1. INTRODUCTION

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The forty-first cruise of *Glomar Challenger* was devoted to the study of the eastern part of the central North Atlantic. The ship left Abidjan on 17 February 1975 and docked at Malaga on 10 April, after having drilled five sites off West Africa (Figure 1). The results of the cruise, which are reported in this volume, include the preliminary description of the material recovered, made on board the ship (see Site Chapters, this volume) and additional studies performed on shore after the end of the cruise, either by scientists having participated in the cruise or by other investigators. The main purpose of this volume is not an exhaustive study of the material recovered, but a description, as detailed as possible, of that material accompanied by interpretations and conclusions that remain of preliminary nature.

OBJECTIVES FOR LEG 41

The general objective of this cruise was to study the evolution of the eastern basins of the North Atlantic, off the continental margin of West Africa. Previous cruises, particularly Leg 14 (Hayes, Pimm, et al., 1972), provided a reconnaissance of the main facies, but did not provide material pertinent to the earliest evolution of the basins because most drill sites were located too far from the margin on relatively young crust, or failed to sample the lowermost part of the sedimentary section. Furthermore, during Leg 14, as for most cruises of the early phases of the Deep Sea Drilling Project, a compromise was made between the density of sampling at any given hole and the number of holes that could be drilled in one cruise, so that coring was very discontinuous at most sites. A different approach was considered for Leg 41 because the available data already showed that most litho-stratigraphic units in the deep basins of the Atlantic had enough lateral extension so that drilling a limited number of sites in key areas would allow for large-scale regional interpretation. For this reason, only five first priority sites were selected by the JOIDES Atlantic Advisory Panel to be cored as continuously as possible (Figure 1). Two of these sites are located in deep basins—one in the Cape Verde Basin (Site 367) and one in the Morocco Basin (Site 370) north of the Canary Islands. It was expected that at these sites, following the sea-

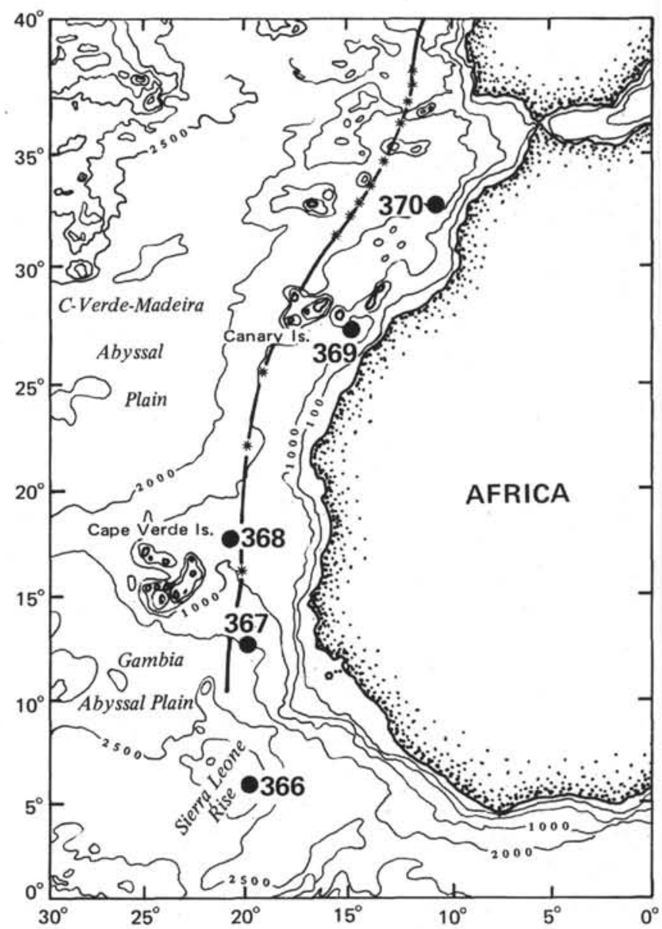

Figure 1. *Leg 41 drill sites. The starred line marks the boundary of the Jurassic magnetic quiet zone (after Hayes and Rabinowitz, 1975).*

floor spreading concept, the early evolution of the North Atlantic could be studied easily because of the preservation of the calcareous microfossils deposited on the oceanic crust at relatively shallow depths, above the carbonate compensation depth (CCD). On the other hand, the subsequent record would probably be barren of calcareous microfossils and would be best studied at sites located in shallower waters. Therefore, in order to obtain as complete a record as possible three other sites were chosen on Sierra Leone Rise (Site 366), on Cape Verde Rise (Site 368), and on the Continental Slope off Spanish Sahara (Site 369), with water depths

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of 2860 meters, 3367 meters, and 1760 meters, respectively.

It was believed that with carefully chosen drill site locations and extensive sampling, Leg 41 results could be combined with those of previous cruises, both in the eastern and western basins in order to view the evolution of the eastern North Atlantic within the general evolution of the North Atlantic Ocean.

SITE LOCATIONS

Sierra Leone Rise

The Sierra Leone Rise marks the boundary between the North and South Atlantic eastern basins. Its origin and structural significance remain unclear and cannot easily be determined from geophysical data alone because (1) the nature and age of the basement between the rise and the African margin as still subject to speculation, and (2) the age of the crust immediately to the west of the rise cannot be easily determined because of a lack of well-identified magnetic anomalies in this low latitude region. As a consequence, the nature of the basement of Sierra Leone Rise is also debatable and could possibly be continental or oceanic.

In any case, the sedimentary cover of the Sierra Leone Rise provides a unique opportunity to obtain a nearly complete record of the Tertiary and Upper Cretaceous sediments in the eastern North Atlantic, in a clearly pelagic setting (i.e., away from the path of turbidity currents), and in such a water depth that apart from the possibility of a young tectonic uplift, the subsidence history of the rise would have kept its summit always above the CCD.

The major objectives for this site were: (1) to obtain a good stratigraphic record for the Late Cretaceous and Tertiary; (2) to decipher the subsidence history of Sierra Leone Rise and assess its possible role as an obstacle to the circulation of bottom waters between the North and South Atlantic in the past; and (3) eventually determine the nature of the underlying basement if it could be reached.

Cape Verde Basin

A large amount of geophysical data, collected mainly during the past five years by Lamont-Doherty Geological Observatory, Woods Hole Oceanographic Institution, and Bundesanstalt für Geowissenschaften und Rohstoffe research vessels, provide the structural framework necessary to interpret the results of any drill site located in the deep basins of the eastern Atlantic. In particular, such data allow for the extrapolation of these results over large areas of the sea floor. The validity of such extrapolations has been already demonstrated be several previous DSDP cruises (see, for example, Lancelot et al., 1972). In addition, the symmetry in the structural evolution of the basins on both sides of the Mid-Atlantic Ridge, derived from the sea-floor spreading concept, might lead to a generalized picture of the evolution of the deep basins on an ocean-wide basis. The "acoustic stratigraphy" in the Cape Verde Basin was found to be rather complete even within the Jurassic magnetically quiet zone (JQZ). In the Cape Verde Basin the local reduction of the thick wedge of Tertiary sediments that constitute the Continental Rise in most of the North Atlantic could offer a chance to reach layers as old as or older than those reached in the northwest Atlantic and in a position nearly symmetrical with some of the Leg 11 drill sites. Therefore, the Cape Verde Basin site possibly would allow a good comparison between the western and eastern basins since the Late Jurassic. The possible correlation of seismic reflectors with major events in the history of these basins would then provide data that could be used for reconstruction of the history of the eastern North Atlantic.

Cape Verde Rise

The Cape Verde Rise is one of the most prominent features of the West African continental rise. Prior to Leg 41 the origin of that rise was not clearly understood. In particular, seismic reflection profiles available to us did not show a clear picture of the basement beneath the rise, or at least they suggested that no large-scale basement high could account for the large dome-shaped elevation. The acoustic character of the sedimentary cover, showing the presence of abundant, parallel, finely layered reflectors, suggests that the rise might be of purely sedimentary origin and possibly was constructed by bottom current-controlled processes. If a relatively recent tectonic uplift of the rise was not considered, then most of the sediments should have been deposited above the CCD. Therefore, the upper sedimentary section should contain enough calcareous microfossils, even if they were diluted by terrigenous material spread on the rise by bottom currents, to supplement the data obtained at the Cape Verde Basin site in deeper water. The good continuity of the reflectors established through several seismic profiles between the two sites was particularly encouraging in this respect. Comparisons could also be attempted with the site previously drilled on Sierra Leone Rise where terrigenous contribution would be minimal and with Site 140 (Leg 14) located in deep water in the Canary Basin. The combination of these four sites could then provide a very complete record of the evolution of that part of the eastern Atlantic as well as an explanation of the origin of the Cape Verde Rise.

Continental Slope off Spanish Sahara

The only attempt at drilling on a continental slope prior to this cruise was during Leg 11 (Site 108) when very short penetration was achieved on the slope off New York during a test of a turbocorer. Technical difficulties allowed recovery of only two cores at that site. Sedimentation processes involved in the evolution of a continental slope were very poorly known. The slope is located between areas characterized by thick accumulations of sediment and is believed to be a region of much restricted sedimentation and extensive erosion. This erosion was supposed to have been instrumental in maintaining both the shape and position of the slope over long periods of time. The slope off Cape Bojador (Spanish Sahara) was exceptionally attractive because of the very thin sedimentary cover overlying layers expected to be as old as Middle Cretaceous. The thin cover has been related to the absence of progradation on the "starved" northwest African margin caused by the climatic evolution of the African continent during the Tertiary. The occurrence of the anticline structure affecting the sediments just beneath the slope and within reach of the drill string of *Glomar Challenger* also provided an exceptionally attractive target. Such an anticlinal could be tentatively related to a deep seated structural high of unknown origin similar to the one which is frequently observed on many other rifted continental margins. Reaching the sediments of the anticline could provide enough data to decipher the subsidence history of the continental slope and allow an understanding of whether the structural high was entirely passive or related to processes such as igneous intrusions or salt diapirism.

Moroccan Basin

The deep basin off the Atlantic coast of Morocco offered a particularly good opportunity to sample old sediments very close to the continental margin, because of the almost complete absence of a Tertiary Continental Rise along that particular margin. Sediments possibly as old as Middle Jurassic, hopefully, could be sampled. Although basement is clearly out of reach at that site, there appeared to be a chance to reach sediments below a major reflector (reflector C) that regionally was believed to correspond with the Oxfordian (Late Jurassic). Not only was there an opportunity to sample the oldest reachable sediments from the Atlantic Ocean (and probably from the World Ocean) but the nature of the pre-Oxfordian sediments was of a special intrest. The middle Oxfordian has indeed been recognized on the margins of the North Atlantic as being the time of a major and abrupt transgression characterized by the occurrence of a truly open marine facies over a lagoonal or fluviatile one.

The nature of the basement is unknown and its age remains speculative. If oceanic basement is indeed present near the base of the Moroccan continental margin, its age could be estimated as Early Jurassic (Sinemurian). The presence of evaporites in the deep basin, very close to the chosen site, poses a major problem. If these evaporites were deposited at the same time as the ones observed on the margin, and if the underlying basement is indeed oceanic, one could consider that the narrow Early Jurassic oceanic trough of the North Atlantic (between Nova Scotia and Morocco) could have been momentarily desiccated in a manner similar to that invoked to explain the presence of salt in the deep Mediterranean basins. If, on the other hand, evaporites are underlain by foundered continental crust, a tectonic separation of the margin area from the adjacent basin would have to be invoked. The nature of the Middle to Upper Jurassic sediments from the deep basin could be used as a clue in order to try to solve that question.

PRESENTATION OF DATA AND RESPONSIBILITIES FOR AUTHORSHIP

The results of Leg 41 are presented in this volume in a manner similar to that of earlier volumes of this series. The first section contains one chapter for each of the five sites. The contributions to these site chapters were written by various members of the Shipboard Scientific Party as follows: Background and Objectives, by Yves Lancelot and Eugen Seibold; Operations, by Yves Lancelot; Lithology, by Walter E. Dean, Lubomir F. Jansa, and James V. Gardner, with additional contributions by Vladislav Eremeev for the igneous petrology. Geochemical measurements were written by J. Graham Rankin and physical properties by Peter Trabant. Correlation of seismic reflection profiles with drilling results were written by Yves Lancelot. Foraminiferal paleontology was written by Valery Krasheninnikov and Uwe Pflaumann, nannofossil paleontology by Pavel Cepek, and radiolarian paleontology by David Johnson. Sedimentation rates were compiled by Uwe Pflaumann. The conclusions were written by Yves Lancelot and Eugen Seibold but were contributed by the entire scientific party.

In a second section appear separate contributions by various authors. These contributions result from analyses of the results in shore-based laboratories. The scientific editing of these chapters was performed by James V. Gardner and James R. Herring and the final editorial responsibility for the volume belongs to the Deep Sea Drilling Project.

OPERATIONAL SUMMARY

Leg 41 officially began on 15 February 1975 in Abidjan, Ivory Coast, although departure was actually delayed about two days because of logistics problems. The ship docked in Malaga, Spain, 54 days later on 10 April traveling 3344.5 nautical miles and after having drilled seven holes at five sites. Water depths varied between 1770 meters and 4758 meters. Hole sub-bottom depths averaged 836 meters and ranged from 42 meters to 1176.5 meters. A total of 2786 meters of coring was attempted with 1673.0 meters of recovery which represents 60.0%. Time distribution for the leg was 2.52 days in port, 16.56 days cruising, and 34.82 days on site. The on-site time consisted of 3.72 days of running drill pipe in or out (tripping), 5.7 days drilling, 22.97 days coring, 0.35 days positioning the ship, 0.18 days for mechanical downtime, and 1.9 days for miscellaneous problems.

Re-entry was not available for this cruise, so that all the holes had to be single-bit holes. The details of the operation for each site are given in the separate Site Chapters, and we will review here only general technical problems encountered that bear directly on operational limitations. In particular we will briefly review the causes for termination of each hole.

Site 366—Sierra Leone Rise (water depth 2860 m; total penetration 850.5 m)

Cause for termination: plugged bit and time constraints.

The strategy used at this site was similar to the one successfully used on several occasions during previous cruises. It consisted in bypassing the upper 400 meters of relatively soft sediment in a first attempt in order to sample continuously the hard rock at the base of the section, down to a maximum depth possible before destruction of the bit, without spending too much time in the upper part of the hole. It has been observed before that total time in a single hole while continuously coring could indeed jeopardize the chances to achieve deep penetration because of hole instability. In a second phase the upper 400 meters would be continuously cored in a slightly offset hole. There was a good chance that the bit destruction would have been extensive enough to prevent hard rock coring, but not sufficient to prevent punch coring with or without rotation in soft sediment. Unfortunately, during the first attempt, after 850.5 meters of penetration, the bit was plugged by sediment during an inadvertent lowering of the drill string while the core barrel was not in place. Because of time constraints this incident marked the termination of coring in the deepest part of the section. It also made the strategy planned for coring the upper part of the section untenable because of the necessity to clear the throat of the bit. The entire drill string had to be pulled out for this operation and before the upper 400 meters of one section could be cored in a second hole. Weather and sea conditions were exceptionally good at this site.

Site 367—Cape Verde Basin (water depth 4748 m; total penetration 1153 m)

Cause for termination: bit destroyed.

Operations went normally at this site, with the usual number of minor incidents such as beacon failure, line tar plugging of the overshot tool, and minor failure of a valve in the Bowen pump unit, etc. Core recovery was average and shortly after penetrating basaltic basement the bit failed. One of the cones broke and another one cracked, preventing rotation whenever the drill string would be lowered to the bottom of the hole. That bit drilled for a total of 81.2 hours and penetrated about 200 meters of hard rock (hard limestone and basalt). Weather and sea conditions were close to ideal.

Site 368—Cape Verde Rise (water depth 3367 m; total penetration 984.5 m)

Cause for termination: nature of gas present in sediments.

Again, apart from minor technical problems, operations went smoothly at this site. The only operational limitation encountered was the occurrence of small amounts of hydrocarbon gas in the sediments. Total amounts of gas remained relatively low, but a regularly increasing ethane content toward the base of the section called for extra caution. The hole was terminated when methane/ethane ratio decreased to 325. This value was chosen somewhat arbitrarily on the basis of experience from previous cruises. Subsequent operations conducted with more sophisticated monitoring equipment during later cruises have shown that this ratio, although indicative of possible maturation and leading to extra caution in drilling operations, is not in itself the single determining factor, and that additional data must be considered when deciding to terminate or continue operations. Higher ratios might sometimes be encountered in potentially dangerous gas accumulations, whereas lower values can also be found in relatively safe conditions. Weather conditions remained perfect throughout the operation.

Site 369—Spanish Sahara Continental Slope (water depth 1760 m; total penetration 488.5 m)

Cause for termination: nature of gas present in sediments.

No technical difficulties were encountered at this site, and termination after only 488.5 meters of penetration was decided solely on the basis of safety and pollution prevention considerations. Operations were stopped when the methane/ethane ratio decreased to less than 500. Extra caution was necessary because of the location of the site, close to the top of an anticline structure, and because of the possibility of encountering shallow water sediments that could have been characterized by relatively high porosities. Weather and sea conditions were ideal.

Site 370—Moroccan Basin (water depth 4216 m; total penetration 1176.8 m)

Cause for termination: time constraints.

For the first and only time during this cruise, weather conditions caused some 18.5 hours of delay in the operation, just before spudding in. Thereafter, however, the weather remained ideal during the total time spent on site. Minor incidents were also experienced, but operations were conducted without much delay. The most frustrating apsect of the operation was the very slow progress of the drilling, probably caused by the inadaptation of the drill bit to the formations penetrated. Apparently, much longer teeth would have been necessary to improve the gouging action of the bit in plastic clayey sediments. The bit was recovered in relatively good operating conditions (although bearings showed considerable wear) after a record-breaking life (actual rotation) of 121.6 hours. Excellent weather conditions might have been a determining factor in obtaining that record.

Drilling and Coring Equipment

Generally, all equipment performed well at all sites. No major technical difficulty that could limit the operations was encountered. One of the limiting factors was the limited choice of drill bits available. (Only Smith F 94CK and F94C bits—with relatively short tungsten carbide inserts—were available for this cruise.) This is inevitable in the absence of a re-entry capability where a compromise has to be made in view of the very different lithologies anticipated in a single hole. In case of re-entry holes, however, there should be a larger choice and bits more adapted to fast penetration in clays and compacted hemipelagic sediments.

EXPLANATORY NOTES AND CONVENTIONS

System of Numbering Sites, Holes, and Cores and of Locating Samples

Each drill sites is designated by a number, for example, Site 366. If more than one hole was drilled at a site, these additional holes are designated by the site number followed by letters in alphabetical order. For example, Hole 366A corresponds to the second hole drilled at Site 366.

Cores recovered from each hole are numbered consecutively in the order in which they were taken; i.e., Core 1, Core 2, etc. Material retrieved in the catcher is labeled "core catcher" or "CC" (Core 4, CC, for example). Each core is subdivided into 150-cm sections. beginning at the bottom of the core barrel. The number of sections depends upon how much material was actually recovered. A completely full core barrel would yield about 9.3 meters of sediment core so the sediment would be divided into six (6) full sections 150 cm long and a short "zero section" at the top (Figure 2A).

In a partially full core barrel the numbering begins with the uppermost section in which core material occurs. That section, sometimes only partially full, is labeled Section 1, and numbering continues downward to the lower end of the barrel (Figure 2B).

Samples or points of interest within the core are located by hole number, core number, section number, and depth in the section in centimeters (i.e., 366-17-3, 25-26 cm), which locates a sample between 25 and 26 cm in Section 3 of Core 17 from Hole 366.

In reporting the depths of samples below the sea floor, or below the derrick floor of the drilling vessel, the convention is that for partly filled core barrels, all the recovered material comes from the upper portion of the cored interval. The true location is, of course, unknown, and in some cores, where only a small amount of material was recovered. the uncertainty can be as much as 9 meters. Two "adjacent" samples could be nearly 19 meters apart because of this uncertainty alone. Additional uncertainties about depths arise from the play in the bumper subs and the heave of the vessel.

Coring Technique and Disturbance of Sediments Recovered

Drilling and coring techniques used on *Glomar Challenger* may affect the sediments in such a way that they are not always truly representative of the in situ sediments.

Cores are obtained by the punch core-rotary drilling method. The drill bits used are typically 10.75 inches in outside diameter with a bit opening of 2.5 inches in diameter. The drill string is lowered to the sea floor, the drilling assembly is rotated and drilling fluid, composed most commonly of seawater but at times of a mud slurry, is pumped down the drill string around the outside of the core barrel and finally out into the sediments through holes located above the cones of the drill bit. The cuttings are mixed with the drilling fluid and are lifted up to the sea floor along the annulus

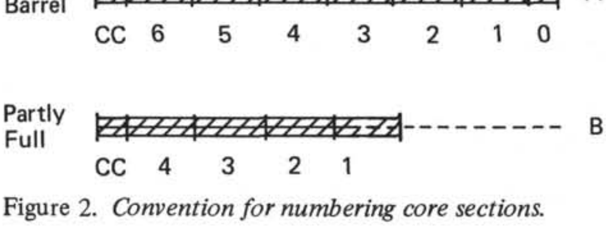


Figure 2. *Convention for numbering core sections.*

between the walls of the hole and the drill string. The cores are retrieved in a core barrel lowered to the end of the drill string through the drill pipe. The bottom of the barrel rests on a support bearing, while the upper end of the barrel is held down by a latch. A swivel bearing between the barrel and the latch allows the barrel to remain stationary while the drill string rotates around it. When enough sediment has entered the core barrel to allow frictional coupling of the barrel with the in situ sediments, the barrel probably becomes stationary.

Careful coordination is necessary to balance the rate of descent of the drill sting, the fluid pressure, and the speed of rotation to avoid either washing all the sediment away from the bit by fluid jetting ahead of the bit (fluidized cores or no cores at all) or using so little fluid, or rotating so slowly that the cutting process is inhibited or the drill bit becomes stuck in the hole (excessively compacted cores).

The desirable balance differs with the nature of the rocks being penetrated. In soft sediments, if no cores are required, it is common to "wash down," using only the jet action of the water plus the weight of the drill string to make progress. If a core is desired in this kind of sediment, then circulation of drilling fluids is drastically reduced or even stopped and rotation, if necessary, is very slow. In most cases, this technique permits the recovery of relatively undisturbed cores; in some cases, much of the volume of the sediments displaced by the drilling assembly is forced into the core barrel. Distortion produced by this phenomenon is usually quite obvious. Color variations in the sediment due to mottling or bedding may be highly contorted. Sediment layers can have a diapiric appearance, and some are vertically oriented. The amount of distortion varies from complete intrusion to intact cores with horizontal bedding planes.

In more indurated rocks it is necessary to use higher fluid pressures and to rotate the drilling assembly more rapidly. In some instances a segment of rock several centimeters in length would be cut on the first increment of progress. This segment would then be broken off, and the next segment of rock would be ground into a paste and the paste forced into the core barrel. This alternation of intact core and drilling paste is especially common in chalk.

In the laboratory, on board the ship, core sections are split longitudinally. If sections contain material in a very liquid state they are not opened. Typically the core liners of plastic sediments are cut on both sides. Then the core is sliced with a wire. Most such cores are little damaged by the cutting process, except that the surface is smeared. Only where pyrite or chert nodules, loose cavings of chert, rust flakes, or the plastic sock used as a core catcher are present, are plastic sediments disturbed, and sometimes severly, by the slicing process. Semi-indurated sediments are cut with a saw. This technique is more damaging, particularly in sequences of alternating layers of indurated chalk and soft calcareous ooze. Sections of indurated rock are split with a diamond saw. It is obvious that some cores retrieved are truly representative of the in situ sediments with respect to some properties. In other cases, it is obvious that they are not. Most cores retrieved are between those two extremes.

Three fundamental alterations result from the coring and handling techniques described above. First, the retrieved materials undergo a shift in properties simply by being removed from their in situ environment to the laboratory. Second, the coring process causes mechanical disturbance which tends to mix, displace, disrupt, or contaminate the retrieved materials. Third, the process of splitting and sampling the core sections in the laboratory introduces more disturbances. These effects are discussed at length in the introductory chapters of earlier volumes of the Initial Reports (for example, Gealy et al., 1971).

Handling of Cores

After a core is cut in 1.5-meter sections, sealed, and labeled, it is brought into the core laboratory for processing. Sediment porosity and density are determined by the GRAPE (Gamma Ray Attentuation Porosity Evaluator) prior to splitting of the sections. Sonic velocity measurements, using a Hamilton Frame velocimeter, and other physical property data are obtained from suitable cores after splitting. One of the split halves is designated a working half. Samples, including those for grain size, X-ray mineralogy, water content, carbon-carbonate, and samples for shipboard and shore-based studies of nannoplankton, foraminifers, radiolarians, diatoms, and silicoflagellates or other paleontological studies are taken.

The other half of the core section is designated an archive half. The color, texture, structure, and composition of the various lithologic units within a section are described on standard visual core description sheets (one per section) and any remarkable features noted. Smear slides are made for each distinct lithology, microscopic examinations are made, and the descriptions are recorded. The archive half of the core section is then photographed. Then both halves are stored in the ship's cold storage.

All cores now reside in cold storage at the DSDP East Coast Repository at Lamont-Doherty Geological Observatory, Palisades, New York, and are available to investigators.

Sediment Analyses

Shore-based organic carbon and calcium carbonate analyses were performed using a Leco 70-Second Analyzer following procedures outlined in Volumes 9 and 18 of the Initial Reports of the Deep Sea Drilling Project. Accuracy and precision of the results are as follows:

Total carbonate	±0.3% (absolute)
Organic carbon	±0.06% (absolute)
$CaCO_3$	±3% (absolute)

Analyses designated "$CaCO_3$ bomb" were made aboard ship using a method of measuring the CO_2 pressure after acidification of the sample, described by Muller and Gastner (1971). The stated accuracy of this method is ±1% $CaCO_3$.

The size classification used here is that of Shepard (1954) with the sand, silt, and clay boundaries based on the Wentworth (1922) scale: sand from 2000 to 62.5 μm, and clay less than 3.91 μm. Standard sieve and pipette methods were used on shore to determine the grain-size distribution (Krumbein and Pettijohn, 1938). X-ray diffraction analyses were performed routinely on selected samples (at least one from each core), and analytical procedures are given in a separate chapter (Mélières, this volume).

Sediment Classification

The sediment classification used on Leg 41 is outlined below. It is based exclusively on smear-slide examination, along with shipboard measurements of carbonate content.

Classification and Nomenclature Rules

I. Rules for class limits and sequential listing of constituents in a sediment name.
   A. Major constituents
      1. Sediment assumes names of those constituents present in major amounts (major is defined as >25%). See example in rule 1B.
      2. Where more than one major constituent is present, the one in greatest abundance is listed farthest to the right. The remaining major constituents are listed progressively farther to the left in order or decreasing abundance. (see example in rule 1B).
      3. When two or more major constituents are present, class limits are based on percentage intervals: 0-5, 5-25, 25-75, 75-100.
   B. Minor constituents
      Constituents present in the amounts of 5%-25% are prefixed on the sediment name by the term "bearing."
      Example: 50% nannofossils, 30% radiolarians, 20% zeolites would be called a zeolite-bearing rad nanno ooze. Examples illustrating rules 1A and 1B and the resulting sediment names:

% Clay	% Nannos		
0-5	95-100	=	Nanno ooze
5-25	75-95	=	Clay-bearing nanno ooze
75-95	5-25	=	Nanno-bearing clay
95-100	0-5	=	Clay

II. Specific rules for calcareous and siliceous tests.
   A. "Nanno" is applied only to the calcareous tests of coccolithophorids, discoasters, etc.
   B. The term calcareous or siliceous, depending on skeletal composition, is applied where no attempt is made to distinguish fossils as to major subgroup. Thus, if no estimate is made, a mixture of radiolarians, diatoms, and silicoflagellates would be called a siliceous ooze. Where this distinction is made, the appropriate fossil name is used.
   C. Fossil tests are not qualified by a textural term unless very obviously redeposited.
   D. Abbreviations, as nanno for nannofossil, rad for radiolarian, etc., may be used in sediment name.
   E. The terms ooze, marl, and clay are used to designate >60%, 30% to 60%, and <30% carbonate, respectively (see Table 1).
   F. The term chalk is used to represent a compacted, semilithified ooze.

TABLE 1
Sediment Name Designations

$CaCO_3$ Content (%)	Induration: Unconsolidated	Semilithified	Lithified
0-30	Clay	Clay	Claystone
30-60	Marl	Marl	Marlstone
60	Ooze	Chalk	Limestone

G. Limestone is restricted to cemented calcareous rocks.
H. Shale applies when sediment is fissile.

III. Clastic sediments

A. Clastic constituents, whether detrital, volcanic, biogenous, or authigenic, are given a textural designation. When detrital[3] grains are the sole clastic constituents of a sediment, a simple textural term suffices for its name. The textural term can be preceded by a mineralogical term when this seems warranted. Such mineralogical terms are applied as per rules 1A and B.

B. Clastic volcanics
Redeposited pyroclastics also become a clastic component. They are recognized by the term volcanic and receive a textural term such as gravel, sand, silt, etc. It is particularly difficult at times to differentiate between volcanic sand (i.e., transported by tractive mechanisms) and crystal ash (i.e., direct outfall resulting from explosion of a volcano).

C. Clastic authigenic constituents
Where authigenic minerals are recognized as a redeposited constituent, they are given a textural designation in addition to their mineral names.

IV. Volcanic and authigenic constituents

A. Volcanic constituents
Pyroclastics are given textural designations already established in the literature. Thus, volcanic breccia = >32 mm, volcanic lapilli = <32 mm to >4 mm. It is at times useful to further refine the textural designations by using such modifiers as coarse or fine.

B. Authigenic constituents
1. Authigenic minerals enter the sediment name in a fashion similar to that outlined under rules 1A and B. Normally, as with a fossil thanatocoenosis, the authigenic minerals are not given a textural designation and texture.
2. The terms ooze and chalk are applied to carbonate minerals of all types using the same rules that apply to biogenous constituents.

The lithologic symbols used in the core forms are shown in Figure 3.

Determinations of Shipboard Mineralogy and Lithology

Smear Slides

Smear slides are the principal means of identification of sediment components on board the ship. Smear-slide estimates of component abundances are based on a semiquantitative visual estimate of the abundances of the different components as follows:

0- 5%	Rare
5-25%	Common
25-75%	Abundant
>-75%	Dominant

Specific mineral identification and estimates of abundance was attempted for sands, but for silts and clays only the textural categories were used. Many cores contain important minor lithologies as well as a dominant lithology. The description of the dominant lithology is indicated in most cases and descriptive information for minor lithologies is included wherever possible.

An example of a core form with legend and explanatory notes appears in Figure 4.

Biostratigraphy

The biostratigraphic zonation for Leg 41 material follows the references in Table 2. The time scale used for computation of accumulation rates at each site appears on Figure 5. It has been adapted by Leg 41 shipboard paleontologists from various sources, including Berggren (1972), Berger and von Rad (1972), and van Hinte (1972, 1976).

Drilling Deformation

Four degrees of drilling deformation were recognized and are noted by symbols on the sample core form (Figure 4). Slightly deformed cores exhibit a slight bending of bedding contacts; extreme bending defines moderate deformation. In highly deformed cores, the original bedding may be completely disrupted by forcible injection of sediment into the core barrel so as to produce a "drilling breccia." Watery intervals generally have lost any bedding characteristics originally available. Great care and considerable judgment must be used in determining whether structural features of sediment are original or are artifacts introduced by the drilling and coring techniques.

Downhole Contamination

Downhole contamination is a serious problem. Hard objects (manganese nodules, chert, lithic fragments, and pebbles) are often washed or dragged downhole. They are commonly lodged in at the top of cores or incorporated into the middle of cores at levels far below their proper stratigraphic position. Displaced manganese nodules can usually be detected. However, displaced chert, lithic fragments, and pebbles are more difficult to recognize.

Core Forms

The basic lithologic data are contained on core summary forms in both symbolic (Figure 3) and descriptive form. As far as possible the data are presented in the following order:

Sediment name

Color name and Munsell or GSA number

The reader is advised that colors recorded in core barrel summaries were determined during shipboard examination immediately after splitting the core sections. Experience with carbonate sediments has shown that many of the colors will fade or disappear with time after opening and storage. Colors particularly susceptible to rapid fading are purple, light and medium tints of blue, light bluish gray, dark greenish black, light tints of green, and pale tints of orange. These colors change to white or yellowish white or pale tan.

Composition

Structure(s)

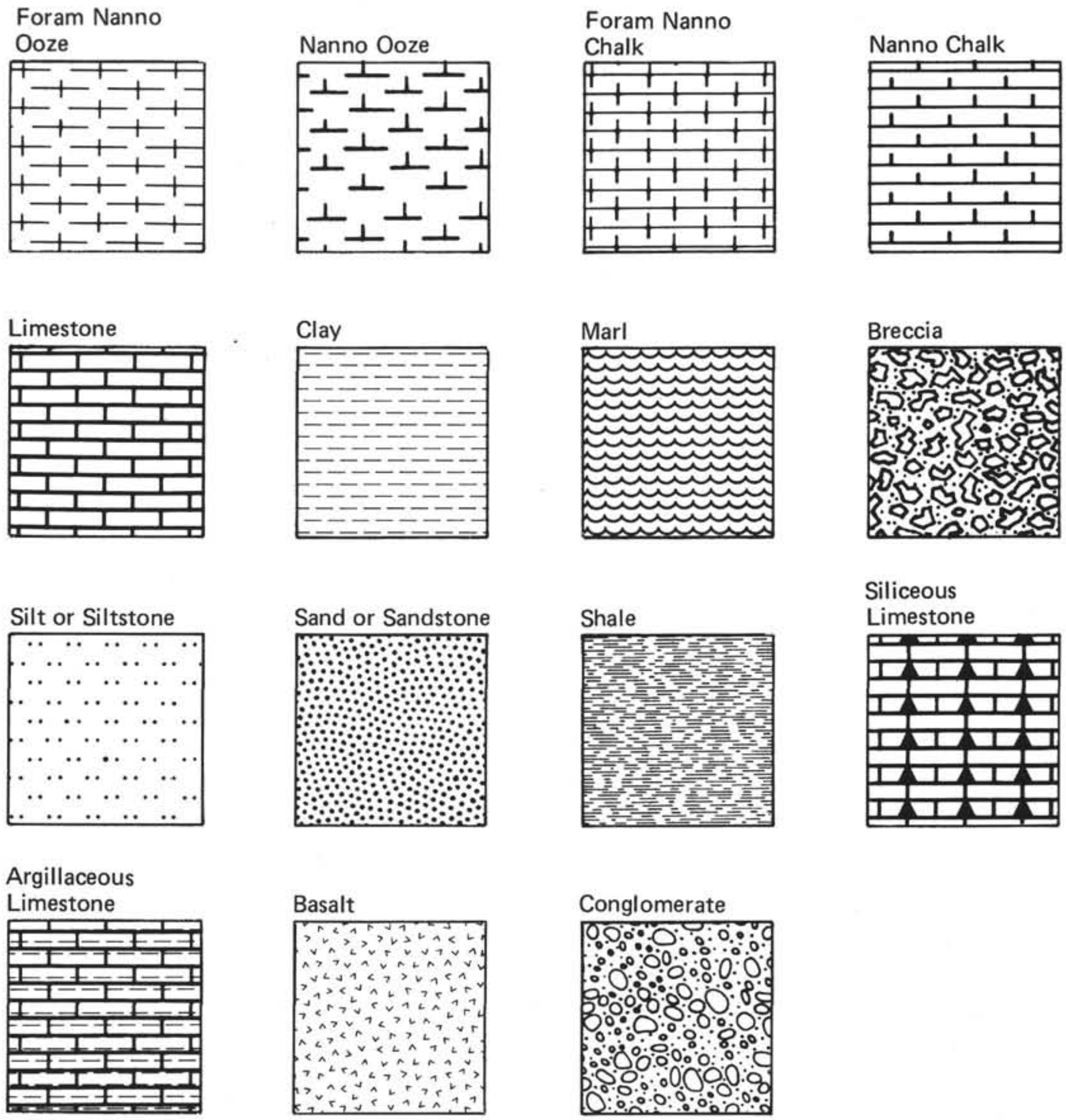
Analytical Techniques

Procedures for Measurement of Physical Properties

A thorough discussion of physical properties and standard shipboard procedures for their determination are presented by Boyce (1973, 1976); Bennett and Keller (1973); and Rocker (1974a, b). Only a brief review is given here, with details of modifications used during Leg 41.

The mass bulk properties of sediments retrieved during Leg 41 include: wet bulk density, water content,

[3]Detrital here means all clastic grains derived from the erosion of pre-existing rocks, except for those of biogenous, authigenic, or volcanic origin.



V = Volcanic Ash
F = Forams
R = Rads
D = Diatoms
N = Nannos

Z = Zeolitic
◺ = Turbidite
Fe = Ferruginous
△ = Porcellanite
▲ = Chert
⩓ = Barite

Figure 3. *Lithologic symbols used for description of Leg 41 cores.*

void ratio, porosity, and specific gravity of solids. Samples were obtained from one section of each core. Sound velocity, shear strength, and GRAPE (gamma ray attenuation porosity evaluator) were made where feasible, prior to sampling for mass bulk property measurements.

Wet volume and mass determinations were made on 10 to 15 g samples by means of an air-comparison pycnometer and a triple beam balance, after which the samples were dried for 24 hours in an oven at 105°C. The dry volume and weight of the sediments were then similarly obtained, and the mass bulk physical properties computed as follows:

(1) Bulk density: $= \frac{\text{wet weight}}{\text{wet volume}}$, g/cc

(2) Water content (% dry weight method):

$$Wn = \frac{\text{weight water}}{\text{weight solids}} \times 100, \%$$

(3) Porosity: $n = \frac{\text{volume of water}}{\text{volume of solids and water}} \times 100, \%$

(4) Void ratio: $e = \frac{\text{volume of water (voids)}}{\text{volume of solids}}$

(5) Specific gravity of solids:

$$Gs = \frac{\text{weight solids}}{\text{volume solids}}, \text{g/cc}$$

assuming a unit weight for water of 1.00 g/cc.

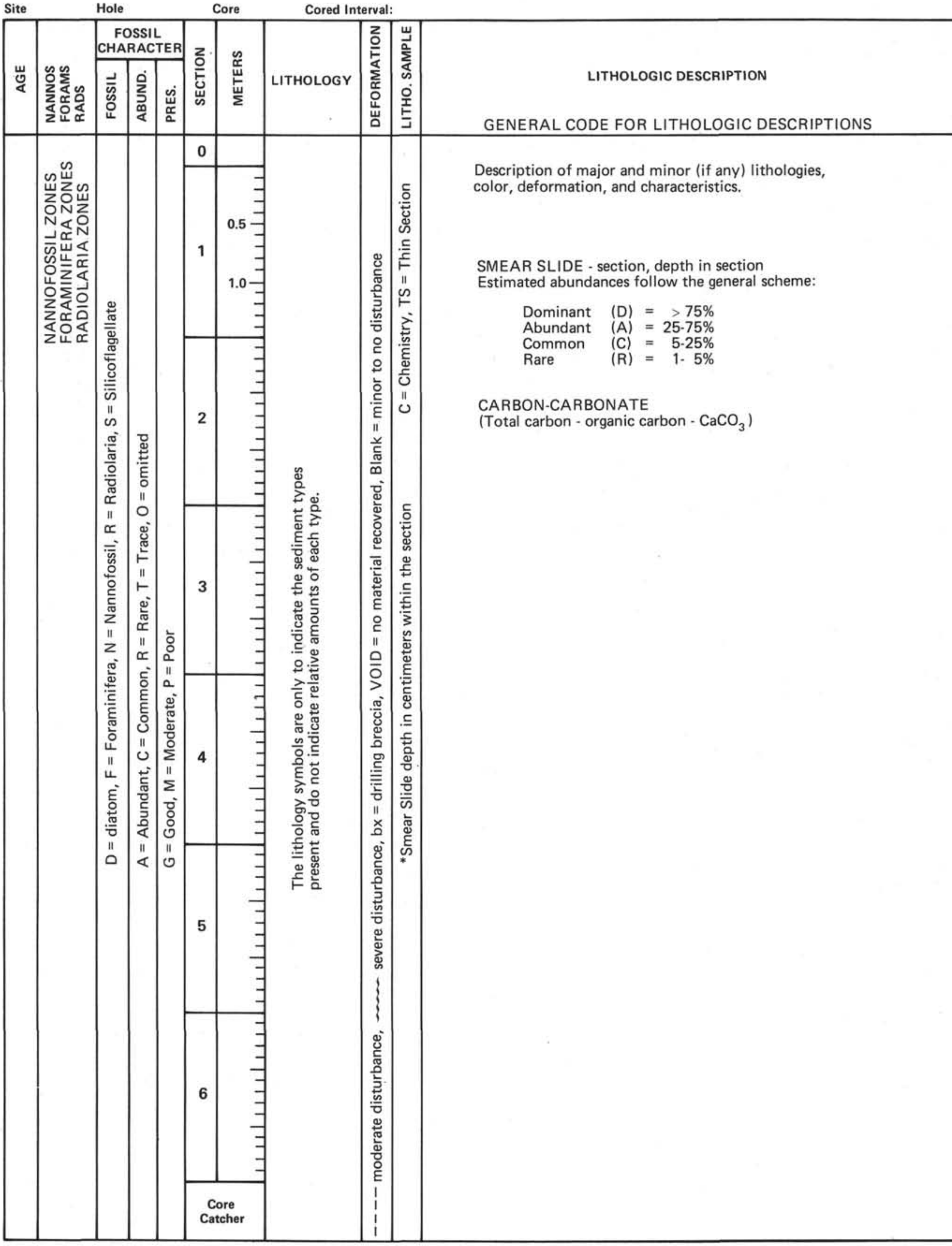


Figure 4. *Type of core forms used for description of Leg 41 cores.*

TABLE 2
Biostratigraphy

	Cenozoic	Mesozoic
Nannofossils	Martini, 1971	Thierstein, 1971
Foraminifers	Bolli, 1966 Banner and Blow, 1965	van Hinte, 1972
Radiolarians	Riedel and Sanfilippo (in press)	Riedel and Sanfilippo, 1974

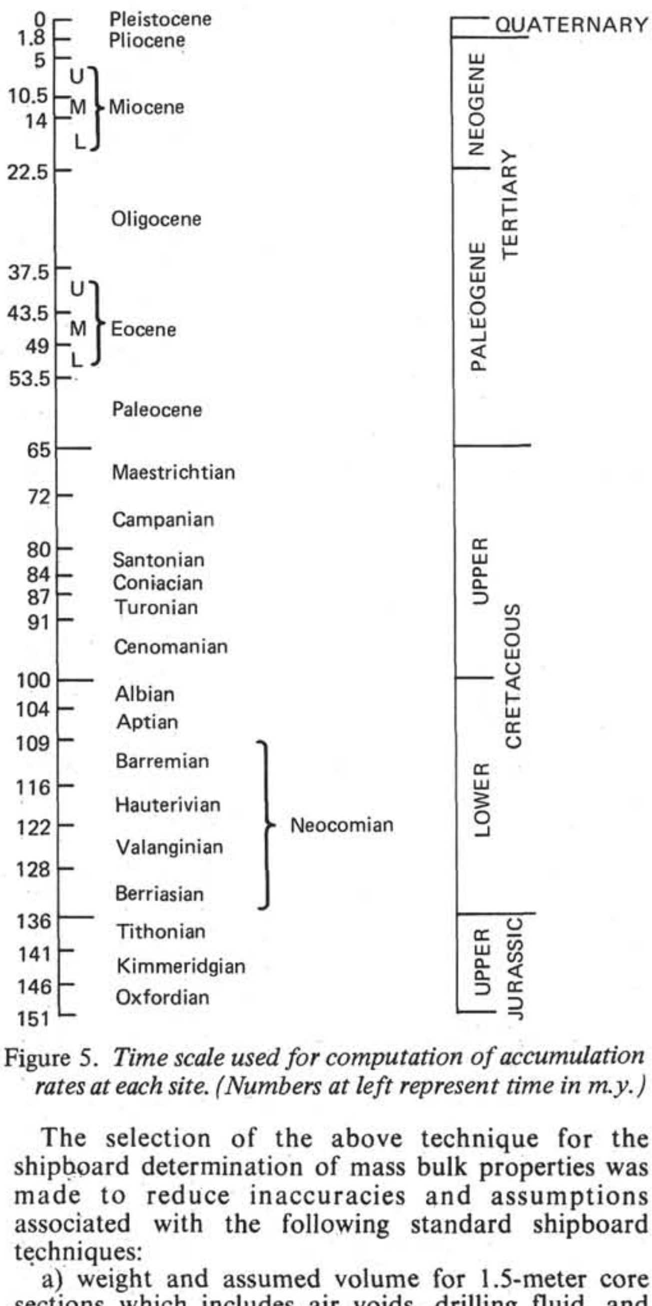


Figure 5. *Time scale used for computation of accumulation rates at each site. (Numbers at left represent time in m.y.)*

The selection of the above technique for the shipboard determination of mass bulk properties was made to reduce inaccuracies and assumptions associated with the following standard shipboard techniques:

a) weight and assumed volume for 1.5-meter core sections which includes air voids, drilling fluid, and disturbed or "remolded" sediment.

b) syringe samples of relatively small volumes within soft sediments.

c) GRAPE method which was reviewed by Bennett and Keller (1973).

A miniature vane shear apparatus was employed aboard *Glomar Challenger* for the measurement of the cohesion within unconsolidated sediments. The procedure and theory are outlined by Boyce (1975). The shear strength of a sediment at failure t_f, is given by:

$$t_f = c + (\sigma - \mu) \operatorname{Tan} \phi$$

where c = cohesion
σ = normal overburden stress
μ = excess pore-water pressure
$(\sigma\text{-}\mu)$ = effective overburden stress
ϕ = angle of internal friction

The shear strength at failure was measured by a miniature vane-shear apparatus by applying a torque through a calibrated spring to a vane of known surface area. Torque was applied by rotating the vane-spring assembly at a rotation rate of 89° per minute.

The above method of determining shear strength assumes that $(\sigma\text{-}\mu)$ tan ϕ=0, which only holds for normally consolidated cohesive sediments and is therefore not applicable to cohesionless material such as coarse silts and sands. Shipboard shear-strength values are dependent upon the degree of sample disturbance which is frequently large, and do not account for excess pore pressures which may exist in situ.

The data show that shipboard shear strength values obtained by the miniature vane method do not necessarily reflect true in situ strengths, but usually represent lower values.

Compressional wave velocity measurements were made on a Hamilton Frame velocimeter. This unit permits the measurement of both distance and time required for a short acoustic pulse to travel through a sample. Measurements were made on relatively undisturbed samples in either half liners for soft sediments or removed samples cut to fit between the transducers. Measurement of velocities were made in both the horizontal and vertical planes in order to assess acoustic anisotropy. The procedure for measuring acoustic velocity with the Hamilton Frame is described in detail by Boyce (1973).

Techniques Used for the Analysis of Organic Geochemical Parameters

Shipboard analysis of cores for organic carbon content and organic carbon versus total nitrogen atomic ratio were performed using a commerical CHN analyzer. Samples containing as little as 0.1% organic carbon could be analyzed reproducibly. Chief sources of error are absorption of water prior to weighing, giving a negative error for carbon content, and inaccurate weighing due to the ship's motion which would give a random error. Carbon content and C/N ratio were apparently proportional indicating a more or less constant low level of inorganic nitrogen content of the sediments and a nearly uniform C/N ratio of the organic matter.

The procedures used aboard ship were as follows: A sample weighing 0.5 to 1 g was refrigerated immediately after collection. Prior to analysis the sample was homogenized and 3 ml of 6*N* HCl was added to remove carbonate carbon. The acid was evaporated on a hot plate, then the acidified sample was dried for at least 2 hours at 105°C. The sample was cooled in a desiccating cabinet, then weighed on a Cahn electrobalance mounted on a gimballed table. A sample weight from 8-25 mg was used, depending on the suspected carbon content.

The CHN analyzer used is a Hewlett-Packard Model 185B, in which the sample, in an aluminum boat, was oxidized in the presence of a metal oxide catalyst at 1100°C. Nitrogen oxides were reduced on copper turnings to nitrogen gas. The gas products were separated by a Porapack Q column attached to a thermal conductivity detector. Detector response, as measured by peak height, was calibrated daily with weighted samples of cystine. Conversion of weight ratio to atomic C/N ratio was by multiplying the ratio of weight percents by 1.167.

Laboratory analysis of some samples was done by the Oceanography Department of Texas A&M University on a similar model CHN analyzer. These samples are identified in the tables as TAMU in the Remarks column. This model was equipped with a digital integrator thus peak area was used for these calculations.

Additional organic carbon determinations made by Scripps Institution of Oceanography (SIO) and Shell Development Company, Houston, Texas (LECO-SHELL) were performed with the LECO carbon analyzer method.

Interstitial Gas and Water

Due to the lack of quantitative standards of each pure gas, standardization is based upon a known natural gas mixture supplied by Phillips Petroleum (UO-3200), the composition of which is given in Table 3. One milliliter of this gas at atmospheric pressure was injected in each of the two gas chromatographs (GC) used. The Carle GC is capable of resolving "air," methane, carbon dioxide, and ethane, but no higher hydrocarbons. The Bendix Gas Chromatograph (on loan from Phillips Petroleum Corp.) can resolve ethane, carbon dioxide, propane, and isomers of butane and pentane. However, the Bendix GC cannot resolve methane from "air" on the same column as the higher hydrocarbons. Therefore, both chromotographs were used simultaneously. "Air" (actually nitrogen and oxygen), methane, and CO_2 were measured on the Carle GC. Ethane and propane were measured on the Bendix GC as ratios of CO_2, then multiplied by CO_2 concentration from the Carle GC data. Equations for determining the concentrations in an unknown sample by comparison with known mixture are given below.

K_A = response factor for gas A

A, B, etc. = concentration of such gas in either standard or unknown

P_A = peak height × attenuation for gas A in either unknown or standard

$$K_A = \frac{A}{P_A} \tag{1}$$

$$K_{A/B} = \frac{K_A}{K_B} = \frac{P_B}{P_A} \cdot \frac{A}{B} \tag{2}$$

$$A = P_A \cdot K_A \tag{3}$$

$$A_{(ppm)} = \frac{A \text{ (abitrary units)}}{\sum_I (P_I K_I)} \tag{4}$$

Equation 4 is a correction used for cases when the vacuum can is not at atmospheric pressure; thus concentration of A as calculated by Equation 3 is in arbitrary units. Likewise, A does not need to be included in the term $\Sigma(P_I K_I)$ if A is minor compared to other gases. In practice, the air, methane, and CO_2 values are summed, but not ethane or propane values. The response factor for "air" actually is for gaseous nitrogen, but it was assumed that the response for O_2 is close to that of N_2 and, because the sediments are usually in a reduced state, O_2 content is small in these gas samples. Some O_2 is no doubt present as air contamination, especially near the end caps, when the sections are cut from the core.

Although the methane concentration in the samples was high (90%), the total volume of gas present in the sediments was not very high. Methane to ethane ratios were very high (>1000) even when propane was added to ethane to give M/(E+P) ratio.

Alkalinity, *p*H, and salinity were measured routinely on cored sediments that were soft enough to provide interstitial water when squeezed by a method similar to that described by Manheim (1966). Surface seawater, which was the drilling fluid at the sites, was also measured to give an indication of possible contamination.

Shipboard laboratory measurements have been described at length in several recent DSDP volumes, for example, by Whitmarsh et al. (1974). For *p*H, the flowthrough method (Waterman, 1970), which had been discontinued on more recent DSDP legs, was again used along with the standard procedure punch-in method.

TABLE 3
Interstitial Gas Standard
Phillips Petroleum Co.
(#UO-3200)

Nitrogen	1.55% (Mole %)
Oxygen	0.01
Carbon dioxide	0.31
Helium	0.18
Methane	87.49
Ethane	2.98
Propane	1.86
Propylene	0.01
n-Butane	0.93
iso-Butane	0.92
1-Butene	1.11
cis-2-Butene	0.95
trans-2-Butene	1.10
n-Pentane	0.29
iso-Pentane	0.31
$\frac{M}{(E+P)}$ = 18.08	

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