1. OBJECTIVES, PRINCIPAL RESULTS, OPERATIONS, AND EXPLANATORY NOTES OF LEG 40, SOUTH ATLANTIC

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Leg 40 was historically significant as the first expedition of the Deep Sea Drilling Project devoted exclusively to continental margin drilling. The thick sedimentary successions penetrated at all six sites consistently pushed to the limit the technology for single bit penetrations.

The leg commenced on 17 December 1974 at Cape Town, South Africa, and terminated 60 days later on 15 February 1975 at Abidjan, Ivory Coast. Three geographic regions were visited in the South Atlantic Ocean, all on the western continental margin of Africa. These regions included: (1) the upper and lower continental rise in the southern Cape Basin; (2) the abutment area of the Walvis Ridge against the continental slope of Namibia (southwest Africa); and (3) the marginal salt plateau of the continental slope of Angola. The site locations are shown on Figure 1.

GENERAL OBJECTIVES

The primary objectives of the continental margin drilling program in the South Atlantic were to obtain as complete a representative sedimentary sequence as possible from continental slope and rise physiographic settings north and south of the Walvis Ridge morphologic barrier, as well as sediments from the ridge itself. Recognizing the effects of carbonate dissolution of fossil tests at great depths in the ocean (past and present), the mixing and reworking of faunas that can occur with a strong clastic-type sedimentation, and the problem of stratigraphic gaps or condensed sections which accompanies erosion and winnowing by strong ocean floor currents, the Leg 40 drill sites were coordinated so as to have:

One relatively shallow setting in an area of high fertility free from a significant input of terrigenous components and not subject to strong bottom current activity (Site 362 in a subsurface trough within the Walvis Ridge abutment plateau).

One relatively shallow setting which might have received a moderate amount of sediment derived from the continental edge and which would have been influenced by bottom currents if they had been active in the past (Site 360 on the upper continental rise in the Cape Basin).

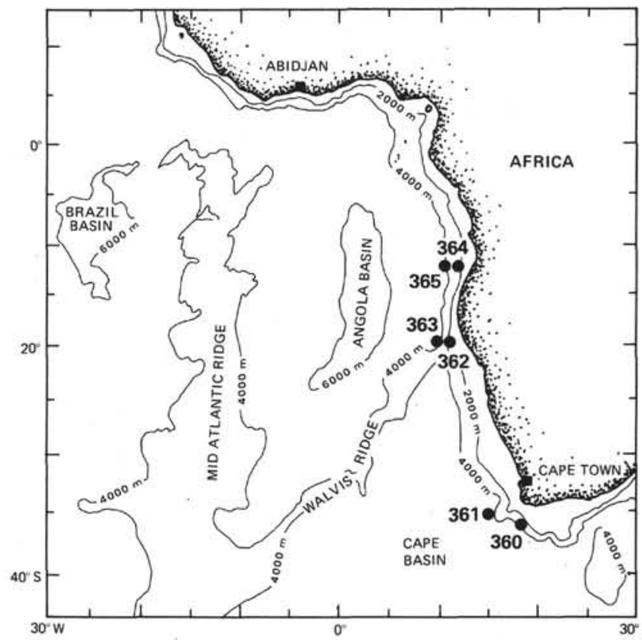

Figure 1. *Leg 40 drill sites, Cape Town to Abidjan.*

One relatively shallow setting which would have received a significant terrigenous sedimentation by its proximity to continental margin by-pass systems (Site 365 originally targeted on the upper continental rise, but later shifted into a deep-sea canyon dissecting the continental slope of Angola).

One site in a relatively deep setting so as to have received basinal-type sediments, but situated at the same time near enough to the continental edge so that the deepest sediments encountered would have formed within the first 10 million years of South Atlantic evolution while the juvenile ocean was less than 500 km in width (Site 361 on the lowermost continental rise in the Cape Basin).

One site to reach down to and hopefully sample the early Cretaceous (Aptian-age) evaporites which accumulated in a narrow and isolated embryonic South Atlantic north of the Walvis Ridge barrier (Site 364 on the salt plateau of the continental slope of Angola).

One site that would have been very shallow during the early restricted phase of the South Atlantic and which could be used to evaluate the paleodepth of the floor of the salt basin during the Aptian salinity crisis (Site 363 on the crest of the northern Walvis Ridge marginal escarpment).

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Two sites which would sample a basaltic-type crust. One would be targeted in a typical abyssal setting in an ocean basin possessing magnetic lineations (Site 361 in the Cape Basin) and the second over a high-standing aseismic ridge (Site 363 on the Walvis Ridge). Neither objective was successfully reached because of the destruction of the drill bits in the sediment columns within tens of meters of the surfaces of the acoustically definable basement.

In order that Early Cretaceous strata could be reached at each of the three geographic regions, we found it necessary to take advantage of local unconformities which allowed a by-passing of the superficial young strata when the deepest layers were the principal objective of a particular site. Hence, in both the Cape Basin continental rise and Walvis Ridge abutment areas, stratigraphic sections had to be assembled by splicing together a composite of two holes. In the Cape Basin the combined sequence (Site 360 and 361) is continuous from the early Pliocene to the earliest Aptian. The late Pliocene and Quaternary were unfortunately not sampled due to marginal dynamic positioning capabilities which mandated an immediate burial of the 80-meter-long bottom-hole assembly before commencing coring operations. In the Walvis Ridge area two overlapping columns (Sites 362 and 363) provide an ~110 million year succession from the late Pleistocene into the late Aptian except for an approximate 10-m.y. gap within the early Turonian and Cenomanian. A single site on the Angola margin (364) turned out to be sufficient for attaining a succession extending from the Pleistocene into the late Aptian, but this site suffered from a major 15-m.y. erosional gap in the Oligocene and late Eocene and an 8-m.y. gap across the Mesozoic/Cenozoic boundary, as well as a condensed interval comprising the Turonian and Cenomanian stages.

SPECIFIC SCIENTIFIC OBJECTIVES

Among the specific objectives of Leg 40 was the calibration of the Cape Basin lineations (magnetic) to the biostratigraphic time scale. We addressed this objective by targeting Site 361 above Anomaly M-4, and Site 363 on a projection of Anomaly M-O into the Walvis Ridge. We considered the dating of Cape Basin lineations (Larson and Ladd, 1973; Emery et al., 1975a; Mascle and Phillips, 1972) to be of great importance in determining the timing of the opening of the South Atlantic (Valencio and Vilas, 1969; Cox, 1970; Dietz and Holden, 1970; Dingle and Klinger, 1971; Le Pichon and Hayes, 1971; Francheteau and Le Pichon, 1972; Ladd et al., 1973) and the commencement of active ocean floor accretion at an axial spreading center.

Additional objectives included the sampling of old sediment layers deposited when the South Atlantic was narrow, and was restricted from the ancestral Indian and Pacific oceans by high-standing barriers including the Madagascar and Mozambique ridges, the Falkland Plateau, and the Walvis Ridge-Torres Arch.

We further considered it important to learn from the associated faunal assemblages present in these early sediment layers whether the initial entrance of marine water to the opening South Atlantic (Reyment and Tait, 1972; Kennedy and Cooper, 1975) came from the south (carrying a boreal assemblage) or from the north via the equatorial Atlantic (with a tropical or Tethyan assemblage).

We considered it likely that evidence of restricted environments would be found by recovering facies deposited under conditions of abnormal salinity and oxygen depletion (Arthur, 1976).

The subsidence history of the aforementioned topographic barriers and sills would determine the similarity or lack of similarity of sediment types in the separate basins. One important question concerned whether the basin shared the same deep-water current systems in the Cenzoic and whether they had a common history in respect to the fluctuations of the level of carbonate dissolution (Maxwell, von Herzen, Hsü, et al., 1970; Berger, 1972) degree of fertility, and rate of sediment supply (van Andel, 1975).

The origin of the South Atlantic (Angola Basin) salt deposit (Belmonte et al., 1965; Brink, 1974; Brognon and Verrier, 1966a, b; Vidal et al., 1975; Pautot et al., 1973; Delteil et al., 1975; Leyden et al., 1972, 1976; von Herzen et al., 1972; Roberts, 1975; Burke, 1975) remained an unsolved problem particularly in light of whether the salts were laid down in ancient coastal lagoons or sabkhas beneath the modern continental slope (Kinsman, 1975) and within the confines of former rift valleys of a subsiding continental crust, or whether the salt was deposited in a hypersaline sea whose axial area was floored by oceanic crust extruded since the initial separation of Africa from South America. Paleobathymetric considerations were of paramount interest (Sclater and McKenzie, 1973) and resolution of the ancient depths depended critically on the correct interpretation of the origin of Walvis Ridge. Some researchers had postulated a young uplift of the ridge (Connary, 1972; Emery et al., 1975), while others postulated the ridge to be a high-standing feature as early as the Albian-Cenomanian (Pastouret and Goslin, 1974).

We had considerable interest in the stratigraphic and lithologic nature of certain prominent seismic reflecting horizons mapped along the margin by various research groups. Specific key reflectors included Horizon D (first mapped by du Plessis et al., 1972 and named after the research vessel *Thomas B. Davie*) and Horizon AII (named after R/V *Atlantis II*). These reflectors were postulated by Emery et al. (1975) to be marker beds for the base of the Neogene and the base of the Paleogene, respectively.

Several angular unconformities and subsurface erosion surfaces were recognized in reflection records, particularly within the continental rise prism of the Cape Basin. Further elucidation of the age of the stratigraphic gaps would provide information related to paleocirculation which in turn might shed light on aspects of Cenozoic climatic cooling and the initiation of a vigorous bottom-water activity in response to the formation of an ice cap on Antarctica (Kennett et al., 1975; van Andel et al., 1975).

We judged the attainment of a section rich in calcareous planktonic foraminifers and nannofossils ranging from the Pleistocene back to at least the early Eocene to be highly desirable in order to quantify more precisely the various stages of climatic cooling (Jenkins, 1968; Douglas and Savin, 1971; Shackleton and Kennett, 1975) and also to permit study of that part of the climatic record often missing in other oceans due to Cenozoic hiatuses (Moore et al., 1975; Berger and von Rad, 1972; Johnson, 1972; Margolis and Kennett, 1970; Pimm and Hayes, 1972; Rona, 1973; Kennett and Watkins, 1975).

A continuous sedimentation across through the late Miocene and into the Pliocene at moderately high southerly latitudes would clarify the precise timing of a particularly strong and brief burst of Southern Ocean glaciation during the latest Miocene (Kapitean Stage of the New Zealand nomenclature). The stratigraphic position of the Kapitean stage had been recognized with predominantly boreal faunas (Hornibrook and Edwards, 1971, Kennett and Watkins, 1974; Edwards and Perch-Nielsen, 1974) and still remained to be calibrated accurately to European stages recognized with tropical and temperate faunas (Cita and Blow, 1969; Selli, 1960; Rio et al., 1976; Cita and Gartner, 1973; Gartner, 1973; Martini, 1971; Sprovieri, 1975; Stradner, 1973; Bukry, 1975).

This late Miocene glacial event on Antarctica (Hayes and Frakes, 1974) might have produced a significant drop in eustatic sea level which some workers have postulated as the mechanism which cut off the Mediterranean from the open ocean and induced the late Miocene salinity crisis there (Hsü et al., 1973; Nesteroff, 1973; van Couvering et al., 1976).

Sediment sequences laid down in continental margin settings would provide information on the development of belts of coastal upwelling which may have developed in response to climatic changes (Bornhold, 1973; Frakes and Kemp, 1972; van Andel and Calvert, 1971; Stander, 1964; Simpson and Needham, 1967; Siesser, 1972; Dingle, 1972). Episodes of high and low fertility could be recognized by determination of sedimentation rates for discrete stratigraphic intervals and by quantitative analyses of organic matter in the strata.

We had no insignificant desire to examine the hydrocarbon resource potential of the continental rise sedimentary province by searching for evidence of clastic sands diagnostic of fan valley settings, meandering across Early Cretaceous sedimentary aprons constructed when the ocean was still narrow and the ocean crust thermal regime still hot (Fischer and Judson, 1975; Klemme, 1975). The possibility of early euxinic environments was of interest because organic-rich muds laid down under stagnant conditions would be potential source rocks for petroleum and gas.

Although the sedimentary successions to be penetrated by *Glomar Challenger* on Leg 40 would not themselves be excessively thick and therefore prospective, they would be diagnostic of conditions that might make the much thicker deposits beneath the lower continental slope attractive at some date in the future (Emery, 1976) when exploration drilling extends into deeper water beyond the edge of the continental slope.

Even with the modestly deep anticipated Leg 40 penetrations, important new information would be gained relative to hydrocarbon maturation and sedimentary diagenesis, especially in relation to post-burial solution of calcium carbonate following the production of biogenic methane and carbon dioxide, and the extent of precipitation of the interstitial solution to alter the porosity and permeability of deeply buried clastic horizons.

The chemical composition of the interstitial waters of the Leg 40 cores could be expected to be extremely diverse because of a variety of drill-site locations ranging from salt basins to highland ridges which might have experienced subaerial emergence and to axial depocenters situated directly above basaltic lavas to the oceanic crust.

SUMMARY OF PRINCIPAL RESULTS

Age of Opening of the South Atlantic

Fossil-bearing sedimentary successions from the deepest cores at Sites 361 and 363, substantiate the paleomagnetic calibrations of Larson and Ladd (1973) placing the M-O anomaly within the Aptian stage of the Early Cretaceous. The Cape Basin lineations extend from Anomaly M-O back to Anomaly M-10N which, based on published DSDP results from Leg 32 in the Pacific Ocean (Larson, Moberly, et al., 1975) and preliminary observations on Leg 43 (Tucholke, Vogt, et al., 1975) in the North Atlantic, has a chronostratigraphic position within either the earliest part of the Hauterivian or within latest Valanginian stage of the Early Cretaceous. Such a stratigraphic position would imply an initiation of active separation of the continents of Africa and South America and the birth of the South Atlantic Ocean approximately 125 to 127 m.y. ago according to the geochronologic time scale of van Hinte (1976) which has been adapted for use by a Leg 40 shipboard scientific team. According to other published time scales the stratigraphic level could range from as young as 123 m.y. (Lambert, 1971; Bukry, 1975) to as old as 132 m.y. (Casey, 1964; Dickinson and Rich, 1972).

Early Cretaceous Oxygen Starvation in the South Atlantic

The most unusual and revealing lithologies cored on Leg 40 were the Aptian sapropelic shales interbedded with siltstones and massive silty sandstones at the base of Site 361 (Lithologic Unit 7) and upper Aptian to lower Albian sapropelic shales and marly dolomitic limestones overlying salt at Site 364 (Lithologic Unit 7). The sapropelic sediments are rich in pyrite and plant debris, especially at Site 361 where wood chips turned to coal up to 18 cm in length were recovered. These sediments indicate that oxygen-deficient euxinic conditions persisted for as long as 10 m.y. during the Early Cretaceous in the Cape Basin and intermittently in the Angola Basin. At Site 361, shales and sandstones filled the basin at this time at an incredible rate of over 60 m/m.y. Bottom-water conditions and/or interstitial brine concentrations were apparently so adverse to the preservation of calcite that calcareous microfossils were dissolved leaving only occasional remains of the internal linings of their tests but leaving beautifully preserved casts of their original shape in the soft shales (Noël and Melguen, this volume). Abundant spar-calcite cement in the coarse sandstones indicates that much of this carbonate migrated in solution to more permeable strata.

The rapid sedimentation of silt-laden sandstones and sapropelic shales at Site 361 is inferred to result from rapid denudation of rugged, marginal block-faulted mountains produced by sundering the continent within the pre-existent Cape Fold Belt. The large percentage of coarse plant debris—wood chips, seed pods, pollen grains, etc.—are indicative of a humid coastal climate and luxuriant plant growth on the continental edge.

Bottom waters within the Angola Basin at this time of the Early Cretaceous were also at times stagnant, but the climate was not nearly so humid. Evaporites accumulated to great thickness. Results of Site 364 plus dating of fossils above outcropping salt deposition as no later than lower upper Aptian. As the South Atlantic widened, circulation patterns allowed oxygenation of bottom waters at Site 361 by Albian time. Salt deposition had ceased in the Angola Basin, but intermittent euxinic conditions persisted at Site 364 into the lower Albian, and recurred again in late Albian to Santonian times. There was clearly a barrier between the Cape and Angola basins at this time. That barrier appears to have been the Walvis Ridge.

Origin and History of the Eastern Walvis Ridge

Site 363 was targeted out along a portion of the Walvis Ridge abutment plateau known as the Frio Ridge. This drill site is situated along the strike of magnetic anomaly M-O projected northwards from the Cape Basin (Barnaby, 1974). Anomaly M-O was dated at Site 361 as Aptian, also the age of the oldest fossils recovered at Site 363, thereby placing the origin of this portion of the Walvis Ridge at the Mid-Atlantic Ridge effectively at the same time as the adjacent oceanic crust. Recent geophysical work shows that there is an unusual thickness of a basaltic crust along the Frio Ridge (Goslin et al., 1974), yet bathymetry suggests a fracture zone alignment of the steep northern escarpment of the Frio Ridge (Barnaby, 1974) from which badly altered basalts have been dredged (Hekinian, 1972) as well as shallow water Albian-Cenomanian fossils (Pastouret and Goslin, 1974). The deepest core of Site 363, located just below the summit of a peak on the northern escarpment of the Walvis Ridge, recovered calcarenites, presumably fragmented in a rather high energy (nearshore?) regime, in addition to calcareous algae remains, and a small amount of phosphorite, all suggesting a nearby source of shallow water material. The nannofacies points to neritic conditions for the site at this time. All younger cores have bathyal assemblages. There is no evidence for a re-emergence of any proximate portion of the ridge at any later date, nor any evidence of ash falls or volcano-clastic breccias that would suggest any nearby emergent volcanoes active at a later date. Terrigenous influx from the African continent to Site 363 was small in the Aptian, but reached a peak in Upper Cretaceous times, dropping abruptly at the end of the Campanian. The history that emerges is of a shallow ridge, possibly capped with islands, formed virtually atop the Mid-Atlantic Ridge by some combination of transform faulting and excess volcanism such as that occurring on Iceland or the Azores. In its early history, Site 363 was relatively isolated from continental sediment sources, but subsidence coupled with progradation of the continental shelf over the eastern Frio Ridge brought an increased influx of terrigenous material to the site. This was rather abruptly terminated (the result of a Late Cretaceous transgression?) and terrigenous material was never again a major sediment component at Site 363. Chalks and calcareous oozes form the entire post-Campanian sediment column. The site is now beneath 2247 meters of water.

One core of Site 363, Core 26, has several black, pyritic, or carbonaceous mudstone layers. An unconformity has been detected directly above this core (261) with parts of the Cenomanian and Turonian missing, the largest of several gaps at Site 363, most of them erosional in origin judging from current and erosional structures in the sediments. The black layers indicate that oxygen deficient conditions may have prevailed far up on the Frio Ridge at this time. The layers correlate with mid-Cenomanian euxinic facies at Site 364 in the Angola Basin indicating that perhaps a stagnant water mass at least 2 km deep briefly filled the Angola Basin.

Post-Evaporite Depositional Environment in the Angola Basin

Sediments were reached at Site 364 that were deposited immediately after the Aptian salinity crisis. These carbonate beds, now extensively dolomitized, directly overlie a massive salt and evaporite layer which exceeds 2 km in thickness and which in turn covers acoustic basement. The sedimentary facies of the post-evaporite series reflects an intermittently restricted environment of moderate water depth above the level of aragonite dissolution (contains Albian age ammonites); however no indicators of the photic zone were detected. Depth differences between the crest of the Walvis Ridge in the vicinity of Site 363 and the top of oceanic basement (layer 2) of the Angola Basin immediately to the north indicate that with the measured evaporite thickness at Site 364, the water depth in latest Aptian time would have been in the range of 500 to 1000 meters. The sedimentation at Site 364 remained predominantly biogenic until the late Coniacian when this region received a significant supply of clastic material.

Cenozoic Carbonate Dissolution Cycles

During the Cenozoic, relatively shallow settings on the Cape Basin and the Angola Basin continental margins seem to have been affected at the same time by a very similar degree of carbonate dissolution reflecting major CCD fluctuations, both north and south of the Walvis Ridge. The major dissolution phase occurs during the Eocene and earliest Oligocene (with both sites situated well below the foraminifer lysocline). A less intensive dissolution phase occurs from middle to upper Miocene (with both sites situated above the lysocline at the upper Miocene). Because of lack of continuous coring at Site 364, comparison of the two sites for the middle Miocene is quite impossible. The Walvis Ridge sediments, however, do not reflect major fluctuations of carbonate preservation, except perhaps in the middle-upper Miocene.

SUMMARY OF OPERATIONS

Seven holes were drilled at six site locations (Figure 1) in three geographic regions (Table 1). Thirty-four days were spent on site permitting a net penetration of 6528 meters with a total recovery of 1502 meters (Table 2). Sixty-four percent of the section cored was actually recovered. The time underway steaming to and from the drill sites amounted to 17.1 days, and 8.6 days were spent in port affecting major repairs to the No. 2 bow thruster (Figures 2 and 3).

A DSDP penetration record of 1314 meters was achieved at Site 361. In addition, the rotating bit life record was broken three times, the longest of which was 89.25 hours. Part of the credit for these successes must be attributed to consistently good weather and the fact that no chert or basalt was drilled.

Site 360—Cape Basin

The first site was the most southerly, approximately 120 miles south of the Cape of Good Hope. The beacon was dropped on Site 360 less than 20 hours after leaving Cape Town.

The hole was spudded in 2977 meters of water and washed to 80 meters (so as to rapidly bury the bottom-hole assembly while the vessel was in manual positioning), and coring commenced.

All went smoothly until 26 December, when a check of an apparent tachometer malfunction indicated that the motor of No. 2 bow thruster (forward tunnel) was freewheeling and somehow disconnected from the thruster propeller. The weather, which had been unsettled for days, became a critical factor now that position-holding capabilities were reduced. An unfavorable forecast by the ship's meteorologist prompted a consensus decision to abandon the hole slightly short of the original projected penetration.

Although no hydrocarbons were detected, the location of Site 360 on the landward flank of the Cape Basin placed it technically on the continental rise. The hole was filled with weighted mud prior to abandonment in compliance with the recommendations of the JOIDES Panel on Pollution/Prevention and Safety.

A mudline punch core was attempted on the trip out of the hole but yielded no recovery. The string was pulled in deteriorating weather and a full gale was blowing by the time the ship was secured for sea. As the transit back to Cape Town for thruster repairs began, 80 mph winds were experienced and *Glomar Challenger* took rolls in excess of 20 degrees.

Although Site 360 was completed with only three thrusters, there was insufficient holding power to complete the leg without undue hazard to the drill string. The decision was made to return to Cape Town for repairs to bow thruster No. 2 and its tunnel. A total of 5.7 days were spent at Cape Town for these repairs.

Site 361—Cape Basin

Site 361 was located to the northwest of Site 360 and slightly deeper into the Cape Basin. The objectives of this site were to sample the lower Tertiary and Cretaceous sediments not penetrated at Site 360 and to determine the nature of the basement.

At about 1000 meters penetration (Core 28), a small amount of methane gas was detected. Some gas persisted in subsequent cores with the appearance of an ethane component. Continuous coring commenced with the first detection of gas and the methane/ethane ratio was monitored closely. No trends of increasing gas content or ethane percentage were noted. In fact, both parameters seemed to show, in general, a slight decrease with depth. The gas was found in black carbonaceous shales which were interbedded with sandstones and appeared to be in situ rather than migratory.

Basement was not reached in this hole due to bit failure at 1314 meters penetration which was a DSDP record for both penetration and bit rotating life (70 hours). A few basalt fragments in the last core indicated that basement was very close and age determination of the sediments showed them to be the oldest expected in this area. As gas had been encountered, the hole was plugged with cement and weighted drilling mud.

Upon completion of Site 361, we again headed for Cape Town on the recommendation of the ship's surgeon that a rotary helper be put ashore for finger surgery. He was transferred to a boat outside Cape

TABLE 1
Deep Sea Drilling Project Site Summary, Leg 40

Hole	Latitude	Longitude	Water Depth (m)	Number of Cores	Cores With Recovery	Percent of Cores With Recovery	Meters Cored	Meters Recovered	Percent Recovered	Meters Drilled	Total Penet. (m)	Average Rate Penet.	Time on Hole	Time on Site
360	35°50.75'S	18°05.79'E	2967	51	50	98	475.0	278.11	58.6	364.5	839.5	13.4	166.0	166.0
361	35°03.97'S	15°26.91'E	4547.5	49	49	100	465.5	222.07	47.7	848.5	1314.0	18.8	194.0	194.0
362	19°45.45'S	10°31.95'E	1326	44	44	100	418.0	367.25	87.9	387.5	805.5	45.5	70.3	
362A	19°45.45'S	10°31.95'E	1326	12	12	100	109.5	77.05	70.4	971.5	1081.0	24.8	75.0	145.3
363	19°38.75'S	09°02.80'E	2237	40	40	100	380.0	226.90	59.7	335.0	715.0	25.0	91.7	91.7
364	11°34.32'S	11°58.30'E	2439	46	46	100	427.5	295.61	69.2	658.5	1086.0	12.2	177.0	177.0
365	11°39.10'S	11°53.72'E	3040	7	7	100	63.0	34.65	55.0	624.0	687.0	30.5	50.4	50.4
Total				249	248	99.6	2338.5	1501.64	64.2	4189.5	6528.0	19.5		824.0

TABLE 2
Deep Sea Drilling Project Operations Resumé, Leg 40

Total days (17 December, 1974 - 15 February, 1975		60.10
Total days in port		8.60
Total days cruising[a]		17.10
Total days on site		34.40
trip time	3.9	
drilling time	10.8	
coring time	17.5	
mechanical downtime	.5	
position ship	.3	
other	1.4	
Total distance traveled (nautical miles)		3549
Average speed (knots)		9
Sites investigated		6
Holes drilled		7
Number of cores attempted		249
Number of cores with recovery		248
Percent of cores with recovery		99.6
Total meters cored		2338.5
Total meters recovered		1501.6
Percent recovery		64.2
Total meters drilled		4189.5
Total meters of penetration		6528.0
Percent of penetration cored		35.8
Maximum penetration (m)		1314.0
Minimum penetration (m)		687.0
Maximum water depth (m)		4547.5
Minimum water depth (m)		1326.0

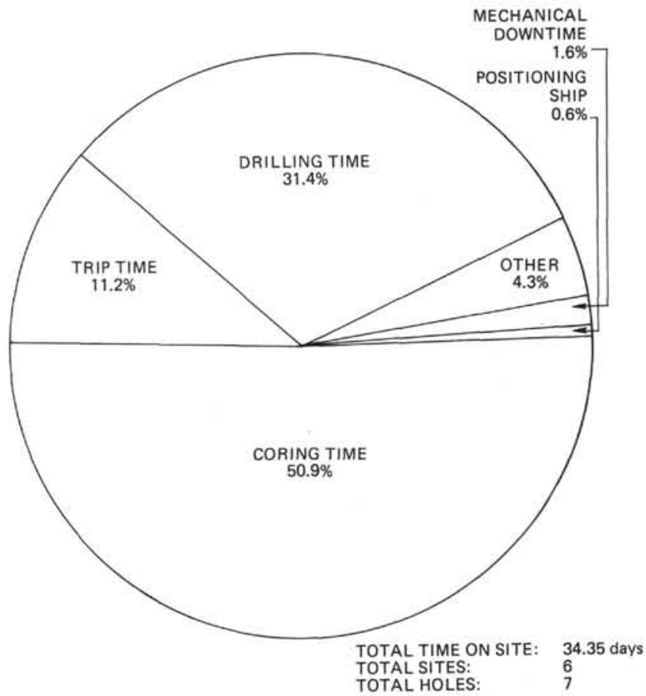


Figure 3. *Deep Sea Drilling Project, on-site time distribution, Leg 40.*

Town Harbor and the ship was immediately underway for Site 362. Some medical supplies and perishable food items were taken aboard from the boat. About 15 hours were lost in going via Cape Town.

Site 362—Walvis Ridge

Located about 120 miles off the coast of South-West Africa, Site 362 was situated atop the Frio Ridge segment of the Walvis Ridge. The objective was to sample a thick stratigraphic section, including several important regional seismic reflectors.

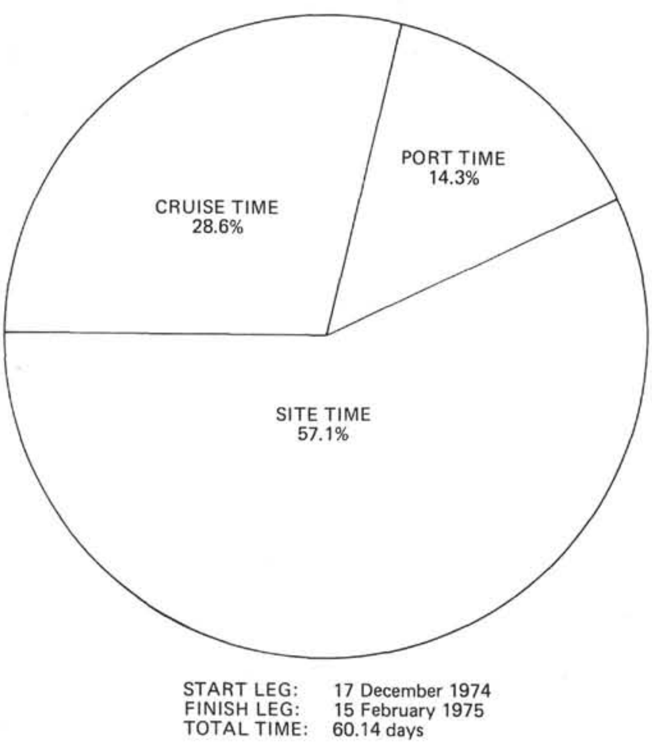


Figure 2. *Deep Sea Drilling Project total time distribution, Leg 40.*

After testing the drill pipe severing system, the hole was spudded in 1336 meters of water. Some methane gas was encountered in the shallower, unconsolidated sediments, but decreased to nothing with depth. Although concentrations were too low to detect by shipboard instruments, a powerful hydrogen sulfide odor permeated the core-handling areas while the uppermost sediments were being processed.

On the second day of drilling, it was noted that the cores showed indications that the inner core barrel was rotating with the outer barrel rather than remaining stationary during the coring operation. After several of these cores, two consecutive cores were pulled with recovery limited to the core-catcher section. Subsequent tests (chalking and running the extended core barrel) indicated that the inner barrels were no longer latching into place within the outer core barrel. At this point drilling was terminated and the drill string pulled. Examination of the bit revealed that the top plate of the experimental inner barrel seal assembly had deformed, preventing the inner barrels from sealing properly.

A new bit (without bit seal) was installed and a second hole, 362A, was spudded without offsetting the ship's position. No cores were taken from this hole until just short of the total depth of Hole 362. The trip to bottom and penetration to 796 meters were accomplished in one day's time. Harder sediments in the form of Eocene hard chalks and limestones were soon encountered, however, and the drilling rate dropped sharply. Drilling was terminated at 1081 meters subbottom in the face of very slow penetration rates and indications of bit locking.

The unforeseen thickness and degree of induration of the Tertiary sequence caused the limitations of time and bit life to be exceeded and frustrated any hope of reaching the Cretaceous objective at this site.

Site 363—Walvis Ridge

This site, located roughly 80 miles west of Site 362, was drilled in an attempt to sample the lower Tertiary and Cretaceous sections not penetrated at Site 362. The ultimate drilling objective was at least nominal penetration into the basement. Water depth was 2247 meters and no hydrocarbons were encountered.

Premature bit failure occurred, but was masked at this site as the failure occurred while progressively softer sediments were being drilled and fairly rapid penetration was being achieved. In fact, the failure was mistaken for a combination of hole sloughing problems and a plugged bit. The decision to pull out of the hole was not made until after a center bit had been pumped down to clear the bit and could not be pulled free by the sandline. When the bit cleared the rig floor, it was discovered that all the cones and the shanks were gone and only the "body" remained. The center bit protruded several inches below the core throat. The basement objective was not achieved.

Site 364—Angola Basin

Site 364, located about 100 miles off the coast of Angola, was selected as an optimum site for sampling the Tertiary and Upper Cretaceous stratigraphic sections and the evaporite sequence directly overlying a massive Lower Cretaceous salt stratum The ultimate drilling objective was to cut sufficient core in the salt to study its depositional history.

After spudding in 2449 meters of water and making 55 meters penetration, the WKM ball valve atop the swivel began leaking copiously. An additional 1-1/2 hours were lost in pulling above the mudline, repairing the valve, and respudding.

The only indications of hydrocarbons noted at Site 364 were petroliferous odors given off by organic and carbonaceous shales which were common through a fairly long section. No gas or fluorescence were encountered.

The drilling effort was again dogged by a stubbornly thick and well-indurated sediment section, this time Upper Cretaceous limestones and shales. In addition, high angle fractures and bedding planes introduced a persistent tendency for cores to jam at or near the core catcher. After a week on site and a heroic 89 hours and 15 minutes of rotating time, all the cones were run off the bit and the hole was abandoned. Pore water salinities indicated the salt was tantalizing near.

Site 365—Angola Basin

With the leg's operating time running out, the final site was a desperate attempt to reach the evaporite body by drilling on a steeply sloping subcrop area about seven miles southwest of Site 364. Rapid penetration was achieved in a section of shales, mudstones and sand much softer than the sediments of Site 364 and only spot coring was done. Some organic shale and sapropelic material similar to that of Site 364 was encountered, but there were no signs of "live" hydrocarbons.

After 687 meters penetration and no salt, time ran out and drilling was terminated. There were some indications that the drill may have entered the evaporites in the last few meters, but none were recovered in the final core.

Considerable drag was experienced in pulling to the mudline. This could have been caused by unstable hole conditions or by deviation of the hole from vertical due to bedding dips of up to 70° measured in the cores.

Leg 40 ended at 0926 on 15 February 1975 when the first line was put over in Abidjan, Ivory Coast.

Drilling and Coring Assembly

A standard DSDP bottom-hole assembly was used on all sites. This consisted of a bit, bit sub (with float valve), core barrel, three 8-1/4" drill collars, two 5' stroke Baash-Ross bumper subs, three 8-1/4" drill collars, two 5' stroke bumper subs, two 8-1/4" drill collars, one 7-1/4" drill collar, and one joint 5-1/2" heavy wall drill pipe.

Coring and Drilling Equipment

The standard DSDP core barrel assembly was used on all sites. In general, core recovery was quite good except in intervals of interbedded sediments of variable induration. Due to time limitations, greater than optimum pump pressures often were utilized while coring in order to achieve more rapid penetration. Although this reduced recovery somewhat and caused moderate to severe erosion of the core (reduced diameter), the compromise was needed to meet the scienific penetration objectives.

Core barrel jamming was the common cause for low recovery, especially at Sites 364 and 365. The jamming appeared to be the result of a wedging action caused by oblique fractures in limestones and hard chalks and by high-angle bedding and parting planes in shaly and laminar formations. It did not seem attributable to any defect in equipment or technique.

Bit Performance

The performance of the core bits was a credit to the years of development the tungsten carbide insert roller cone core bit has undergone. Of the seven bits run, the average rotating time was 49.3 hours (Table 3). Four of these bits were run until they failed. The average penetration rate for the leg was 19.52 meters per hour. Long chisel insert type 93 bits were run at Sites 360, 361, and 365 where sedimentary lithologies of low compressive strength were anticipated and where little or no chert or basalt was expected. Predictably they achieved a faster penetration rate in shales, mudstones, and hard clays than did the type 94 bit with shorter inserts used on the other holes. In hard chalks, limestones, and very soft formations, no real difference could be noted. Both types had difficulty penetrating

TABLE 3
Deep Sea Drilling Project Bit Summary, Leg 40

Hole	Mfg.	Size	Type	Serial Number	Meters Cored	Meters Drilled	Meters Total Penet.	Hours on Bit	Condition	Remarks
360	Smith	10-1/8"	F93C	KN148	475.0	364.5	839.5	62.5	T1, B1, SE	
361	Smith	10-1/8"	93CJS	JK243	465.5	848.5	1314.0	70.0	T8, B8, OG	Three cones gone - fourth locked and flattened
362	Smith	10-1/8"	F94C	PC157	418.0	387.5	805.5	17.7	T1, B1, SE	Bit seal failure - possible rerun
362A	Smith	10-1/8"	F94CK	SZ083	109.5	971.5	1081.0	43.7	T1, B5	Seal gone and evidence of locking (one cone only)
363	Smith	10-1/8"	F94C	KN080	380.0	335.0	715.0	28.7	T8, B8, OG	Three-cone – all cones and shanks gone
364	Smith	10-1/8"	F94CK	SZ092	427.5	658.5	1086.0	89.25	T8, B8, OG	All cones gone - shanks intact
365	Smith	10-1/8"	F93CK	KN144	63.0	624.0	687.0	22.5	T1, B2, SI	Rerun - two seals gone
					120.0	199.5	319.5	10.8		Run on Leg 38
Total					183.0	823.5	1006.5	33.3		Total for bit

well-indurated waxy marls. Only one three-cone bit, a model F94C, was used, at Site 363. It failed after less than 29 hours rotating time, a much shorter lifespan than the pattern established by the four cone bits used.

Dynamic Positioning

Considering the criterion of staying within a distance of the beacon equal to 3% of the water depth, positioning on Leg 40 was satisfactory with one exception. This was an excursion caused by power failure. However, several problems did occur that could have easily caused either the loss of a hole or at least part of a drill string had it not been for the skill of operating personnel and/or good fortune.

Experimental Bit Seal

An experimental bit seal assembly was run in Holes 360, 361, and 362. The assembly is installed in the throat of the bit and is designed to pack off the core-catcher sub diverting nearly all the drilling fluid through the bit jets. The first test was inconclusive as the assembly was inadequately welded into place and broke free. The tests at Sites 361 and 362 produced failures of the top plate and teflon sealing rings. There is some indication that the seal does, indeed, improve bit hydraulics. Nearly 88% of the 418 meters cored at Hole 362 was recovered before deformation of the top plate forced abandonment of the hole.

Hydrocarbons

Methane gas was present in cores recovered at Sites 361 and 362. The presence of an ethane component at Site 361 in carbonaceous sediments resulted in continuous coring and very careful monitoring of the gas analysis. The methane/ethane ratio did not show an increasing trend and the amount of gas present decreased with depth. No heavier hydrocarbons were detected. At Site 362, methane, associated with a strong hydrogen sulfide odor, was limited to shallow incompetent sediments and decreased markedly with depth. No liquid hydrocarbons, remanent fluorescence, or oil staining were detected during the leg. However, with the increasing importance of hydrocarbon safety in this type of drilling, the present method of fluorescence detection should be improved.

Underway Geophysical Measurements

While the *Glomar Challenger* was "underway" traveling to and from drill-site locations or port, continuous observations were made of water depth and magnetic field intensity. In addition, subbottom seismic profiles were generated with an airgun sound source. Two sweep intervals were used in the seismic profiling, one at 10 seconds and one at 5 seconds. The filter settings and gain settings are recorded on the profiles. Underway measurements were not taken within the territorial sea of coastal nations or across their continental shelves as defined by the Geneva Convention. Navigation was provided by orbiting satellite with the gyrocompass and electromagnetic log was used to interpolate positions of course or speed changes while maneuvering. Photocopies of the seismic profiles are available from the Deep Sea Drilling Project on microfilm. The Leg 40 navigational track and the magnetic and bathymetric profile along this track appear in this volume.

Biostratigraphic Zonations

The biostratigraphic subdivisions and age determinations are based where possible on calcareous nannoplankton and planktonic foraminifers. The calcareous nannoplankton scheme used for the Tertiary (Tables 4 and 5) is very close to the standard zonation of Martini (1971). However, where thought to be more reliable, certain zones and subzones were replaced by those of Bukry (1973, 1975). It was not possible to recognize Martini's lower Paleocene subdivision into the four Zones NP1-NP4. This whole interval therefore had to be included in a single *Cruciplacolithus tenuis* Zone. Reference is made to Tables 4a and 4b in Proto-Decima and Todesco (this volume) on the correlation of the Tertiary calcareous nannoplankton zonal scheme as used in this volume to those of Martini (1971) and Bukry (1975). The nannoplankton zones applied to the Upper Cretaceous (Table 6) are based on Cepek and Hay (1969), Martini (1969, 1976), Bukry and Bramlette (1970), Manivit (1971), Perch-Nielsen (1972, 1977), and Roth (1973). The zonal system applied to the Lower Cretaceous is that proposed by Thierstein (1971, 1973).

For the biostratigraphic subdivision of the Tertiary based on planktonic foraminifers, the tropical schemes of Bolli (1957a-c, 1966, 1972 and Saunders et al., 1973) were applied to all sites (Tables 4 and 5). At Sites 360, 362, and 362A where boreal faunas prevail or are present, the Austral-New Zealand scheme of Jenkins (1966, 1967, 1975) is added. The Cretaceous planktonic foraminifer zonal scheme for Sites 363 and 364 (Table 6) is synthesized from van Hinte (1976), Longoria (1974), Moullade (1966), and Porthault (1974). In the Cretaceous of Site 361 where planktonic foraminifers are virtually absent and the calcareous nannoplankton exceedingly poorly preserved, pollen, spores, and dinoflagellates were successfully applied to an age subdivision. In addition to calcareous microfossils, palynomorphs were also used for dating in the Cretaceous of Site 364 and in the Tertiary of Site 365. Ammonites present in the Lower Cretaceous of Sites 363 and 364 also proved age diagnostic. Radiolarians occur only very irregularly and mostly in small numbers in the Leg 40 sites; only in a very few instances did they turn out to be of stratigraphic value.

Chronostratigraphy

The chronostratigraphy for the Leg 40 Neogene (Table 4) is based on the linear time scale of Ryan et al. (1974) determined by means of paleomagnetic calibrations of European type-sections and equatorial Pacific piston cores. The nannofossil zonal boundaries are directly calibrated to this time scale. Hence the widths of these zones as illustrated in Table 1 are considered indications of their approximate durations in time in continuously deposited sedimentary successions. The tropical planktonic foraminiferal zonal boundaries are not individually calibrated. By convention, certain zonal boundaries are placed coincident with Epoch boundaries or the subdivisions of the Epochs in lower, middle, or upper parts. Within each such subdivision, the tropical foraminifer zones have equal widths. Such a scheme is required until the individual faunal datums used to define the zones are separately calibrated by means of the paleomagnetic reversal sequence.

Only a few of the Austral-New Zealand planktonic foraminifer zonal boundaries have been individually calibrated to the paleomagnetic reversal sequence. These include the base of the *Globorotalia truncatulinoides* Zone, the base of the *G. inflata* Zone, and the base of the *G. conomiozea* Zone. Other zonal boundaries have been determined only by their relative position to the calcareous nannoplankton zonal boundaries and tropical planktonic foraminifer boundaries. By convention the base of the *Globorotalia miotumida* Zone has been placed at the base of the upper Miocene, the base of the *Orbulina suturalis* Zone at the base of the middle Miocene, and the base of the *Globigerina woodi connecta* Zone at the base of the lower Miocene.

The base of the *Globorotalia puncticulata* Zone in the Leg 40 scheme is somewhat older than the determination of Kennett and Watkins (1974), but this limit is not well defined and is based almost entirely on the record from Site 360. Its position at Site 362 at a level correlated with the late Miocene calcareous nannofossil zones is not understood.

The Paleogene chronostratigraphy (Tables 4 and 5) is based to a great extent on the time scale of Berggren (1972). Again the width of the tropical planktonic and Austral-New Zealand planktonic foraminifer zones are not indicative of the relative duration of these zones. Only the calcareous nannoplankton zones provide an indication of the time duration between selected faunal datums which act as the zone markers.

The Cretaceous chronostratigraphy (Table 6) is adapted directly from the calibrated time scale of van Hinte (1976). The only departure is the placement of the base of the Maestrichtian stage at 71 m.y. instead of 70 m.y. As in the Neogene and Paleogene the calcareous nannofossil zonal boundaries are chronostratigraphically calibrated, whereas the planktonic foraminifer zones have equal widths within single Cretaceous stages.

Paleomagnetic Stratigraphy

The paleomagnetic reversal sequence for the Neogene (Table 4) is from a recent compilation of LaBrecque et al. (in press) based in part on the magnetic anomaly patterns of Talwani et al. (1971), Blakely (1974), and the integration of Ryan et al. (1974). The reversal sequence for the Paleogene (Tables 4 and 5) is also from LaBrecque et al. (in press) adjusted from that of Heirtzler et al. (1969) to account for the position of Anomaly 29 just above the Cretaceous/Paleocene boundary (Sclater et al., 1974).

The reversal sequence for the Late Cretaceous (Table 6) is based only in part on the paleomagnetic determinations of the Gubbio section in Italy (Alvarez et al., in press), and to a greater extent on the relative spacing of ocean floor magnetic Anomalies 30 through 34 by Cande and Kristoffersen (in preparation). This sequence has been tied to the biostratigraphic zonation within the Gubbio section so that its chronostratigraphic calibration is better than that of the foraminifers, because uniform widths of the anomalies were arbitrarily assigned to the foraminifer zones.

The Early Cretaceous reversal sequence is from Larson and Pitman (1972, 1975) with adjustments which are documented in Chapter 2 (this volume). Additional anomalies have been recognized in the Cape Basin site surveys and corresponding polarity reversals in the Cape Basin drill cores (Keating and Helsley, this volume) and are noted as Anomalies M minus 1, M minus 2, and M minus 3. The latter anomaly is calibrated to the Albian-age *Eiffellithus turriseiffeli* nannoplankton Zone, based on paleomagnetic reversals discovered in Cores 20 to 23 of Site 263 in the Indian Ocean (Green and Brecher, 1974; Jarrard, 1974).

Physical Properties

The mass physical properties of soft and indurated sediments which are routinely recorded onboard *Glomar Challenger* are: color, water content, bulk density, porosity, shear strength, and sonic velocity. From these basic data, information regarding consolidation characteristics, pore volume-overburden pressure relationships, and sound velocity gradients can be derived. The latter, sound velocity gradients, provide a means to correlate seismic profiles with the lithologies

TABLE 4
Pleistocene Through Oligocene Time Scale, Biostratigraphic Zonations, and Magnetic Reversal Sequence Used on Leg 40

Age: m.y.	Age: Series		Tropical Planktonic Foraminiferal Zones [a]	Austral-New Zealand Planktonic Foraminiferal Zones [a]	Calcareous Nannoplanktonc Zones	Magnetic Reversal Sequence: Epoch	Magnetic Reversal Sequence: Anomaly
0	Pleistocene		*Globorotalia truncatulinoides truncatulinoides*	*Globorotalia truncatulinoides truncatulinoides*	*Emiliania huxleyi/ Gephyrocapsa oceanica*; *Emiliania ovata*	Brunhes; Matuyama	1; 2
	Pliocene	U.	*Globorotalia truncatulinoides cf. tosaensis* *	*Globorotalia inflata*	*Discoaster brouweri*	Gauss	2'
		M.	*Globorotalia miocenica*		*Reticulofenestra pseudoumbilica*		
5		L.	*Globorotalia margaritae*	*Globorotalia puncticulata*	*Ceratolithus rugosus*; *Amaurolithus tricorniculatus* (*C. acutus*; *T. rugosus*)	Gilbert; 5	3; 3'
10	Miocene	U.	*Neogloboquadrina dutertrei*	*Globorotalia conomiozea*	*Amaurolithus primus*; *Discoaster quinqueramus* (*Discoaster berggrenii*); *Discoaster calcaris*	5; 6; 7; 8; 9; 10	4; 4'; 5
			Globorotalia acostaensis	*Globorotalia miotumida*	*Discoaster hamatus*	11; 12	5A
			Globorotalia menardii			13	
		M.	*Globorotalia mayeri*	*Globorotalia mayeri mayeri*	*Catinaster coalitus*	14	
			Globigerinoides ruber		*Discoaster kugleri*		
			Globorotalia fohsi robusta *		*Discoaster exilis*	15	5B
15			*Globorotalia fohsi lobata*		*Sphenolithus heteromorphus*		
			Globorotalia fohsi fohsi *				
			Globorotalia fohsi peripheroronda	*Orbulina suturalis*		16	5C
		L.	*Praeorbulina glomerosa*	*Praeorbulina glomerosa curva*	*Helicosphaera ampliaperta*		5D
			Globigerinatella insueta	*Globigerinoides trilobus trilobus*	*Sphenolithus belemnos*	17; 18	5E
20			*Globigerinita stainforthi*		*Discoaster druggii*	19	6
			Globigerinita dissimilis	*Globigerina woodi connecta*		20	6A
			Globigerinoides primordius			21; 22	6B
25	Oligocene	U.	*Globorotalia kugleri*	*Globigerina woodi woodi*	*Triquetrorhabdulus carinatus*; *Sphenolithus ciperoensis*	23; 24	7
			Globigerina ciperoensis ciperoensis	*Globoquadrina dehiscens*	*Sphenolithus distentus*		8; 9
30			*Globorotalia opima opima*	*Globigerina euapertura*			10
		M.	*Globigerina ampliapertura*	*Globigerina angiporoides angiporoides*	*Sphenolithus predistentus*		11; 12
35		L.	*Cassigerinella chipolensis/ Pseudohastigerina micra*	*Globigerina brevis*	*Helicosphaera reticulata*; *Ericsonia subdisticha*		13; 14

[a] Foraminiferal zonal widths are not indicative of durations within individual series. Nannoplankton Zones are, however, calibrated.

* Indicates that zone was not recognized on Leg 40.

TABLE 5
Eocene and Paleocene Time Scale, Biostratigraphic Zonations, and Magnetic Reversal Sequence Used on Leg 40

Age: m. y.	Age: Series		Tropical Planktonic Foraminiferal Zones [a]	Austral-New Zealand Planktonic Foraminiferal Zones [a]	Calcareous Nannoplankton Zones	Magnetic Reversal Sequence: Anomaly
	Eocene	U.	*Globorotalia cerroazulensis* s. l.	*Globigerina brevis*; *Globigerina linaperta*	*Sphenolithus pseudoradians*	14, 15
40			*Globigerinatheka semiinvoluta*		*Isthmolithus recurvus*; *Chiasmolithus oamaruensis*	16, 17
		M.	*Truncorotaloides rohri*	*Globigerinatheka luterbacheri*	*Reticulofenestra umbilica*	18
			Orbulinoides beckmanni			19
45			*Globorotalia lehneri*	*Globigerinatheka* cf. *index*	*Nannotetrina fulgens*	20
			Globigerinatheka s. subconglobata	*Pseudogloboquadrina primitiva*		
			Hantkenina aragonensis		*Discoaster sublodoensis*	
		L.	*Globorotalia palmerae*		*Discoaster lodoensis*	
50			*Globorotalia aragonensis*		*Tribrachiatus orthostylus*	21
			Globorotalia formosa formosa			
			Globorotalia subbotinae		*Discoaster binodosus*	
			Globorotalia edgari		*Tribrachiatus contortus*	22
	Paleocene	U.	*Globorotalia velascoensis*		*Discoaster multiradiatus*	
55			*Globorotalia pseudomenardii*		*Discoaster nobilis*	23
		M.	*Globorotalia pusilla pusilla*		*Discoaster mohleri* *	24
			Globorotalia angulata		*Heliolithus kleinpellii*	
			Globorotalia uncinata		*Fasciculithus tympaniformis*	25
60		L.	*Globorotalia trinidadensis*		*Cruciplacolithus tenuis*	26
			Globorotalia pseudobulloides			27
			Globigerina eugubina *			28, 29

[a] Foraminiferal zonal widths are not indicative of durations within individual series. Nannoplankton zones are, however, calibrated.

* Indicates that zone was not recognized on Leg 40.

TABLE 6
Mesozoic Time Scale, Biostratigraphic Zonations, and Magnetic Anomaly Sequence Used on Leg 40

Age: m. y.	Age: Stage	Planktonic Foraminiferal Zones [a]	Calcareous Nannoplankton Zones
65	Maestrichtian	*Globotruncana mayaroensis*	*Micula mura*
		Globotruncana gansseri	*Lithraphidites quadratus*
70		*Globotruncana havanensis*	*Arkhangelskiella cymbiformis*
	Campanian	*Globotruncana calcarata* *	*Tetralithus trifidus*
75		*Globotruncana ventricosa* *	*Eiffellithus eximius*
		Globotruncana fornicata *	
80	Santonian	*Globotruncana concavata carinata* *	*Marthasterites furcatus*
		Globotruncana concavata *	
	Coniacian	*Globotruncana primitiva*	
85		*Globotruncana sigali*	*Micula staurophora*
	Turonian	*Globotruncana helvetica* *	
90		*Hedbergella portsdownensis* *	*Corollithion exiguum* *
	Cenomanian	*Rotalipora cushmani* *	*Lithraphidites alatus* *
		Rotalipora reicheli *	
95		*Rotalipora greenhornensis* *	
		Rotalipora gandolfii *	
		Rotalipora brotzeni *	
100	Albian	*Rotalipora openninica* *	*Eiffellithus turriseiffeli*
		Planomalina buxtorfi *	
		Rotalipora ticinensis	
105		*Biticinella breggiensis*	*Prediscophaera cretacea*
		Ticinella primula	
		Ticinella bejaouensis	*Parhabdolithus angustus*
110	Aptian	*Hedbergella trochoidea*	
		Hedbergella gorbachikae	
		Globigerinelloides algeriana	
		Schackoina cabri *	*Chiastozygus litterarius*
115		*Globigerinelloides blowi* *	
	Barremian	*Hedbergella sigali* *	*Micrantholithus hoschulzii* *
120			*Lithraphidites bollii* *

Magnetic Anomaly Sequence

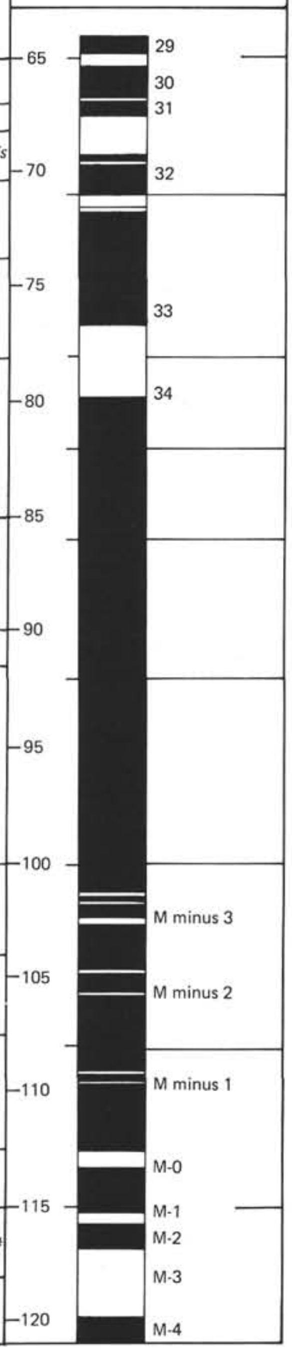


Table 6 shows the correlation with stage units of the planktonic foraminiferal and calcareous nannoplankton zonal schemes as established separately for each of the two fossil groups (see Caron, Figure 3 and Proto Decima et al., Table 2, this volume). The planktonic foraminiferal and the calcareous nannoplankton zonal schemes therefore are not necessarily directly correlatable.

The Leg 40 data for the Maestrichtian to upper Turonian concur with the correlation between the zones as shown on Table 6. No data from Leg 40 are available for the lower Turonian to Cenomanian. The Albian to Aptian correlation between the planktonic foraminiferal and the calcareous nannoplankton zones as reported from Leg 40 is however not in agreement with that on Table 6 and is shown on Table 7.

[a] The foraminiferal zonal widths are not indicative of the durations within individual stages.

* Indicates that zone was not recognized on Leg 40.

TABLE 7
Correlation of Calcareous Nannoplankton and Planktonic Foraminiferal Zones in the Albian and Aptian of Leg 40 Sites 363 and 364

Albian	U	*Eiffellithus turriseiffeli*	*Rotalipora ticinensis*	U	Albian
			Biticinella breggiensis	M	
			Ticinella primula		
			Ticinella bejaouensis	L	
	M	*Prediscosphaera cretacea*	*Hedbergella trochoidea* *Hedbergella gorbachikae*	U	Aptian
	L		*Globigerinelloides algeriana*		
Aptian	U	*Parhabdolithus angustus*			

recovered. Shear strength data are used by geologists as a quantitative measure of induration of sediment sensitivity of remolded samples, which is an indicator of the sediment's susceptibility to man-made or natural disturbance. In addition, shear strength measurements are used to determine slope stability and to indicate if any rapid or catastrophic events have occurred in a given section. Moreover, the shear strength of cohesive sediments is closely related to the bearing capacity for bottom structures.

The equipment utilized for physical properties evaluation onboard Leg 40 of *Glomar Challenger*, in order of use, is as follows: GRAPE, the Hamilton Frame Velocimeter, a Wykeham-Ferrance shear vane, and balances for gravimetric determinations. The GRAPE (Gamma Ray Attenuation Porosity Evaluator) is used (in an analog mode) to measure sediment porosity and bulk density. The GRAPE system consists of a drive train which carries a sample material between a shielded gamma ray source (Ba^{133}) and a shielded scintillation detector. On the present leg, this unit is being operated chiefly in an analog mode which uses a computer to calculate an apparent wet-bulk density from the measured parameters (Boyce, 1974; and Evans and Cotterel, 1970). The biggest area of uncertainty in the GRAPE system is the diameter of the sample when the core liner is not completely filled. Only when the total geometry of the system is known can reproducible results be obtained.

Below are definitions of terms related to the determination of water content, bulk density, porosity and specific gravity (Lambe and Whitman, 1969).

The Hamilton Frame velocimeter uses a time-distance relationship of a compressional sound wave through the sediment or rock to determine a sonic velocity. The Hamilton Frame velocimeter was used in its standard configuration as described by Boyce (1973a). This system, which uses a compressional sound wave of 300 kHz, is provided with a dial micrometer for measuring the distance traveled and an oscilloscope display to measure the time delay. The velocity of samples that were too weak to be handled without being destroyed was measured through longitudinally split core liner. Average correction of 0.256 cm linear thickness and a 1.180 microseconds time delay were used in calculating velocities.

A Wykeham-Ferrance motorized shear vane was installed in such a manner that the vane could penetrate split cores parallel to bedding. A four-bladed vane (diameter = 1.278 cm, height = 1.2785 cm) was used with a known torque being applied at a rate of about 65° per minute. When the vane is inserted into a sediment, torque is applied to the vane axis until it shears about a surface area which approximates that of the cylindrical area calculated with the diameter and height of the vane (Boyce, 1973b). From the maximum torque applied to the vane the undrained shear strength of clays can be calculated in g/cm² using Equation 1. where

$$T_f = c' = \left(\frac{2t}{\pi d^2 h \left(1+\frac{d}{3h}\right)}\right) \quad \text{(maximum degree spring stress)}$$

t = spring torque factor in (g/cm) degree;
d = diameter of blades on vane;
h = height of blades on vane;
c = Tf = cohesion and shear strength of clays at failure.

Geochemical Measurements

Introductory Remarks

It was originally anticipated that holes to be drilled along the southwest coast of Africa during the course of DSDP Leg 40 would penetrate strata favorable to the genesis and accumulation of petroleum. Consequently, all cores were monitored by a shipboard petroleum geologist-geochemist (J.B. Foresman) with the responsibility of detecting hydrocarbons and assessing the possibility of encountering high-pressure zones. Accordingly, pertinent recommendations were made jointly to the operations manager and the Co-Chief Scientists onboard.

Methods

Gas samples were extracted by syringe from gas pockets when these were visibly confined in the capped plastic core liner—then injected into a gas chromatograph.

The component composition of a given gas was determined by a portable field gas chromatograph constructed by the Exploration Research Division at Phillips Petroleum Company. Under optimum conditions, this instrument is capable of detecting hydrocarbon components in concentrations as low as 6 ppm. It is operated on a molecular sieve column for detection of hydrogen, nitrogen, methane, and carbon monixide, then switched to a bis-ether column for sensing 16 additional components from ethane-ethane and carbon dioxide through cis-pentene. The peak responses were recorded, normalized, and compared with known standards for quantitative calculations. Samples from the gas encountered were collected in vacuum cans for more sensitive analyses at Phillips shore-based laboratories.

Qualitatively, the standard ultraviolet method was used to examine oil staining in the cores. At the onset of the leg, samples of possible shipboard oil contaminants were collected for comparison and examined in an ultraviolet-light-viewing box where they were alternately subjected to ultraviolet and white light.

In addition, a shipboard device called the "Karbonate-Bombe" was used to provide routine measurements of the $CaCO_3$ content of given samples. Essentially, treatment of a sample with concentrated hydrochloric acid in the closed instrument creates a CO_2 pressure proportional to the $CaCO_3$ content the sample within an error margin of 1%. Data generated in this manner were submitted on forms for addition to the overall chemical analysis and also for incorporation into the sedimentology descriptions.

In addition, solid samples were collected in 20-cc volumes for shore-based study undertaken to investigate and describe genesis of hydrocarbons in the deep marine environment. Using high-resolution mass spectrometric and GC/MS methods, this involved analyses and treatment of the kerogen and lipid fraction, and determination and interpretation of carbon isotopic composition and residual organic matter versus carbonate carbon. This work is reported in Foresman (this volume). In addition, 20-cm sections of nearly every other core were cut and frozen for storage at the DSDP East Coast repository pending distribution to scientists requesting specimens through the JOIDES Organic Geochemistry Panel.

EXPLANATORY NOTES

Organization of the Site Chapters

Because sites in each of the three geographic regions (Cape Basin, Walvis Ridge, and Angola Basin) have a great deal of complementary information and share the same geological background, etc., we have decided to collate these results into single site chapters. Hence there are only three site chapters for the Leg 40 Initial Reports, one for Sites 360 and 361, one for Sites 362 and 363, and one for Sites 364 and 365.

In the process of combining the pairs of sites, we have attempted within each individual geographic region to use a common and integrated nomenclature for the lithologic units, acoustic units, physical proy units, and seismic reflecting horizons. Each chapter has a common background and summary which covers the objectives and results of the paired sites.

Authorship Responsibilities

The background, objectives, and operations sections were written by W.B.F. Ryan with input from the scientific team and operations manager (G.N. Foss). For the lithologic summaries B.K. McKnight was principally responsible for Site 360, W.G. Siesser for Site 361, M. Melguen for Site 362, J. Natland for Site 363, H. Kagami for Site 364, and B. McKnight and W.G. Siesser for Site 365. The Geochemistry sections for all the sites were prepared by J.B. Foresman, the Physical Prospectus sections by W.E. Hottman, and the Correlation of Reflection Profiles by W.B.F. Ryan and W.E. Hottman. The Biostratigraphy sections were written by H.M. Bolli, F. Proto-Decima, and J.F. Longoria with significant input from the shore laboratory investigations, corrected by H.M. Bolli. The Sedimentation Rates and Summary and Conclusion sections were compiled by W.B.F. Ryan and H.M. Bolli with major contributions from most of the scientific team.

Informal Lithologic and Acoustic Nomenclature

The lithologic and acoustic units are used throughout this volume in an informal sense, and there is no implication that, for example, Lithologic Unit 1 in the Cape Basin is equivalent to Lithologic Unit 1 in the Angola Basin or that seismic reflecting horizon blue on the Walvis Ridge is chronologically or in any other way equivalent to horizon blue in the Cape Basin, unless such a correlation is specifically stated.

Reflecting Horizons D and AII of Emery et al. (1975a) and Horizon A of Emery et al. (1975b) have been calibrated by Leg 40 drilling only within the small geographic area of the individual drill sites. Our results show that acoustic horizons are not of the same age on all profiles (as defined by Emery et al., 1975a, b) and hence even this formally published nomenclature is used in an informal sense by the Leg 40 scientific team until some of the miscorrelations can be satisfactorily resolved at a later date.

Numbering of Sites, Holes, Cores, Samples

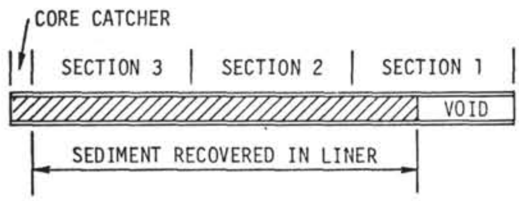
Drill site numbers run consecutively from the first site drilled by *Glomar Challenger* 1968, thus the site number is unique. A site refers to the hole or holes drilled from one acoustic positioning beacon. Several holes may be drilled at a single locality by pulling the drill string above the sea floor ("mud line") and offsetting the ship some distance (usually 100 m or more) from the previous hole.

The first (or only) hole drilled at a site takes the site number. Additional holes at the same site are further distinguished by a letter suffix. The first hole has only the site number; the second has the site number with the suffix A; the third has the site number with the suffix B; and so forth. It is important, for sampling purposes, to distinguish the holes drilled at a site, since recovered sediments or rocks usually do not come from equivalent positions in the stratigraphic column at different holes.

Cores are numbered sequentially from the top down. In the ideal case, they consist of 9 meters of sediment or rock in a plastic liner of 6.6 cm diameter. In addition, a short sample is obtained from the core catcher (a multifingered device at the bottom of the core barrel which prevents cored materials from sliding out during core-barrel recovery). This usually amounts to about 20 cm of sediment and is stored separately. This sample, from each core, represents the lowest stratum recovered in the particular cored interval. The core-catcher sample is designated by CC (e.g., 362-4, CC, core-catcher sample of the fourth core taken at Site 362).

The cored interval is the interval in meters below the sea floor, measured from the point at which coring for a particular core was started to the point at which it was terminated. This interval is generally 9.5 meters (nominal length of a core barrel), but may be shorter if conditions dictate. Cores and cored intervals need not be contiguous. In soft sediments, the drill string can be "washed ahead" without recovering core by applying sufficiently high pump pressure to wash sediment out of the way of the bit. In a similar manner, a center bit, which fills the opening in the bit face, can replace the core barrel if drilling ahead without coring is necessary.

When a core is brought aboard *Glomar Challenger*, it is labeled and the plastic liner and core cut into 1.5-meter sections. A full, 9-meter core would thus consist of six sections, numbered from the top down, 1 to 6. (The discrepancy between the 9-m core and 9.5-m cored interval is discussed below.) Generally something less than 9 meters is recovered. In this case, the sections are still numbered starting with one at the top, but the number of sections is the number of 1.5-meter intervals needed to accommodate the length of core recovered; this is illustrated below:

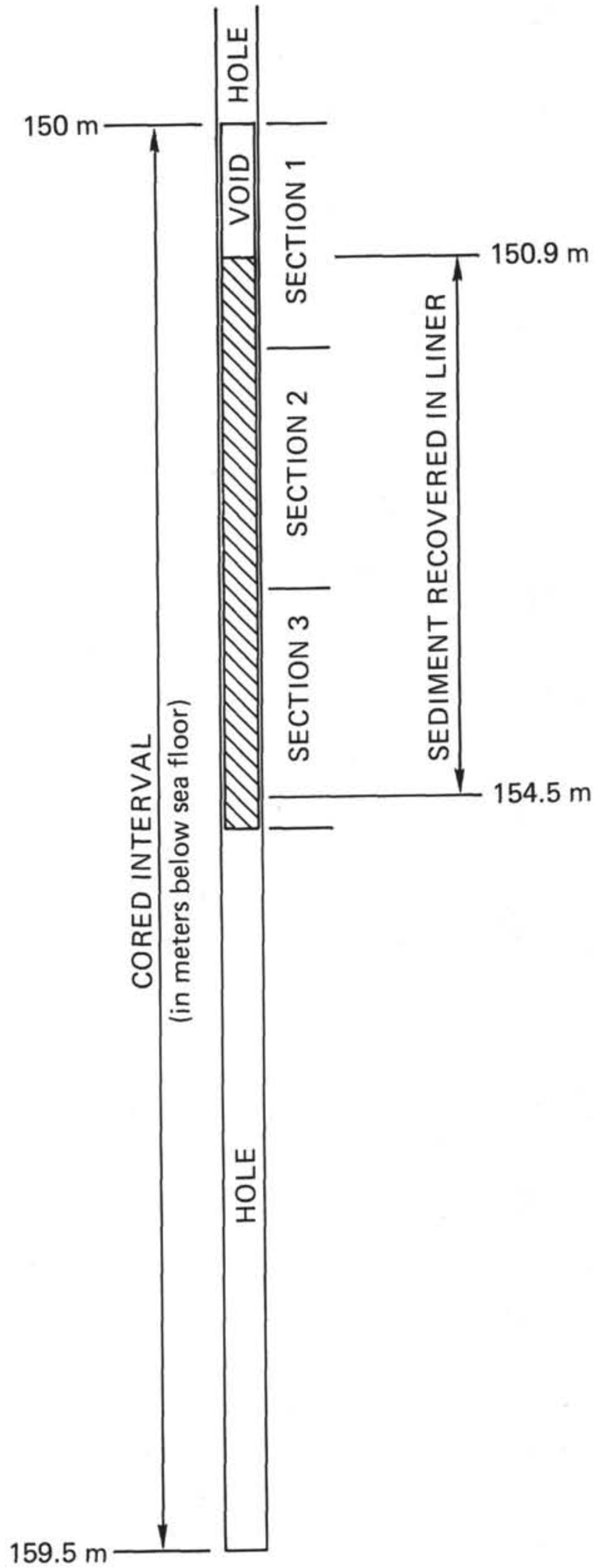


Thus, as shown, recovery of 3.6 meters of sediment would result in a core with three sections, with a void of 0.9 meters at the top of the first section. By convention, and for convenience, in routine data handling at the Deep Sea Drilling Project, if a core contains a length of material less than the length of the cored interval, the recovered material is placed in the top of the cored interval, with the top of Section 1, rather than the top of the sediment, equal to the top of the cored interval. This is shown below for the core in the above example.

Thus, the depth below the sea floor of the top of the sediment of this hypothetical core would lie at 150.9 meters (not 150.0 m) and the bottom at 154.5 meters (the core-catcher sample is regraded as being dimensionless).

It was noted above that a discrepancy exists between the usual coring interval of 9.5 meters and the 9-meter length of core recovered. The core liners used are actually 9.28 meters in length, and the core catcher accounts for another 0.2 meters. In cases where the core liner is recovered full to the top, the core is still cut into six 1.5-meter sections, measured from the bottom of the liner, and the extra 0.28-meter section at the top is designated Section 0, or the "zero section." The zero section is ignored in calculations of depth below the sea floor of cores or levels within cores.

In the core laboratory on *Glomar Challenger*, after routine processing, the 1.5-meter sections of sediment core and liner are split in half lengthwise. One half is designated the "archive" half, which is described by the shipboard geologists, and photographed; and the other is the "working" half, which is sampled by the shipboard and shorebased analysis.



Samples taken from core sections are designated by the interval in centimeters from the top of the core section from which the sample was extracted; the sample size, in CC, is also given. Thus, a full sample designation would consist of the following information:

Leg (Optional)
Site (Hole, if other than first hole)
Core Number
Section Number
Interval in centimeters from top of section

Site 362A-4-3, 122-124 cm (10 cc) designates a 10-cc sample taken from Section 3 of Core 4 from the second hole drilled at Site 362. The depth below the sea floor for this sample would then be the depth to the top of the cored interval (150 m in the example above) plus 3 meters for Sections 1 and 2, plus 122 cm (depth below the top of Section 3), or 154.2 meters. (Note, however, that sample requests should refer to a specific interval within a core section [in centimeters] rather than level [meters] below sea floor.)

Core Disturbance

The rotary drill-coring technique quite often results in a high degree of disturbance of the cored sediments. This is especially true of the softer unconsolidated sediments. A qualitative estimate of the degree of deformation is given in the deformation column of the core forms (see Figures 4 and 6 for symbols).

Carbon-Carbonate Data

Sediment samples are analyzed on a Leco 70-Second Analyzer at DSDP 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 carbon ±0.3% (absolute)
Organic carbon ±0.06% (absolute)
$CaCO_3$ ±3% (absolute)

Also included on the core forms for Leg 40 are carbon-carbonate data determined on organic geochemistry samples (OG on core forms). For all samples, the weight percent of organic carbon and carbonate carbon are presented.

Grain Size Analyses

The DSDP grain size analyses presented on the core forms are performed by standard sieve and pipette techniques, described in detail in Appendix III of Volume 4 of the Initial Reports (p. 745), with modified settling times as in Volume 9.

Sediment Classification

The sediment classification used here was devised by the JOIDES Panel in Sedimentary Petrology and Physical Properties, and adopted for use by the JOIDES Planning Committee in March 1974. It is included as Appendix 1 of this chapter.

Accompanying the sediment classification is the employment of a set of lithologic symbols (Figure 5). These symbols have been used on all core and site summary forms.

Smear Slides

Smear slides are the basic means of mineral identification for sediments on shipboard although thin sections and mineral grain mounts are used in studies of basaltic rocks.

smear slide estimates of mineral abundances were based on the area of the smear slide covered by each component. Past experience has shown that accuracy may approach a percent or so for very distinctive minor constituents but that, for major constituents, accuracy of ±10% to 20% is considered very good. Clays are most poorly estimated, since they have the same index as Caedex and balsam. Their proportion can only be estimated on Caedex-free portions of slides. Of more importance to the geologist than absolute accuracy are relative changes in component abundances. Selection of representative smear slide data was left to the sedimentologist in charge of preliminary core form preparation for each site. At Site 363, all smear slide data for each lithology were averaged for each core.

Figure 4. *Sedimentary structure symbols.*

Core Forms (Figure 6)

The basic lithologic data are contained on core summary forms. As far as possible the data are presented in the following order:

Sediment or rock name

Sediment Disturbance and Sedimentary Structures (Figure 4)

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 core sections. Experience with carbonate sediments shows 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 vi a smear slides

Grain size (Figure 7), carbon-carbonate, and X-ray data

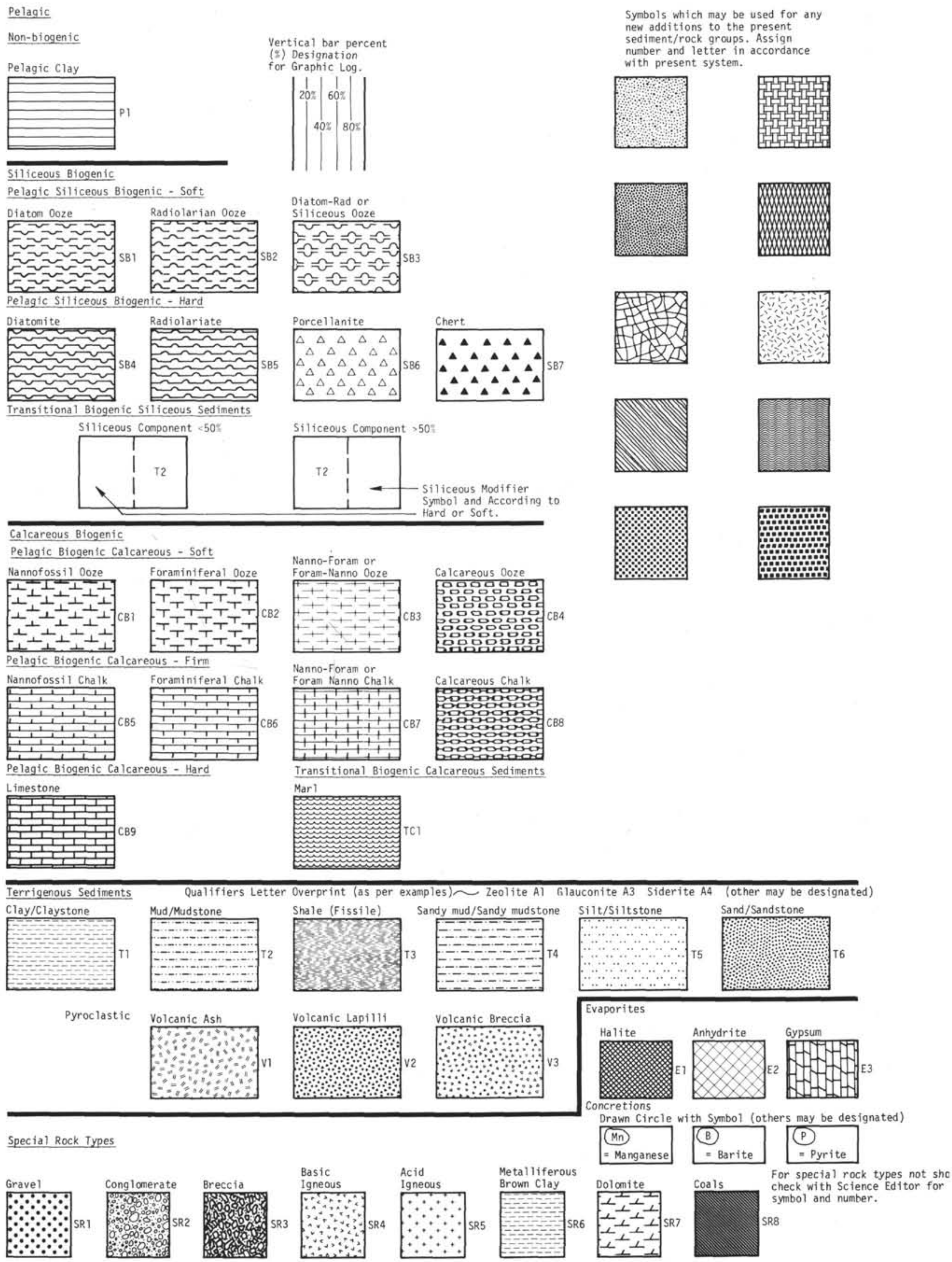


Figure 5. *Graphic symbols to accompany the lithologic classification scheme.*

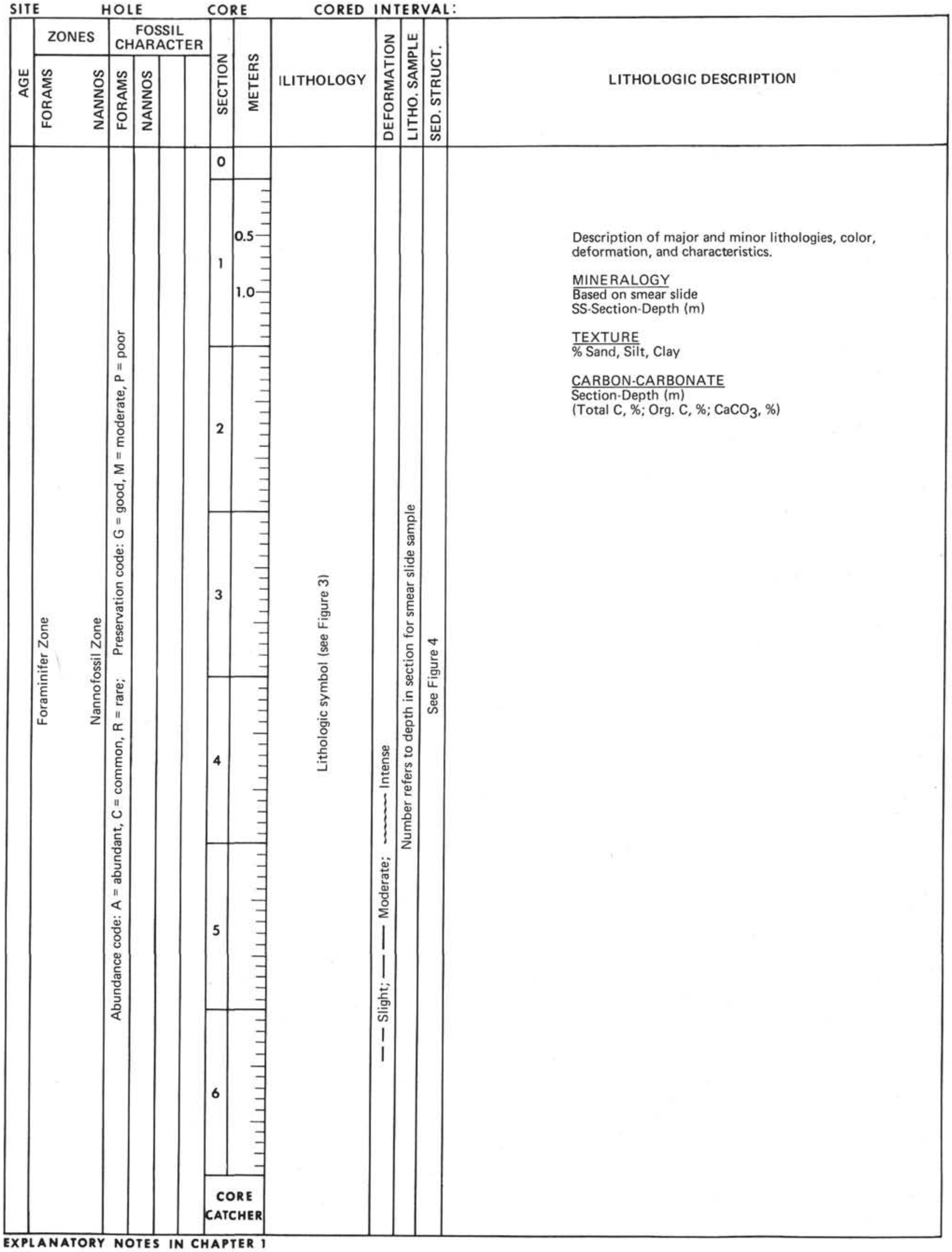


Figure 6. *Sample core form.*

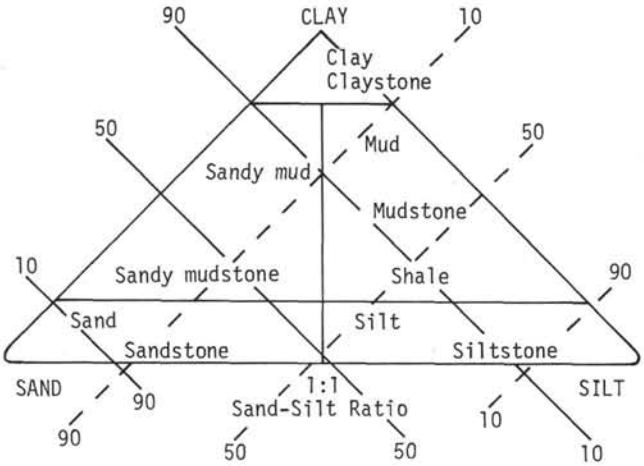


Figure 7. *Textural groups – terrigenous sediments.*

Many cores contain minor important lithologies as well as a basic lithology. The description of the basic lithology is so indicated in most cases, however, descriptive information for minor lithologies is included wherever possible. Grain size and carbon-carbonate results are from the DSDP laboratory at Scripps.

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APPENDIX A
CLASSIFICATION OF SEDIMENTS

Several lithologic classifications designed for the construction of the graphic core and hole summaries have been used during the lifetime of the Deep Sea Drilling Project. The classification system described here has been devised by the JOIDES Panel on Sedimentary Petrology and Physical Properties and adopted for use by the JOIDES Planning Committee in March 1974. It was first used on Leg 38; this is the first publication of it in the Initial Reports.

Principles Used in Classification

1. This is a lithologic summary classification designed to generalize core descriptive material of greater detail into a form suitable for standard core and hole logs. Its systematic use will facilitate core to core and leg to leg comparisons.

2. The classification covers most of the lithologic types encountered so far but does not attempt to be comprehensive. A category "Special Rock Types" allows additional definitions and terminology at the discretion of the shipboard staff for rock types not covered.

3. Sediment names are those in common usage and have been defined within the limits of existing definitions.

4. Categories are based on sediment parameters measured on board ship. Refinement by shore laboratory data is possible but not necessary.

5. The classification is descriptive and genetic implications are not intended.

6. The degree of detail of the classification is scaled to the space limitations of printed graphic hole and core summaries.

Shipboard Parameters Measured

Sediment and rock names are defined solely on the basis of compositional and textural parameters. The compositional factors are most important for description of those deposits more characteristic of open marine conditions, with textural factors becoming more important for the classification of hemipelagic and near-shore facies. Sediment names are thus based solely upon these parameters as determined in smear slides aided by compositional and textural properties apparent to the naked eye or under the hand lens. Other descriptive parameters include: induration, sediment disturbance, sedimentary structures, and color. The determination of these parameters is as follows:

1) Composition—biogenic and mineral components are estimated in percent from smear slides. $CaCO_3$ content is estimated by using the carbonate bomb available on the ship. Even with rapid use, a value to ±5% is achievable.

2) Texture—visual estimates from smear slide examination.

3) Induration—The determination of induration is highly subjective, but field geologists have successfully made similar distinctions for many years. The categories suggested here are thought to be practical and significant. The criteria of Moberly and Heath (1971) are used for calcareous deposits: subjective estimate or behavior in core cutting for others. There are three classes for calcareous sediments: two for all others.

a) Calcareous sediments
   - (i) Soft: Oozes have little strength and are readily deformed under the finger or the broad blade of a spatula.
   - (ii) Firm: Chalks are partly indurated oozes: they are friable limestones that are readily deformed under the fingernail or the edge of a spatula blade. More indurated chalks are termed limestones (see below).
   - (iii) Hard: Limestones as a term should be restricted to cemented rocks.

b) The following criteria are recommended for all but calcareous sediments:
   - (i) If the material is low state of induration as to allow the core to be split with a wire cutter, the sediment name only is used (e.g., silty clay: mud).

(ii) If the core must be cut on the band saw or diamond saw, the suffix 'stone' is used (e.g., silty claystone: mudstone; or shale, if fissile.)

4) Sediment Disturbance—Deformational structures are generally of the type found in piston cores, and are usually simple to visualize and interpret.

a) Soft to firm sediment: The following categories are recommended.
   (i) Slightly deformed—bedding contacts are slightly bent.
   (ii) Moderately deformed—bedding contacts have undergone extreme bowing.
   (iii) Very deformed—bedding is completely disturbed, sometimes showing symmetrical diapir-like structure.
   (iv) Soupy—water saturated intervals which have lost all aspects of original bedding.

b) Hard sediments: There is also the need to indicate the degree of fracturing in hard sediments/rock. This is best accomplished with a written description in the Lithologic Description portion of the Core Form (Figure 6).

5) Sedimentary structures—In many cores it is extremely difficult to differentiate between natural and coring-induced structures. Consequently, the description of sedimentary structures is optional. The following approach is suggested as a guideline, but the specialist is encouraged to use his own preferred system and set of symbols.

a) Median grain size profile: For the sections of terrigenous sediments, with interbeds of varying textural characteristics, the construction of median grain size profile based on hand lens observations provides a rapid method for illustrating graded and non-graded beds, bed thickness, and size distribution.

b) Sedimentary structures: A set of suggested symbols is provided for categories shown on (Figure 4).

6) Color—According to standard Munsell and GSA color charts.

Use of the Core Form

1) Mandatory Graphic Lithology Column—This graphic column is based on the above classification scheme. Completion of the column using the appropriate symbols (Figure 5) *must* be done for each site, and will be included in the Initial Core Description (ICD) and Initial Report Volume. The "Special Rock Type" category should be used for sediment types not in the classification.

a) Optional graphic column: If circumstances or the special skills and interests of the shipboard staff indicate an additional modified or different classification, another graphic column may be added to the right of the Mandatory Column using definitions, terminology and symbols that, in the opinion of the shipboard staff, will increase the information yield. This Optional Column must not substitute for the Mandatory Column.

2) Sediment disturbance column—Completion of the sediment disturbance column using symbols and distinctions given below is mandatory.

3) Sedimentary structure columns — Structures may be designated on the core form in the sedimentary structure column parallel to the sediment disturbance column, and/or on the median grain size profile (for the sections of terrigenous sediments, with interbeds of varying textural characteristics). The median grain size profile is located in the lithologic description portion of the core form. A set of suggested symbols for a few more common structures has been prepared by DSDP (Figure 4), but the shipboard geologist is free to use whatever additional symbols he may wish. These optional columns may not substitute for the mandatory sediment disturbance column and must be distinct from it.

4) Lithologic description column—Format, style, and terminology of the descriptive portion of the core sheets are not controlled by the mandatory column scheme, beyond the minimal name assignment which should be derived from this classification. However, colors and additional information on structure and textures should normally be included in the textural section of the core description.

Lithologic Classification Scheme

The following define compositional class boundaries and use of qualifiers in the lithologic classification scheme:

1) Compositional Class Boundaries

a) $CaCO_3$ content (determined by $CaCO_3$ bomb): 30% and 60%. With a 5% precision and given the natural frequency distribution of $CaCO_3$ contents in oceanic sediments, these boundaries can be reasonably ascertained.

b) Biogenic opal abundance (expressed as percent siliceous skeletal remains in smear slides): 10%, 30%, and 50%. Smear-slide estimates of identifiable siliceous skeletal material generally imply a significantly higher total opal abundance. The boundaries have been set to take this into account.

c) Abundance of authigenic components (zeolites, Fe, and Mn micronodules etc), fish bones, and other indicators of very slow sedimentation (estimated in smear slides); semi-quantitative boundary: common 10%. These components are quite conspicuous and a semiquantitative estimate is adequate. Even a minor influx of calcareous, siliceous, or terrigenous material will, because of the large difference in sedimentation rate, dilute them to insignificance.

d) Abundance of terrigenous detrital material (estimated from smear slides): 30%

e) Qualifiers: Numerous qualifiers are suggested; the options should be used freely. However, components of less than 5% (in smear slide) should not be used as a qualifier except in special cases. The most important component should be the last qualifier. No more than two qualifiers should be used.

Description of Sediment Types

1) Pelagic clay—Principally authigenic pelagic deposits that accumulate at very slow rates. The class is often termed brown clay, or red clay, but since these terms are confusing, they are not recommended.

a) Boundary with terrigenous sediments: When authigenic components (Fe/Mn micronodules, zeolites), fish debris, etc., become common in smear slides. NOTE: because of large discrepancy in accumulation rates, transitional deposits are exceptional.

b) Boundary with siliceous biogenic sediments: <30% indentifiable siliceous remains.

c) Boundary with calcareous biogenous sediments: Generally the sequence is one passing from pelagic clay through siliceous ooze to calcareous ooze, with one important exception: at the base of many oceanic sections, black, brown or red clays occur directly on basalt, overlain by or grading up into calcareous sediments. Most of the basal clayey sediments are rich in iron, manganese and metallic trace elements. For proper identification they require more elaborate geochemical work than is available on board. These sediments are placed in the "Special Rock" category, but care should be taken to distinguish them from ordinary pelagic clays.

2) Pelagic siliceous biogenic sediments — These are distinguished from the previous category because they have more than 30% identifiable siliceous microfossils. They are distinguished from the following category by a $CaCO_3$ content of less than 30%. There are two classes: *Pelagic biogenic siliceous sediments* (containing less than 30% silt and clay); and *transitional biogenic siliceous sediments* (containing more than 30% silt and clay and more than 10% diatoms).

a) Pelagic biogenic siliceous sediments:

soft: Siliceous ooze (radiolarian ooze, diatom ooze, depending on dominant component).

hard: radiolarite, porcellanite, diatomite, chert

(i) Qualifiers:

Radiolarians dominant: radiolarian ooze or radiolarite.

Diatoms dominant: diatom ooze or diatomite

Where uncertain: siliceous (biogenic) ooze, or chert or porcellanite, when containing >10% $CaCO_3$, qualifiers are as follows:

nannofossils only:	nannofossil - -
foraminifers only:	foraminifer - -
nannofossil-foraminifer - -	depending on dominant component
foraminiferal-nannofossil - -	

b) Transitional biogenic siliceous sediments:

Diatoms <50%	diatomaceous mud:	soft
	diatomaceous mudstone:	hard
Diatoms >50%	muddy diatom ooze:	soft
	muddy diatomite:	hard

Radiolarian equivalents in this category are rare and can be specifically described.

3) Pelagic biogenous calcareous sediments—These are distinguished from the previous categories by a $CaCO_3$ content in excess of 30%. There are two classes: Pelagic biogenic calcareous sediments (containing less than 30% silt and clay); and transitional biogenic calcareous sediments (containing more than 30% silt and clay).

a) Pelagic biogenic calcareous sediments:
soft: calcareous ooze
firm: chalk
hard: indurated chalk

The term *limestone* should preferably be restricted to *cemented rocks*.

(i) Compositional Qualifiers≤—
Principal components are: nannofossils and foraminifers. One or two qualifiers may be used, for example:

Foram %	Name
<10	Nannofossil ooze, chalk, limestone.
10-25	Foraminiferal-nannofossil ooze
25-50	Nannofossil-foraminifer ooze
>50 for:	Foraminifer ooze

Calcareous sediment containing more than 10%-20% identifiable siliceous fossils carry the qualifier radiolarian, diatomaceous, or siliceous depending on the quality of the identification. For example, radiolarian-foraminifer ooze.

b) Transitional biogenic calcareous sediments
(i) $CaCO_3$ = 30%-60%: marly calcareous pelagic sediments
soft: marly calcareous (or nannofossil, foraminifer, etc.), ooze (see below)
firm: marly chalk
hard: marly limestone
(ii) $CaCO_3$ >60%: Calcareous pelagic sediments.
soft: calcareous (or nannofossil, foraminifer, etc.), ooze (see below)
firm: chalk
hard: limestone

NOTE: Sediments containing 10%-30% $CaCO_3$ fall in other classes where they are denoted with the adjective "calcareous." Less than 10% $CaCO_3$ is ignored.

4) Terrigenous sediments

a) Sediment falling in this portion of the classification scheme are subdivided into textural groups on the basis of the relative preportions of three grain size constituents, i.e., clay, silt, and sand. Rocks coarser than sand size are treated as "Special Rock Types." The size limits for these constituents are those defined by Wentworth (1922).
Five major textural groups are recognized on the accompanying triangular diagram (Figure 7). These groups are defined according to the abundance of clay (>90%, 90-10%, <10%) and the ratio of sand to silt (>1 or <1). The terms *clay, mud, sandy mud, silt,* and *sand* are used for the soft or unconsolidated sediments which are cut with a wire in the shipboard core splitting process. The hard or unconsolidated equivalents for the same textural groups are *claystone, mudstone,* (or shale, if fissle), *sandy mudstone, siltstone,* and *sandstone*. Sedimentary rocks falling into the consolidated category include those which must generally be cut with the band saw or diamond saw. Sands and sandstones may be subdivided further into very fine-, fine-, medium-, coarse-, or very coarse-grained sands and sandstones according to their median grain size.
(i) Qualifiers—In this group numerous qualifiers are possible, usually based on minor constituents, for example: glauconitic, pyritic, feldspathic. In the sand and sandstone category, conventional divisions such as arkose, graywacke, etc., are, of course, acceptable, providing the scheme is properly identified. Clays, muds, silts, and sands containing 10%-30% $CaCO_3$ shall be called calcareous.

b) Volcanogenic sediments
Pyroclastic rocks are described according to the textural and compositional scheme of Wentworth and Williams (1932). The textural groups are:
Volcanic breccia >32 mm
Volcanic lapilli <32 mm
Volcanic ash (tuff, indurated) <4 mm
Compositionally, these pyroclastic rocks are described as vitric (glass), crystal or lithic.

c) Clastic sediments of volcanic provenance are described in the same fashion as the terrigenous sediments, noting the dominant composition of the volcanic grains where possible.

5) Special rock types—The definition and nomenclature of sediment and rock types not included in the system described above are left to the discretion of shipboard scientists with the recommendation that they adhere as closely as practical to conventional terminology.

In this category fall such rocks as:
Intrusive and extrusive igneous rocks;Evaporites, halite, anhydrite, gypsum (as a rock), etc.;
Shallow water limestone (biostromal, biohermal, coquina, oolite, etc.);
Dolomite;
Gravels, conglomerates, breccias;
Metalliferous brown clays;
Concretions, barite, iron-manganese, phosphorite, pyrite, etc.;
Coal, asphalt, etc.;
and many others.

The mandatory graphic lithology column should be completed by shipboard staff with appropriate symbols for intervals containing special rock types. It is imperative that symbols and rock nomenclature be properly defined and described by shipboard staff.