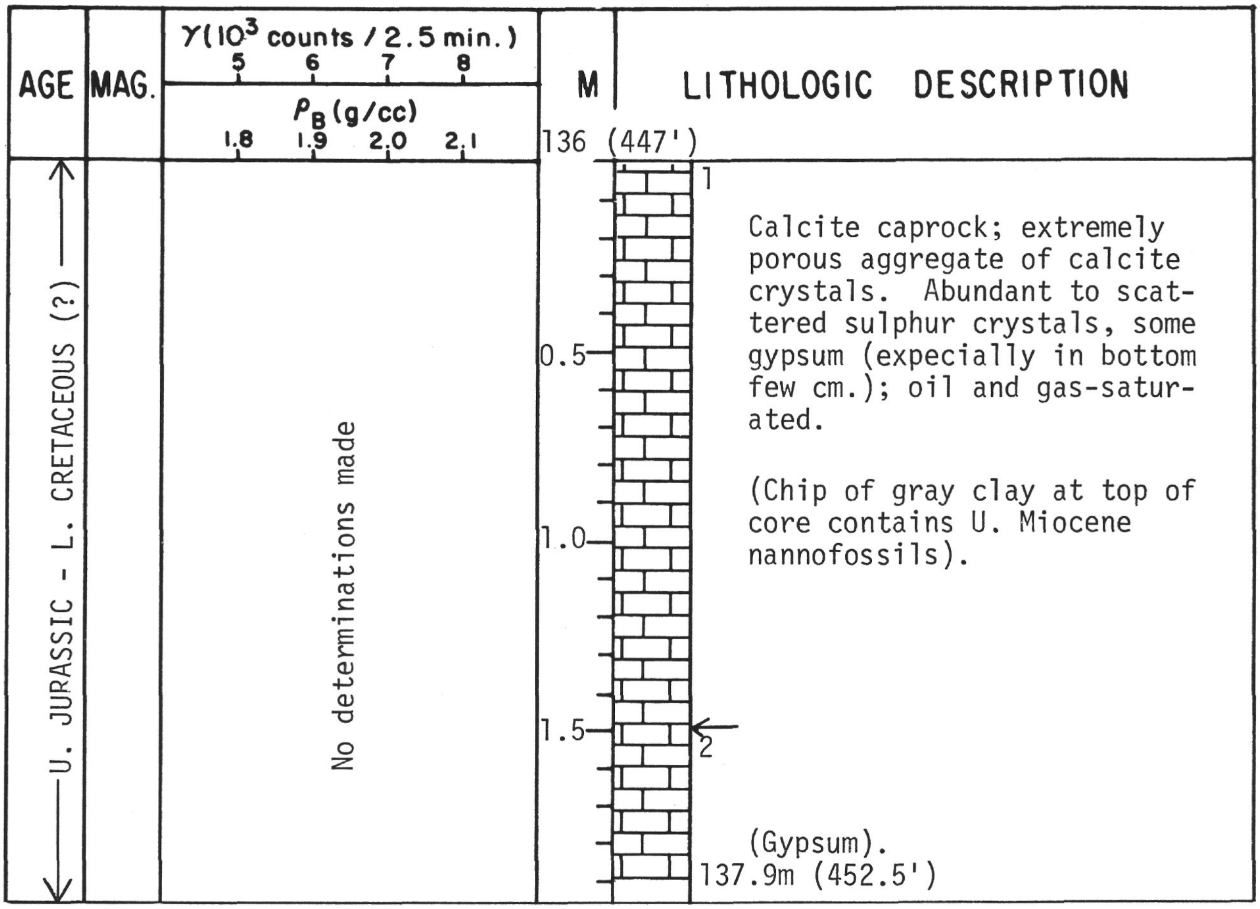
Nannoplankton marl, pale greenish gray. Strong $H_2S$ odor. Predominantly coccoliths, fewer discoasters, some foraminifera as sand fraction. Irregular, darker green laminae and mottling, due at least in part to burrowing. Strong odor of $H_2S$ throughout. Some grains of pyrite, and black FeS in many burrows.

Figure 6. *Hole 2, Core 3.*



Nannoplankton marl, light greenish to bluish gray; some foraminifera. Moderately burrowed and mottled greenish gray. Some pyrite. Strong odor of $H_2S$. Some oil coating liner and released in squeezing water samples.

Figure 7. *Hole 2, Core 4.*

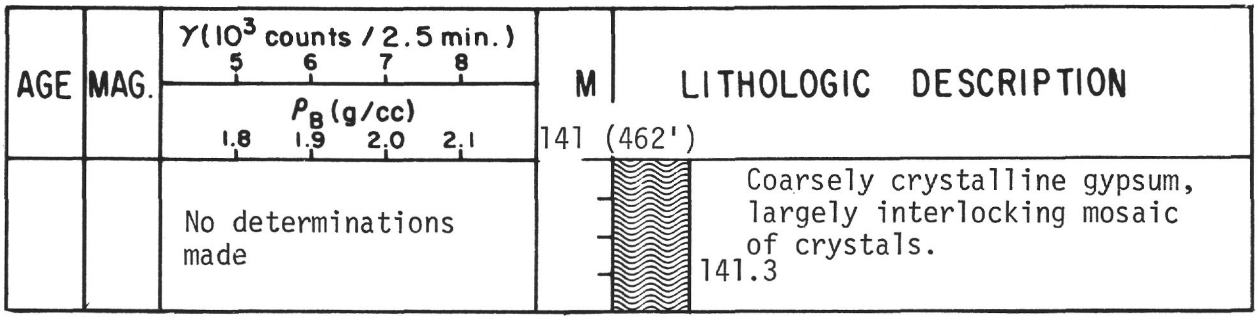


Calcite caprock; extremely porous aggregate of calcite crystals. Abundant to scattered sulphur crystals, some gypsum (expecially in bottom few cm.); oil and gas-saturated.

(Chip of gray clay at top of core contains U. Miocene nannofossils).

(Gypsum).

Figure 8. *Hole 2, Core 5.*



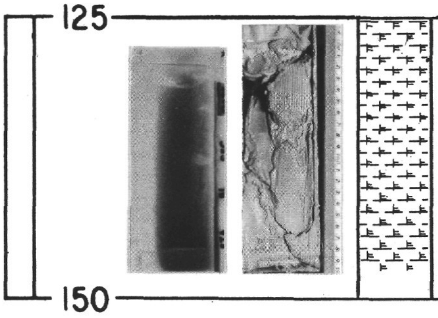
Coarsely crystalline gypsum, largely interlocking mosaic of crystals.

Figure 9. *Hole 2, Core 6.*

Figures 10 through 21 show details of the individual core sections of the cores from Site 2.

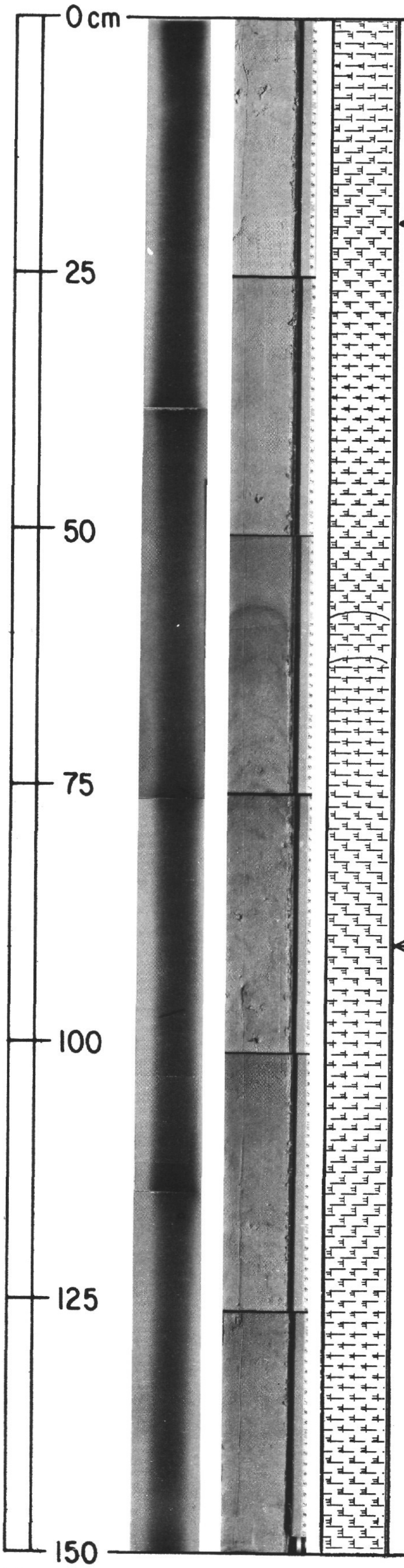
Each figure shows:

1. A scale of centimeters from the top of each section.
2. An X radiograph of the core section.
3. A photograph of the core section.
4. The lithology (see key with Site 1 report).
5. The positions of smear slides (x).
6. Notes on the lithology, carbon content, expressed as a percentage of total sediment (see Chapter 11), the water content (see Chapter 10) and the grain size (see Chapter 9). Colors are given with reference to the GSA Rock Color Chart.



Clay with abundant planktonic foraminifera and nannoplankton; tannish-gray (2.5Y 6/2), disturbed in coring.

Figure 10. *Hole 2, Core 1, Section 1.*



Total C 4.5; Org. C 0.2; $CaCO_3$ 35.7.
Water content 39.1.

Sand 9.5; silt 14.0; clay 76.5.

←X Forams > nannoplankton.
Clay, very rich in planktonic foraminifera (entire sand fraction) and abundant nannoplankton; pteropods rare. Tannish-gray (2.5Y 6/2), slightly to moderately mottled.

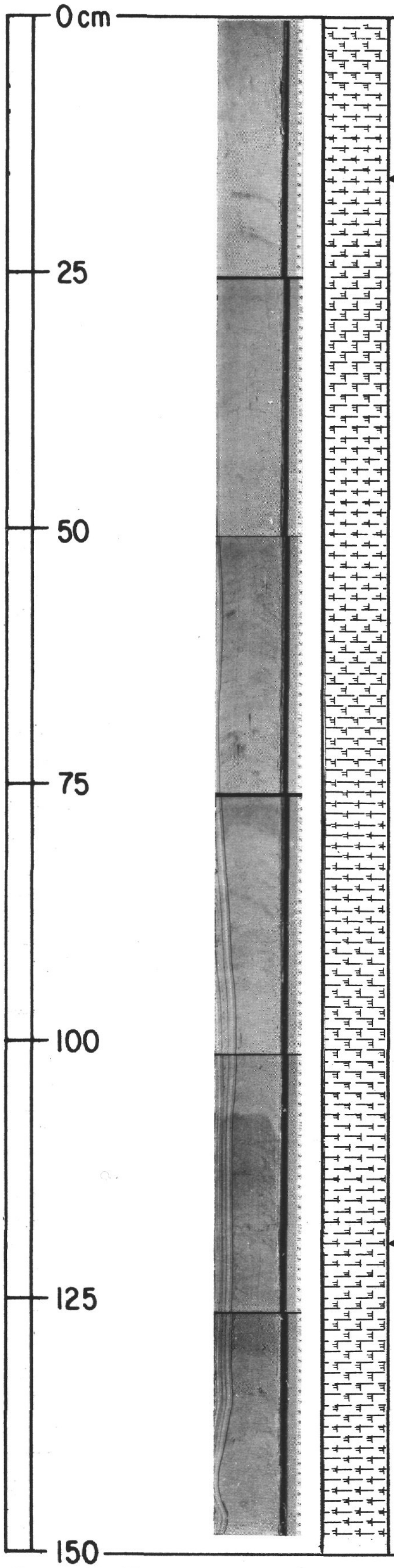
Band of (2.5Y 5/2) and (2.5Y 4/0).

Pale yellowish-brown (10YR 6/2).

←X Forams > nannoplankton.

Concretions of pyrite or marcasite, slender, rod-like: burrow fills?

Figure 11. *Hole 2, Core 1, Section 2.*



Total C 5.2; Org. C 0.2; $CaCO_3$ 41.4.
Water content 49.2.
Sand 6.1; silt 14.3; clay 79.6.

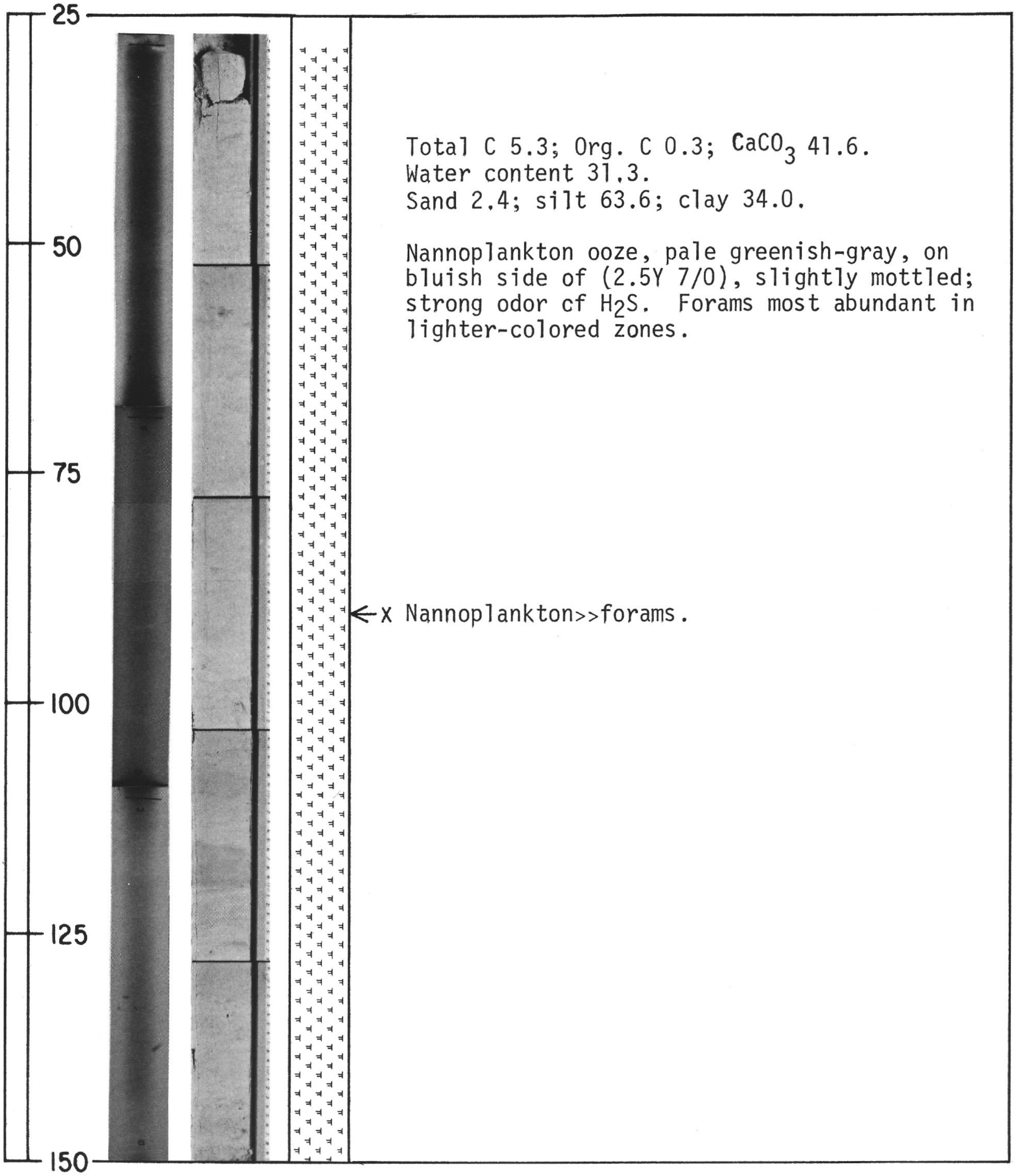
Forams > nannoplankton.

Carbonate-rich clay, with very abundant planktonic forams and abundant nannoplankton; some pteropods. Sediment vaguely banded in lighter and darker shades of gray (2.5Y 5/2, 6/2, 7/2).

Thin bands of yellowish tone (5Y 6/4).

Nannoplankton > forams.

Figure 12. *Hole 2, Core 1, Section 3.*

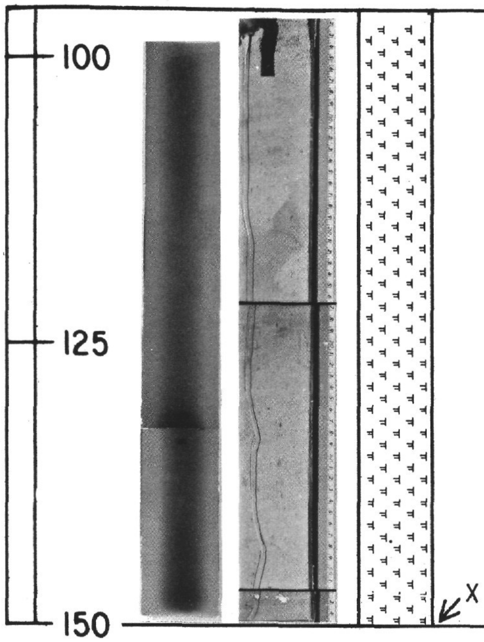


Total C 5.3; Org. C 0.3; $CaCO_3$ 41.6.
Water content 31.3.
Sand 2.4; silt 63.6; clay 34.0.

Nannoplankton ooze, pale greenish-gray, on bluish side of (2.5Y 7/0), slightly mottled; strong odor of $H_2S$. Forams most abundant in lighter-colored zones.

← X Nannoplankton>>forams.

Figure 13. *Hole 2, Core 2, Section 1.*

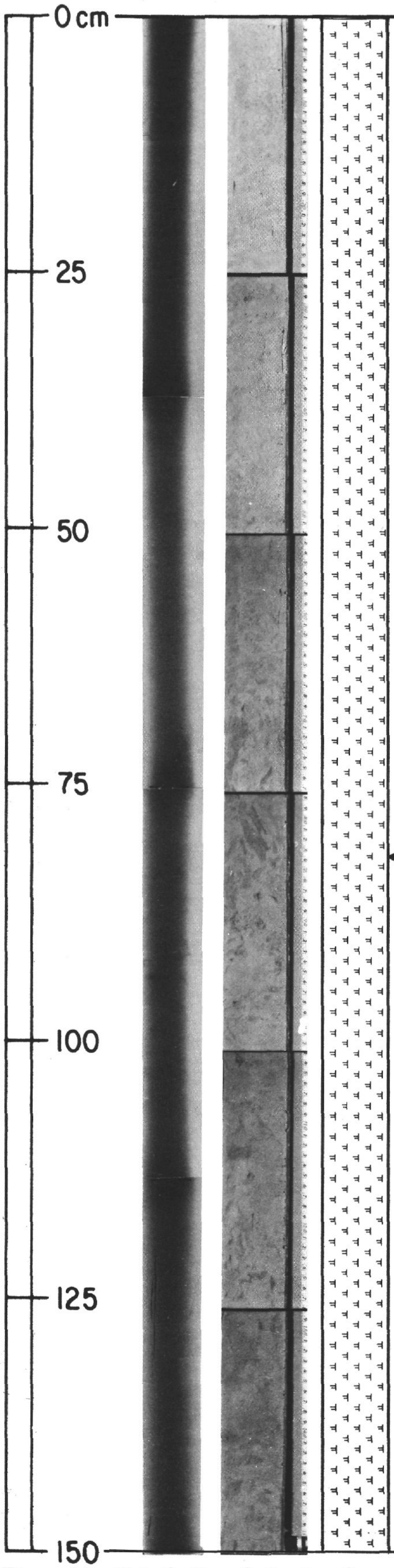


Sand 4.2; silt 12.8; clay 83.0.
Total C 4.8; Org. C 0.2; $CaCO_3$ 38.5.
Water content 32.5.

Nannoplankton ooze, pale greenish-gray (2.5Y 7/0), mottled with (2.5Y 6/0); strong $H_2S$ odor.

Predominant coccoliths, abundant discoasters; sand fraction is forams.

Figure 14. *Hole 2, Core 3, Section 1.*

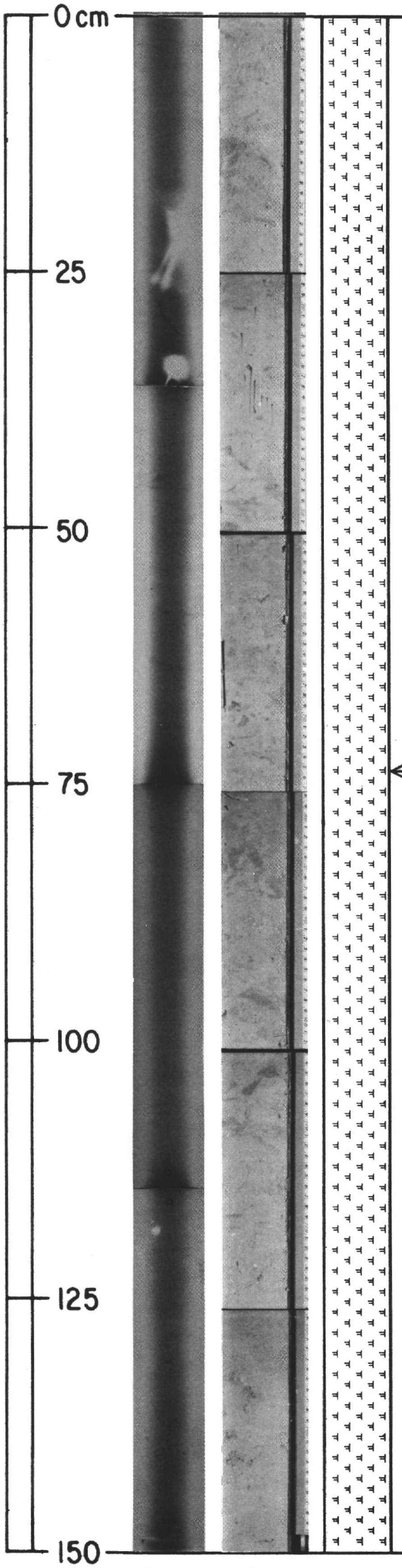


Total C 5.7; Org. C 0.3; $CaCO_3$ 44.8.
Sand 2.1; silt 15.9; clay 82.0.
Water content 34.6.

Nannoplankton ooze, pale greenish-gray, on greenish side of (2.5Y 7/0), mottled with (5Y 6/2). Darker greenish laminae. Intense mottling, in part clearly due to burrowing.

← X Nannoplankton (coccoliths, ceratoliths, discoasters)>>forams. Sand grade material entirely forams; silt-grade includes fossils and some pyrite grains.

Figure 15. *Hole 2, Core 3, Section 2.*

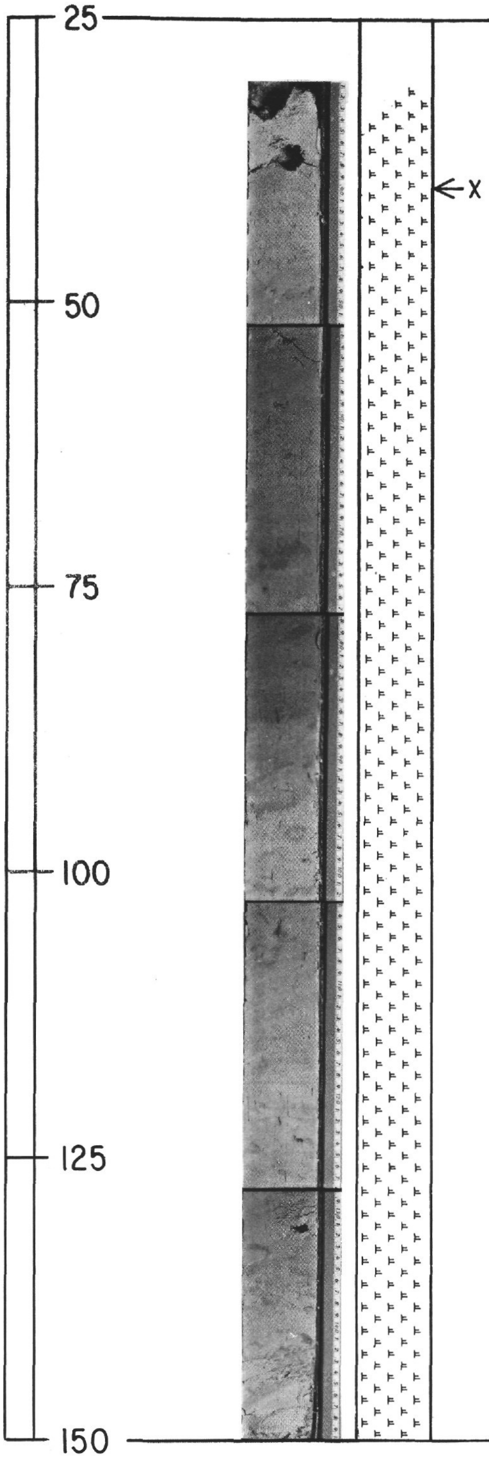


Total C 4.3; Org. C 0.2; $CaCO_3$ 34.2.
Water content 34.8.
Sand 9.0; silt 28.9; clay 62.1.

Nannoplankton ooze, with forams. Greenish-gray (2.5Y 7/0), heavily burrow-mottled with (5Y 6/2). Darker green laminae, irregular, throughout. Black FeS in many burrows; strong $H_2S$ odor.

Nannoplankton (including some discoasters), > forams; a pteropod; pyrite in silt-grade.

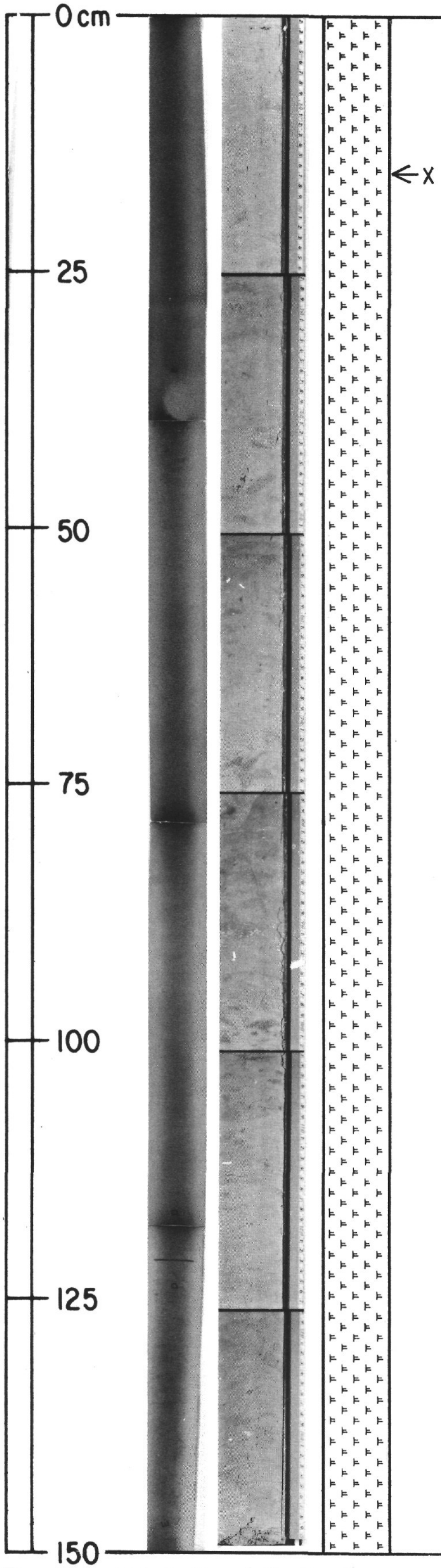
Figure 16. *Hole 2, Core 3, Section 3.*



Sand grade entirely forams; nannoplankton dominant, including discoasters and ceratoliths. Authigenic crystals of carbonate and pyrite/marcasite.
Water content 23.2.
Sand 1.4; silt 20.7; clay 77.9.

Nannoplankton ooze with foraminifera, greenish to bluish-gray (5B 6/1), moderately burrow-mottled with (5B 7/1) and a minor number of (5GY 6/1) mottles. Some oil in this core, bled against liner and in squeezing water sample. Strong $H_2S$ odor.

Figure 17. *Hole 2, Core 4, Section 1.*

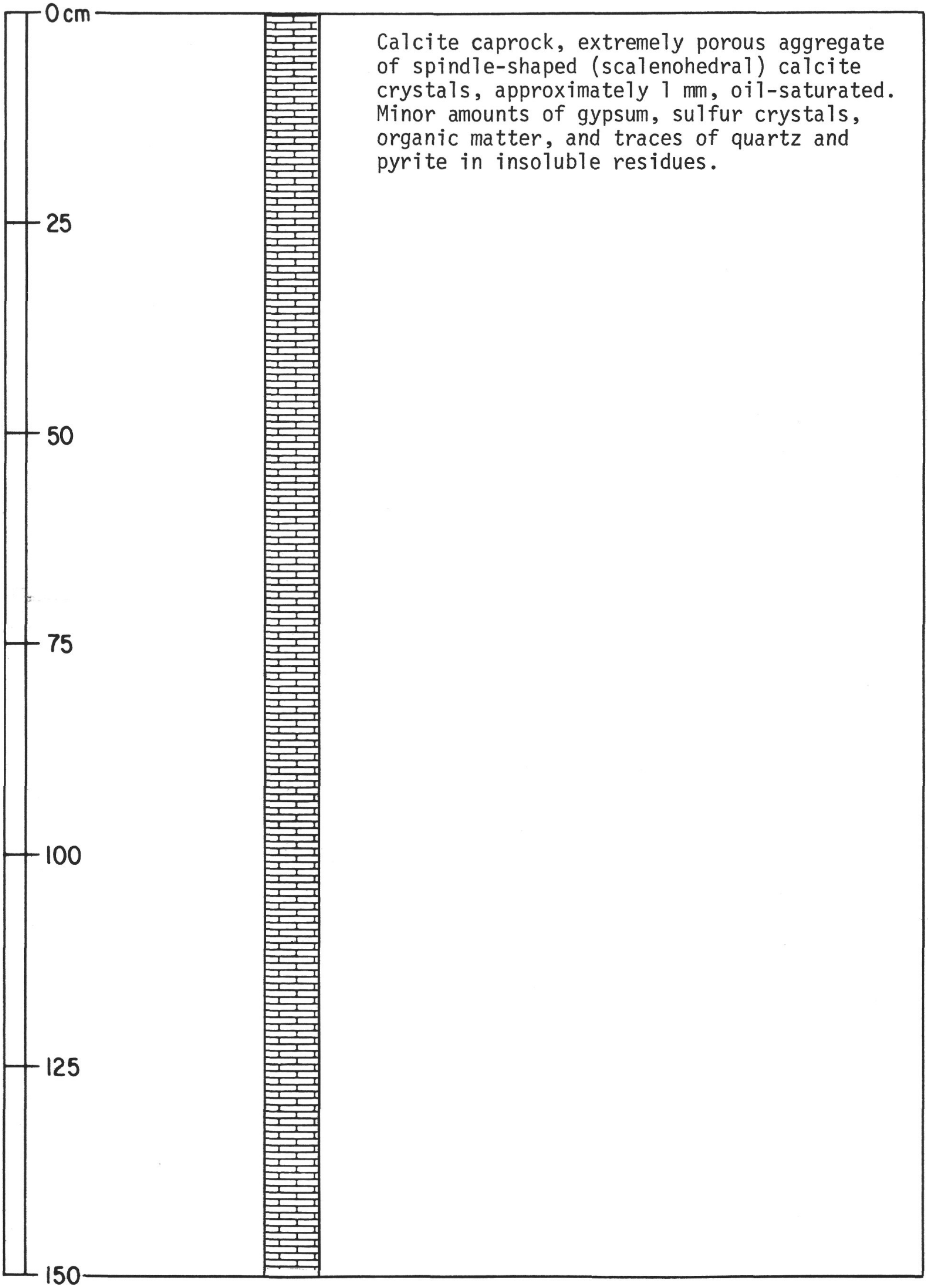


Total C 6.2; Org. C 0.1; $CaCO_3$ 51.0.
Water content 26.1.

Sand 2.5; silt 11.7; clay 85.8.
Mainly small coccoliths, but abundant discoasters; some foraminifera, carbonate rhombs and pyrite grains.

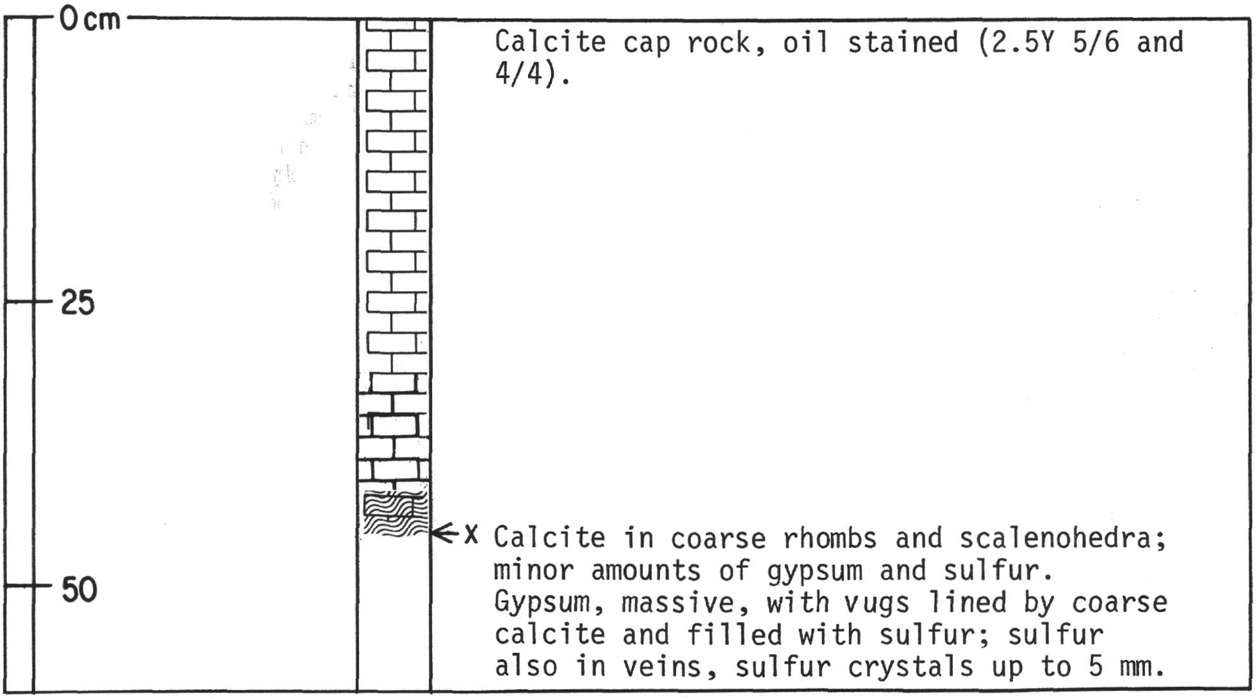
Nannoplankton ooze, with some forams; light blue-gray (5B 6/1), mottled with greenish-gray (5G 6/1 to 5GY 6/1); small rod-like (1 x 3 mm) pyrite concretions, burrow-fills (see X-radiograph). Patches of non-fluorescent oil stain. Strong petroleum odor.

Figure 18. *Hole 2, Core 4, Section 2.*



Calcite caprock, extremely porous aggregate of spindle-shaped (scalenohedral) calcite crystals, approximately 1 mm, oil-saturated. Minor amounts of gypsum, sulfur crystals, organic matter, and traces of quartz and pyrite in insoluble residues.

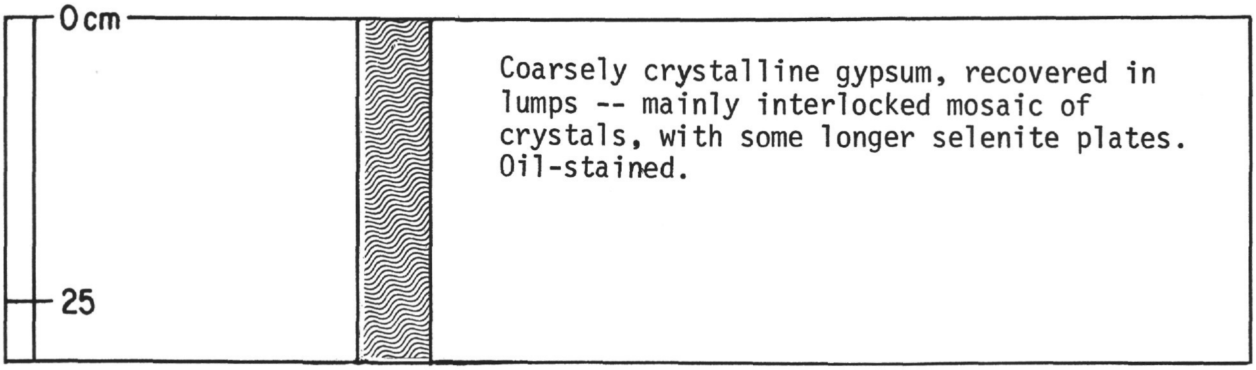
Figure 19. *Hole 2, Core 5, Section 1.*



Calcite cap rock, oil stained (2.5Y 5/6 and 4/4).

Calcite in coarse rhombs and scalenohedra; minor amounts of gypsum and sulfur. Gypsum, massive, with vugs lined by coarse calcite and filled with sulfur; sulfur also in veins, sulfur crystals up to 5 mm.

Figure 20. *Hole 2, Core 5, Section 2.*



Coarsely crystalline gypsum, recovered in lumps -- mainly interlocked mosaic of crystals, with some longer selenite plates. Oil-stained.

Figure 21. *Hole 2, Core 6, Section 1.*

## Nature of the Sediments

### General Description of the Sediments

The cores of Site 2 yielded, in stratigraphic sequence: the cap rock of a salt dome, Pliocene-Pleistocene nannoplankton marls, and Pleistocene clays.

The bottom core (Core 6) barely penetrated into the main mass of cap rock which consists of coarsely crystalline gypsum with selenite veins and fractures stained by residual oil. This is overlain (Core 5) by a zone of highly vuggy calcite, with vugs and veins filled by coarsely crystalline sulfur and traces of gypsum. The top of the cap rock is composed of a highly porous, oil-saturated residue of scalenohedral calcite crystals (Chapter 24, Plate 17G). Residues in the cap rock have now yielded pollen of Jurassic age (see Chapter 22). This sequence of lithologies has been described previously from salt dome cap rocks in the northern Gulf of Mexico shelf.

While caved bits of clay yielded Miocene fossils which suggests that the cap rock is covered by Miocene sediments, the next higher cores (Cores 2, 3 and 4) yielded buff to greenish nannoplankton marls of Pliocene and early Pleistocene age. These are greatly burrowed, give off a very strong hydrogen sulfide odor (as well as a crude-oil odor), and are, in part, full of small, branched, burrow fillings of pyrite, particularly well shown in the X radiographs (Chapter 24, Plate 1, C & D). These nannoplankton marls are notably thinner than their equivalents on the Sigsbee Abyssal Plain, and they lack the interbedded turbidite silts encountered there; phosphatic fish scales and bits of bone also suggest condensed sedimentation. This suggests that Challenger Knoll has been a topographic feature since at least the beginning of Pliocene time. The heavy pyritization of these marls is presumably related in part to the generation of hydrogen sulfide in the cap rock below.

The uppermost core yielded a hemi-pelagic brownish-gray clay with abundant nannofossils and planktonic foraminifera of Pleistocene age. This must represent the sediment deposited since the onset of major glaciation in North America, and it reflects the resultant greater inflow of mud into the Gulf of Mexico. The manner in which this clay reached the top of the Challenger Knoll is unclear. It seems unlikely that a brackish muddy overflow layer should reach this far. The waters of the Gulf of Mexico as a whole must have turned more muddy or the muddy waters must have traveled at depth—the clay being perhaps the fine tails of turbidity currents thick enough to overtop such knolls as this one (Ewing *et al.*, 1958).

### Discussion

If it is assumed that sediments retrieved in Core 1 represent upper Pleistocene pelagites deposited contemporaneously with predominant turbidity current sediment distribution on the surrounding abyssal plain, then the downward transition from clay-rich pelagites in lower Pleistocene time to clay-poor, coccolith-rich pelagites in lower Pleistocene and Pliocene sediments corresponds well with the sequence observed at Site 3 (see Chapter 3).

The presence of cap rock lithologies and associated mineralization similar to those described from salt domes on the northern continental shelf of the Gulf of Mexico is taken as clear evidence for the presence of salt at some unknown distance below the total depth of drilling in Hole 2. Detailed C. D. P.[1] seismic profiling might be used to resolve the thickness of cap rock on the Sigsbee diapirs in order to contrast them with shallow-water analogues.

The presence of possible Miocene and certain Pliocene pelagic sediments on the crest of Challenger Knoll suggests that the knoll has been elevated above the surrounding plain since early Pliocene or Miocene time. The time of initial movement of the salt mass is unknown, but could have begun much earlier than the oldest sediment present on the knoll crest. Thinning of youngest Pleistocene and Holocene sediments on the knoll flanks, as observed by precision depth recording, suggests that vertical movement is still occurring (M. Ewing, personal communication).

## Physical Properties of the Sediments

Within–core variation of natural gamma-radiation, GRAPE, and penetrometer measurements is small for sediments from Site 2. Slight variations of gamma-ray readings in Core 1 may reflect varying quantities of clay, which may in turn be related to eustatic changes in sea level during Pleistocene sedimentation. Thus periods of low sea level turbidity current sedimentation would correspond to slightly higher clay content within the pelagic sequence observed. Further paleontological study is needed on Core 1 before such conclusions can be supported.

Averaged values for GRAPE determinations show a consistent increase downward, as shown in Figure 3, ranging from approximately 1.72 g/cc to 2.01 g/cc. No data were obtained from Cores 5 and 6 due to their highly disturbed state. On the other hand, gamma-ray readings show that Core 1 has a slightly higher count rate than Cores 2 and 3, in spite of the difference in density, which supports the observation of higher clay content in Core 1. The increase in gamma-ray count in

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[1] Common depth profiling.

Core 4 is interpreted to reflect the higher density of Core 4 as compared to Cores 2 and 3; inasmuch as Cores 2, 3, and 4 seem comparable from the standpoint of composition.

Penetrometer readings show a consistent increase in the state of consolidation. All readings fall in the range of unconsolidated sediment with the exception of Core 4 which is semi-consolidated, as defined previously. The cap rock sediments, although not measured, would have penetrometer readings of zero, since they consist of crystalline forms of calcite and gypsum. Penetrometer readings show a close inverse correspondence to GRAPE determinations.

No down-hole logs were obtained at Site 2; thus, interpretations are based solely on extrapolations of data from cored sediment.

## Biostratigraphy

### Foraminifera

The biostratigraphy of Site 2, as deduced from the planktonic foraminifera, is shown in Figure 22. The faunas of the samples listed in Figure 22 are discussed below. Again, as with Site 1, the faunal lists are not necessarily complete or representative but show only the most abundant or significant species.

In the listings presented below, the abbreviations (D) and (S) stand for dextral and sinistral, respectively, and refer to the mode of coiling of a specific species of planktonic foraminifera.

Sample 1 (1-2-1-2, 7-8 cm):
*Orbulina universa, Globorotalia inflata, G. truncatulinoides* (D), *G. menardii, Globigerinoides rubra* (including pink variant), *G. sacculifera, G. conglobata, Hastigerina siphonifera, Sphaeroidinella dehiscens.* Benthonics: *Sigmoilopsis schlumbergeri, Eggerella bradyi, Planulina wuellerstorfi.*
Age: Pleistocene.

Sample 2 (1-2-1-2, 50 cm):
*Orbulina universa, Globigerinoides rubra* (including pink variant), *G. sacculifera, Globorotalia menardii, G. inflata, G. truncatulinoides, Hastigerina siphonifera, Sphaeroidinella dehiscens.* Benthonics: *Planulina wuellerstorfi, Fissurina murrhina, Dentalina* sp. cf. *D. advena, D.* sp. cf. *D. plebeia, Virgulina bradyi, Quinqueloculina* sp.
Age: Pleistocene.

Sample 3 (1-2-1-3, core catcher):
*Orbulina universa, Globigerinoides rubra* (including pink variant), *G. sacculifera, G. conglobata, Globorotalia truncatulinoides* (D), *G. menardii, G. hirsuta, Globoquadrina dutertrei, Sphaeroidinella dehiscens.* Benthonics: *Planulina wuellerstorfi, Uvigerina* sp., *Nonion* sp.
Age: Pleistocene.

Discussion:
The planktonic foraminiferal fauna in Core 1 exhibits moderate fluctuations in species abundances—a reflection most likely of climatic fluctuations in the area. *Globigerinoides rubra* and *Orbulina universa* are generally the most common forms; in Sample 1-2-1-2, sampled at 7-8 centimeters, *Globorotalia inflata* occurs as one of the two more dominant forms, whereas at the bottom of the core, *Globorotalia truncatulinoides* is one of the dominant forms. *G. truncatulinoides* is coiled dextrally throughout this core. The stratigraphic position of this core is estimated as mid-early late Pleistocene.

Sample 4 (1-2-2-1, top):
*Globigerinoides rubra, Globorotalia hirsuta, Globorotalia tosaensis, G. truncatulinoides* (S), *Globoquadrina dutertrei, Sphaeroidinella dehiscens.* Benthonic fauna: *Eggerella bradyi, Eponides bradyi, Cibicides bradyi, Gyroidina* sp.
Age: Pleistocene (basal).
Remarks: The presence of *Globorotalia tosaensis* and *G. truncatulinoides* (strongly involute, with narrow umbilicus and nearly circular outline) together suggests basal Pleistocene age. *Globorotalia menardii* was not found at this level. Abundance of *G. hirsuta* and absence of *G. menardii* suggests somewhat cooler climatic conditions than below.

Sample 5 (1-2-2-1, 40-41 cm):
*Globigerinoides rubra, G. conglobata, Globorotalia hirsuta, Globorotalia menardii* (S), *Hastigerina siphonifera.*
Age: Pleistocene (basal).
Remarks: Rather restricted fauna in terms of diversity. *Globorotalia rubra* and *G. hirsuta* dominate the fauna with *G. menardii* also common.

Sample 6 (1-2-2-1, 99-100 cm):
*Globigerinoides rubra, Globorotalia truncatulinoides* (primitive form, D), *G. menardii* (S), *G. inflata, Globoquadrina dutertrei, Orbulina universa, Sphaeroidinella dehiscens, Pulleniatina obliquiloculata.*
Age: Pleistocene (basal).

Sample 7 (1-2-2-1, core catcher):
*Globigerinoides rubra, Globorotalia crassaformis, G. scitula, Sphaeroidinella dehiscens, Hastigerina siphonifera, Orbulina universa.*
Age: Pleistocene (basal).
Remarks: Only a few specimens of *Globorotalia truncatulinoides* and *G. menardii* were found in the pan fraction.

Discussion:
The presence of *Globorotalia tosaensis* and *G. truncatulinoides* (primitive form with circular outline, narrow umbilicus) suggests that this core is near the Pliocene-Pleistocene boundary (see discussion of Core 3 below).

Sample 8 (1-2-3-1, top):
*Globigerinoides sacculifera, G. fistulosa, G. obliqua, Globorotalia crassaformis, G. exilis, G. miocenica, G. scitula, Globoquadrina dutertrei, Sphaeroidinella dehiscens, Orbulina universa.* Benthonics: *Sigmoilopsis schlumbergeri, Fissurina murrhina, Eponides umbonata.*
Age: Pliocene (latest).
Remarks: Fauna suggests subtropical climatic conditions.

Sample 9 (1-2-3-2, 50 cm):
*Globigerinoides rubra, G. sacculifera, G. obliqua, G. conglobata, Globorotalia crassaformis, G. exilis, G. miocenica, Globoquadrina dutertrei, Orbulina universa.*
Age: Pliocene (latest).

Sample 10 (1-2-3-3, 50 cm):
*Globigerinoides rubra, G. sacculifera, G. obliqua, G. conglobata, Globorotalia tumida flexuosa* (D), *G. exilis, G. miocenica, G. crassaformis, G. scitula, Globoquadrina dutertrei, Orbulina universa, Sphaeroidinella dehiscens.*
Age: Pliocene (latest).

Sample 11 (1-2-3-3, core catcher):
*Globigerinoides rubra, G. sacculifera, G. obliqua, G. conglobata, G. exilis, G. miocenica, G. crassaformis, G. scitula, Globoquadrina dutertrei, Orbulina universa, Sphaeroidinella dehiscens.*
Age: Pliocene (latest).

Discussion:
The planktonic foraminiferal fauna from the samples listed above in Core 3, as well as in other samples examined (but not listed here) exhibits a monotonous similarity in species composition. *Globigerinoides rubra* is generally the dominant form with *G. sacculifera, Orbulina universa,* and *Sphaeroidinella dehiscens* constituting a high percentage of the fauna in one or the other of the various samples. Of stratigraphic importance is the abundant occurrence of *Globorotalia exilis* and *G. miocenica* throughout the core. Their presence and the absence of several other forms which became extinct earlier in the late Pliocene suggest that this core is of latest Pliocene age. Indeed the Pliocene-Pleistocene boundary has been drawn at a level between Cores 2 and 3 at approximately 61 meters subbottom.

Sample 12 (1-2-4-1, top):
*Globorotalia multicamerata, Globorotalia* sp. aff. gr. *miocenica, Globorotalia tumida flexuosa* (D), *G. crassula, Sphaeroidinella dehiscens* (with small supplementary aperture), *S. seminulina, Sphaeroidinellopsis subdehiscens, Globoquadrina altispira, Globoquadrina humerosa, G. venezuelana, Globigerinoides* sp. ex. gr. *canimarensis-conglobata.*
Age: Pliocene (mid).

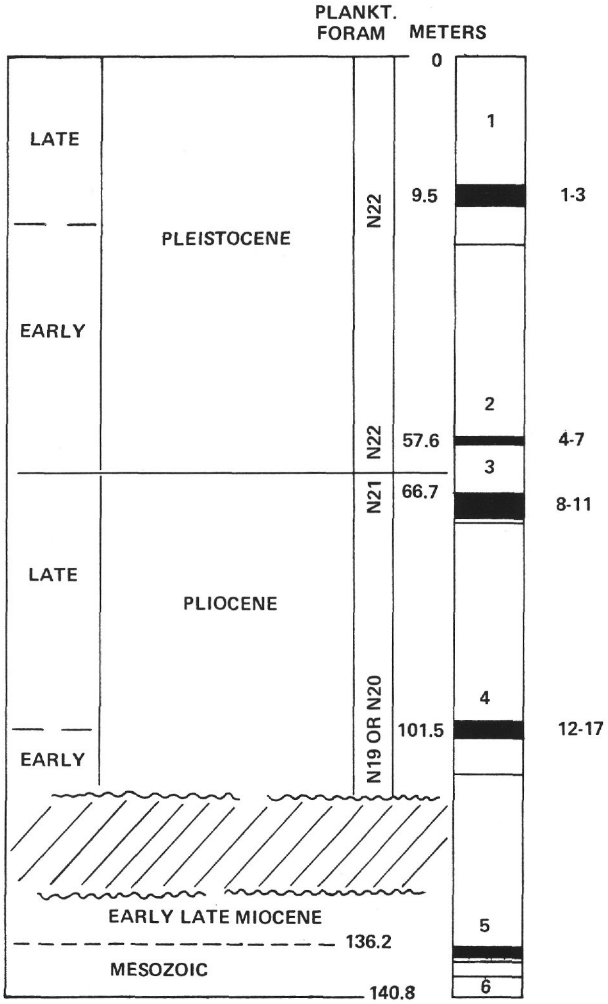

Figure 22. *Summary of the biostratigraphy of Site 2 as deduced from the planktonic foraminifera.*

Sample 13 (1-2-4-1, 100 cm):
*Globorotalia multicamerata, G.* sp. aff. *G. miocenica, Globorotalia tumida flexuosa* (D), *Globorotalia margaritae, G. crassula, Globigerinoides* sp. ex. gr. *canimarensis-conglobata, Sphaeroidinella dehiscens* (with small supplementary aperture), *Sphaeroidinellopsis subdehiscens, Globoquadrina altispira, G. dehiscens, G. venezuelana.*
Age: Pliocene (mid).
Remarks: The planktonic foraminiferal fauna is essentially the same as in the sample from top of core (listed above), however, *Globorotalia margaritae* was found in this sample; this is the highest level at which this species was found.

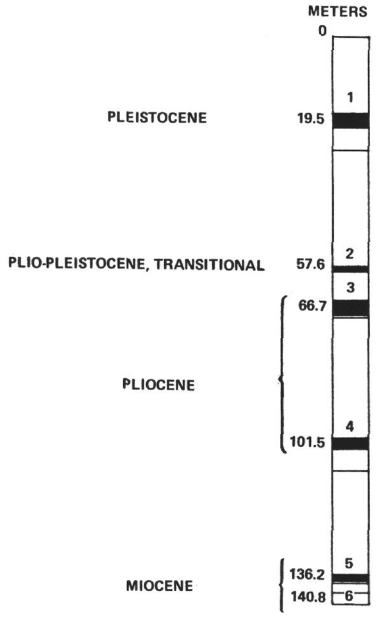

Figure 23. *Summary of the biostratigraphy of Site 2 as deduced from the calcareous nannoplankton.*

Sample 14 (1-2-4-2, top):
*Globorotalia tumida flexuosa* (D), *Globorotalia menardii* s.l. (D), *Globorotalia* sp. cf. *G. miocenica, Globorotalia crassula, Shpaeroidinella dehiscens* s.l. (with small supplementary aperture), *S. seminulina, Sphaeroidinellopsis subdehiscens, Pulleniatina primalis praecursor, Globoquadrina altispira, G. dehiscens, G. venezuelana.*
Age: Pliocene (mid).

Sample 15 (1-2-4-2, 4-6 cm):
*Globorotalia tumida flexuosa* (D), *Globorotalia multicamerata, Globorotalia menardii* s.l. (D), *Globorotalia* sp. cf. *G. miocenica, Globorotalia crassula, Sphaeroidinella dehiscens* s.l. (with small supplementary aperture), *S. seminulina, Sphaeroidinellopsis subdehiscens, Pulleniatina primalis praecursor, Globoquadrina altispira, G. dehiscens, G. venezuelana.*
Age: Pliocene (mid).

Sample 16 (1-2-4-2, 100-102 cm):
*Globigerinoides obliqua, G. sacculifera, Globoquadrina altispira, G. venezuelana, G. humerosa, Sphaeroidinella dehiscens* s.l. (with small supplementary aperture), *Sphaeroidinellopsis subdehiscens, Globorotalia menardii* s.l. (D).
Age: Pliocene (mid).

Sample 17 (1-2-4-2, core catcher):
Foraminiferal test fragments only plus *Globigerinoides* sp. (1 specimen). Benthonic: *Eggerella bradyi.*

Discussion:
The planktonic foraminiferal fauna exhibits a decrease in diversity and numbers downwards in this core. Pyrite occurs in large amounts at the bottom of this core and occurs in moderate amounts up to 41 centimeters from the top of Sample 1-2-4-1, at least. It is present in smaller amounts even at the top of the core. The presence of *Sphaeroidinella dehiscens* s.l. (with small supplementary aperture), *Sphaeroidinellopsis subdehiscens, Globorotalia tumida flexuosa* and *G. margaritae* places this core in the middle of the Pliocene, probably between 3.36 and 3.7 million years ago (see general discussion in Biostratigraphy, Chapter 25).

### Calcareous Nannoplankton

The biostratigraphy of Site 2, as deduced from the calcareous nannoplankton, is summarized in Figure 23. For a detailed discussion of the faunas see the report by Bukry and Bramlette (Chapter 15).

## SUMMARY:
## HISTORICAL AND REGIONAL ASPECTS

The deepest part of the Gulf of Mexico is occupied by the extremely flat and level floor of the Sigsbee Abyssal Plain, which is broken only by a number of small hills, or knolls, rising a few hundred meters above the floor of this plain in its central and southwestern part. Site 2 was chosen to examine the nature of the sedimentary cover of these knolls and to determine the composition of the underlying diapir. The site was situated near the center of the Gulf of Mexico in 3572 meters (11,720 feet) of water (Figure 24), and the hole penetrated 144 meters (472 feet) below the sea floor. The particular knoll drilled was named the Challenger Knoll by the shipboard scientific staff. It rises 180 meters (590 feet) above the adjacent abyssal plain (Figure 25).

The regional importance of this site is perhaps best indicated by the investigations which led eventually to its selection. As early as 1953 studies of 33 cores from the Gulf of Mexico, obtained by Lamont-Doherty Geological Observatory, indicated that turbidites were responsible for the flat floor of the Sigsbee Abyssal Plain, and refraction data suggested that the underlying crust was thin and oceanic in character (Ewing *et al.*, 1955). In 1954, a Lamont expedition—*Vema* Cruise 3—took 124 additional cores and discovered the Sigsbee Knolls. It was noted that in contrast to the cores taken from the surrounding plain, those from the three newly discovered knolls contained only pelagic deposits dating well back into the Pleistocene (Ewing *et al.*, 1958). At this time these knolls were interpreted to be diapirs, probably of salt.

The continuous seismic profiler was used in the Gulf for the first time in 1961, on *Vema* Cruise 17, and numerous similar diapirs were found nearby completely buried beneath a level sea floor (Ewing, Worzel and

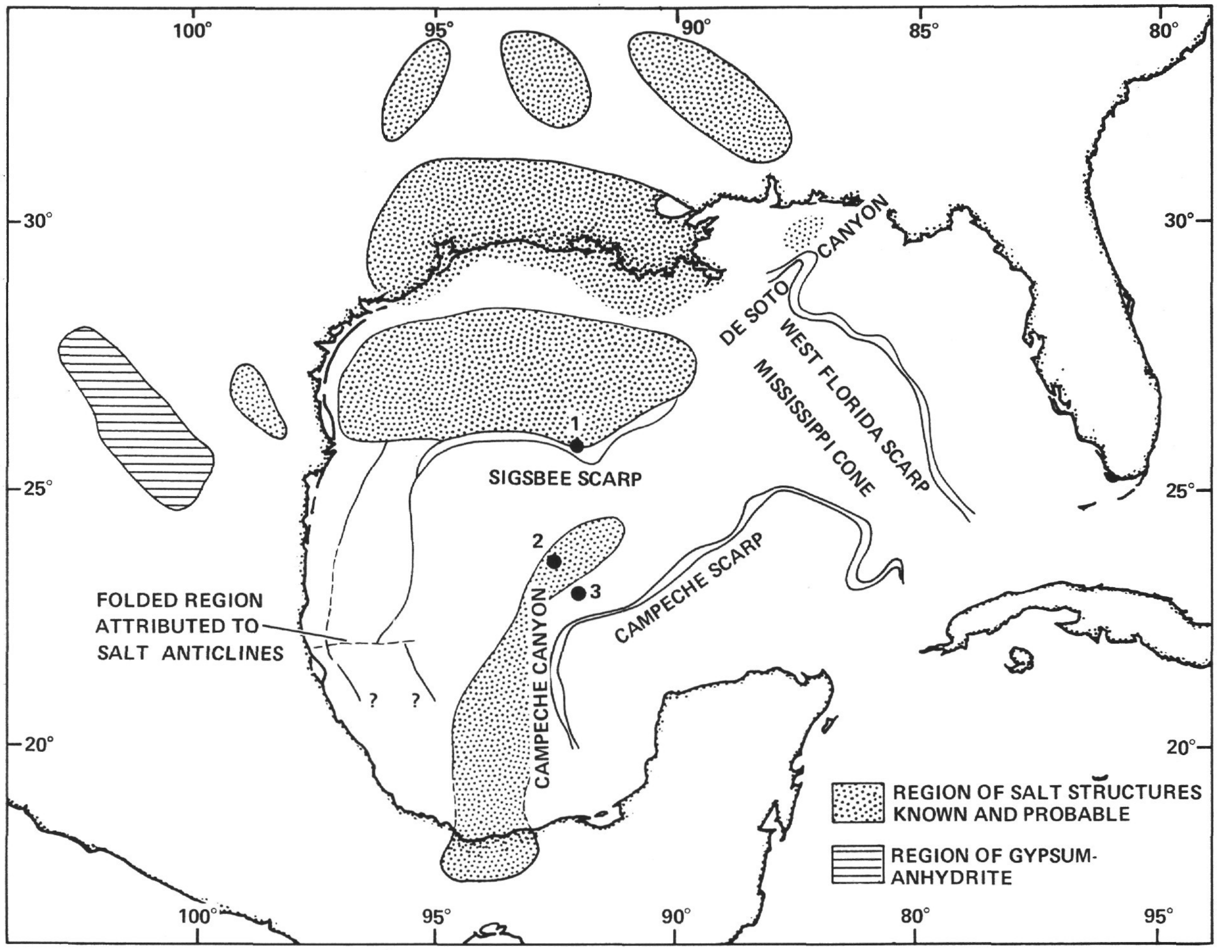

Figure 24. *Physiographic diagram of the Gulf of Mexico showing the positions of Sites 1, 2 and 3.*

Ewing, 1962). It was suggested that the knolls and submerged domes were derived from the mid-Mesozoic Louann Salt; the further suggestion was made that these features would provide rewarding prospects for relatively easy deep-water drilling, and that accumulations of petroleum might likely be associated with them.

Subsequent surveys have shown that this field of diapirs extends southwest toward the Veracruz-Tabasco saline basin area in the Isthmus of Tehuantepec (Worzel *et al.*, 1968).

The coring at Site 2 revealed that all of the sediments overlying the Challenger Knoll are pelagic (see Figure 26). Abundant pelagic foraminifera and nannoplankton suggest a complete Pleistocene and Pliocene section, and some probable late Miocene (Tortonian) discoasters are found in a volcanic-rich clay chip in the lower part of the hole. Clay minerals are abundant only in the upper Pleistocene. The lower Pleistocene and older sediments are calcilutites (calcareous organic oozes), and except for the tannish gray of the upper Pleistocene, all are greenish- or bluish-gray. The high clay influx in the upper Pleistocene suggests higher rates of terrigenous sedimentation generally throughout the basin during this interval, and similarly dominant calcareous sedimentation during the Pliocene and lower Pleistocene. Data from the abyssal plain turbidites of Site 3 confirm this. Site 3 also shows an influx of volcanic debris and a more greenish color in the Miocene turbidites, as reflected also in the pelagic debris of Site 2.

The abundance of hydrogen sulfide and pyrite (and/or marcasite) increased downward markedly in the pre-Pleistocene cores, and shows of petroleum were noted in the lower Pliocene samples (Core 4). Cap rock was encountered near 136 meters (447 feet), nearly 45 meters (150 feet) above the adjacent abyssal plain. The cap rock is typical of that formed over salt diapirs throughout the northern part of the Gulf of Mexico, consisting largely of calcite and gypsum, with locally abundant elemental sulphur.

A series of studies, coordinated by the American Petroleum Institute and directed by Mobil Oil Corporation (see Chapter 22), showed that numerous minerals typical of the insoluble residue of other cap rock are present: detrital quartz, doubly terminated quartz crystals, quartz rosettes, and tourmaline. It is well-known that nearly identical types of quartz crystals are present in the mid-Mesozoic Louann salt. The sulphur isotope data from the gypsum, the hydrogen sulfide collected with the core, and the free sulphur are consistent with biogenic reduction of the anhydrite sulphate and subsequent oxidization of the hydrogen sulfide to free sulphur. The $C^{13}$ abundance in the cap rock calcite also shows that the calcite carbon owes its origin to the cap rock oil.

It thus appears obvious that the Challenger Knoll cap rock is similar in all important respects to cap rock formed over salt diapirs throughout the northern margin of the Gulf of Mexico (both offshore and onshore). Also, palynological studies at Mobil Oil Corporation have shown that the age of the parent salt appears to be the same in all cases. Abundant pollen grains and spores, which were apparently concentrated with the insoluble residues in the Challenger cap rock as the salt was dissolved away, were identified as probably Middle to Upper Jurassic, to possibly Lower Cretaceous.

These same studies suggest that the oil within the cap rock is much younger than Mesozoic. Carbon isotope data and molecular size distributions of the porphyrins are consistent with a petroleum origin in marine organic material; and, other geochemical data also suggest a young, immature crude. The oil is of low gravity and high sulphur content.

The pelagic character of the overlying sediments suggests that this diapir has been a topographic knoll at least since the late Miocene, and the thinning of sediments shown in the reflection profiles (*Vema* Cruise 24) suggest that it is still growing. We may also conclude that cap rock can form beneath deep ocean sediments in the absence of percolating ground water, and that petroleum and sulphur can be generated in a deep ocean environment. It is reasonable that all of the adjacent knolls and domes are similar in all major respects to the Challenger Knoll, and that all owe their origin to a parent salt which is of mid-Mesozoic age throughout the Gulf of Mexico area. The regional problem which probably will be debated most earnestly in the future is whether this salt was deposited in its present deep water environment, or was deposited when the crust may have been much shallower than at present.

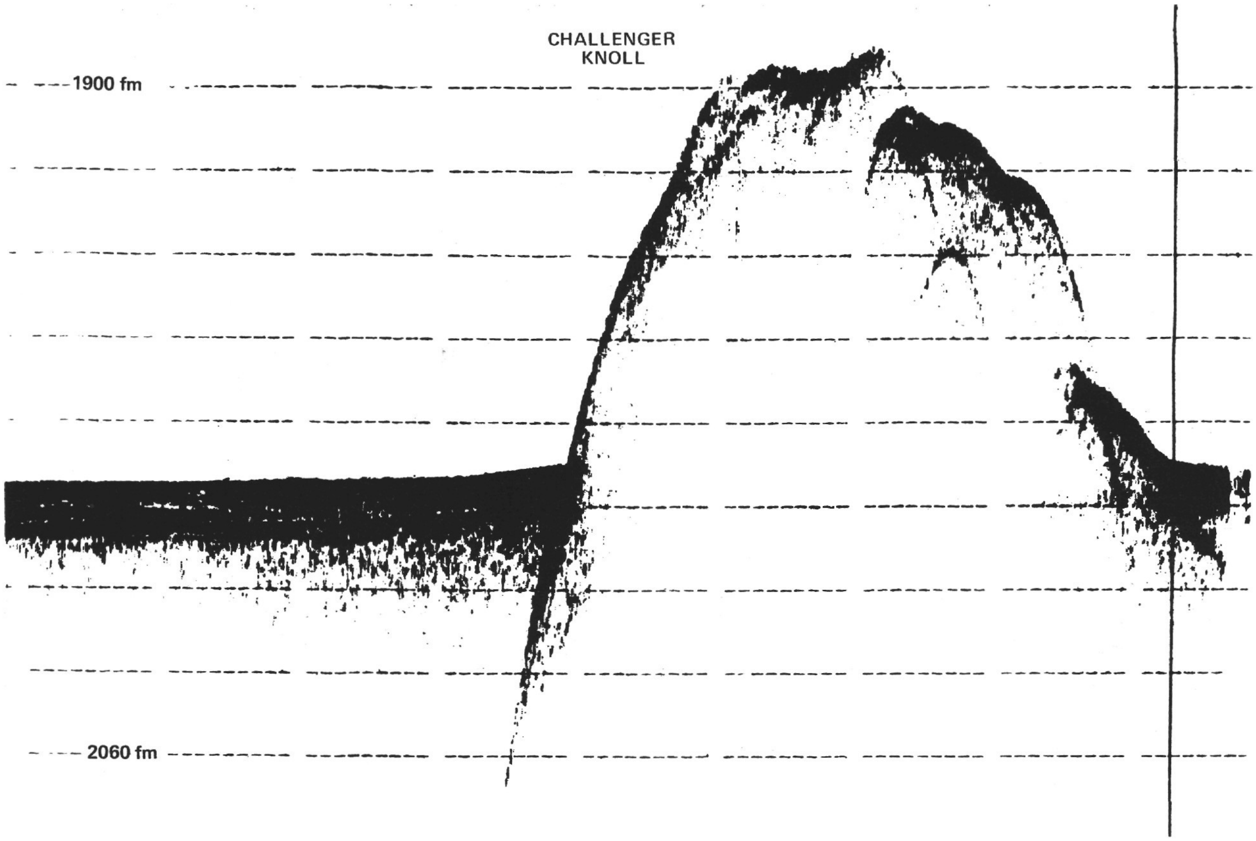

Figure 25. *Echo sounder traverse of Challenger Knoll.*

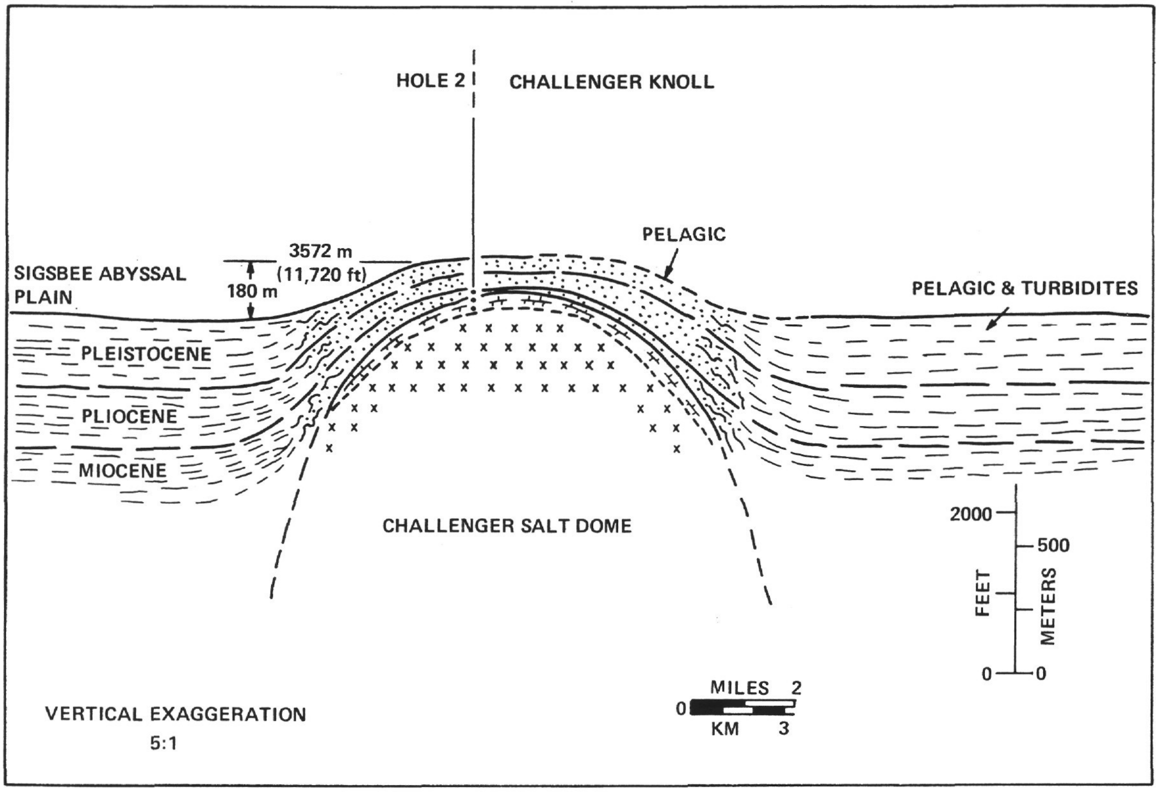

Figure 26. *Structure section of Challenger Knoll.*

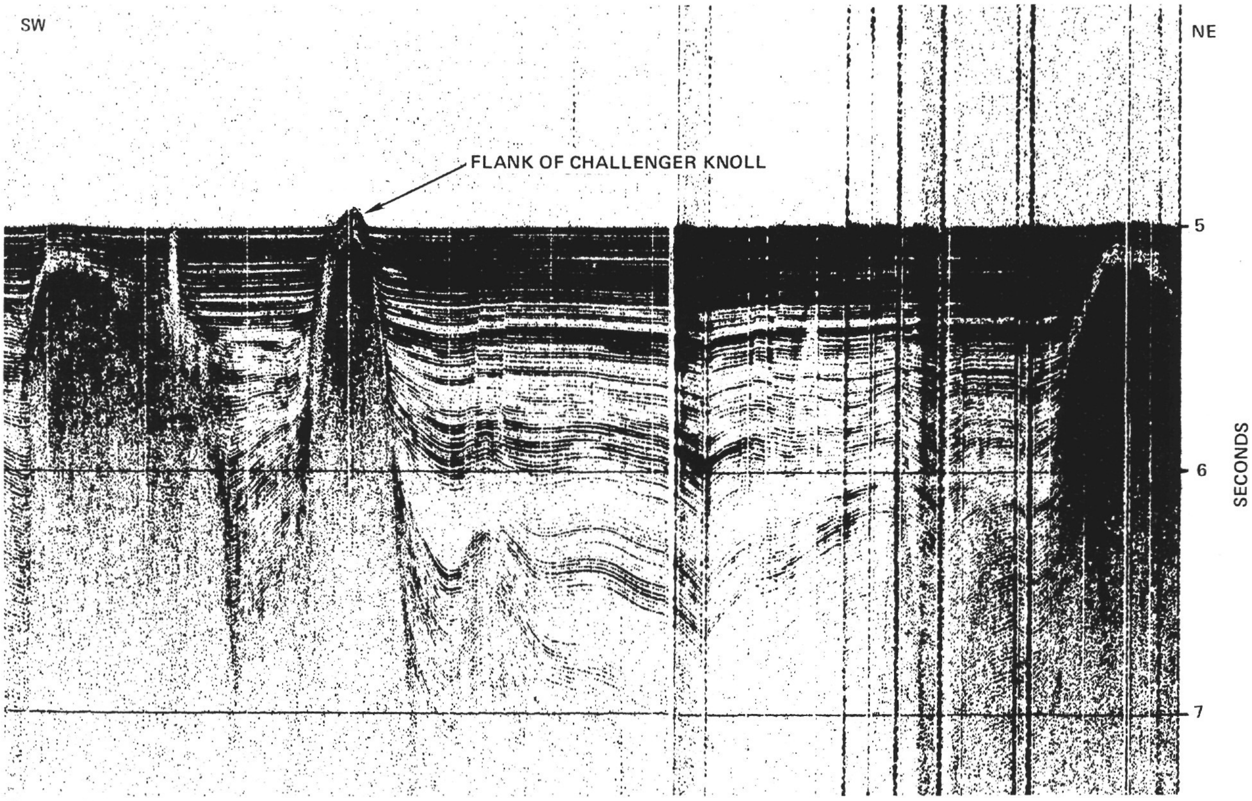

Figure 27. *Profiler traverse of Challenger Knoll area.*

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