1. INTRODUCTION

The Shipboard Scientific Party[1]

Glomar Challenger left Papeete, Tahiti on the 6th of December, 1969 and arrived in Balboa, Panama on the 27th of January, 1970. The primary purpose of Leg 9 of the *Glomar Challenger,* the last in the Pacific during the initial phase of the drilling program, was to obtain as complete sections as possible, of the equatorial Pacific sediments and to penetrate and date basement so as to determine the rate of sea floor spreading from the east Pacific Rise.

In the broadest sense these were the instructions from the JOIDES Pacific Panel, yet there are many problems surrounding this area which the capabilities of *Glomar Challenger* were well suited to solving. We will list the problems that were uppermost in our minds when we left Papeete and through a discussion of these problems provide the reader with background material and an introduction to the organization of this volume.

The pattern of sediment types in the area traversed by Leg 9 has been reviewed by Hays and others (1969) and, in general, consists of calcareous sediments deposited to depths as great as 4800 meters beneath the equator and at shallower depths to the North and south of the equator. A belt of sediments with a preponderance of opaline silica lies to the north of the calcareous sediments with a southern limit corresponding generally to the Clipperton Fracture Zone and a northern limit roughly corresponding to the 15° parallel. To the north of this, the sediments are predominantly red clay.

The equatorial Pacific between Tahiti and Panama has become a classic area for stratigraphic studies (Riedel, 1957, 1959, 1967, 1971; Parker, 1967, Hays *et al.,* 1969). The sediments of this region have merited this interest for two reasons. First, they contain in abundance the shells of Foraminifera, coccoliths, diatoms and Radiolaria. Second, there are broad areas where sediments of early and middle Cenozoic age crop out, thus providing the opportunity to study Cenozoic stratigraphy utilizing piston cores (Riedel, 1957, 1959, 1969; Riedel and Funnell, 1964; Hays *et al.,* 1969). We know of no other area in the world ocean that combines so generously these two complementary factors.

The high concentration of microfossils in the sediments of this region (often greater than 95 per cent of the sediment by weight) is due to the high productivity of the overlying surface waters (Ried, 1962) and the very slow rate of terrigenous sediment accumulation. The equatorial current system streaming westward from the confluence of the Pacific eastern boundary currents has two divergences, one centered on the equator and the other at about 10° North. The equatorial divergence and a very shallow thermocline at the northern edge of the Equatorial counter current bring nutrient-rich deeper waters into the near surface waters. The resulting high primary production sustains a high standing crop of zooplankton which has a distribution similar to the nutrient distribution (Ried, 1962).

Because of the abundance and diversity of fossil species in these sediments, one of our primary aims was to acquire one or several continuous or nearly continuous sections extending as far back in time as possible Consequently, we continuously cored four of our eight sites, Sites 77, 78, 83 and 84, which are at the western and eastern extremities of our leg, and heavily cored, although not continuously, one other (Site 80). Much attention is given in this report to delineating the stratigraphic ranges of as many species as time would permit. Included in each site report are range charts for each microfossil group which indicate the stratigraphic ranges of selected species. Each site report also contains comparison charts that provide a comparison of the ranges of diagnostic species of foraminifera, Radiolaria and nannofossils. Two synthesis chapters are devoted to detailing the stratigraphy and illustrating species of fossil Radiolaria and foraminifera. We believe that these data will provide a useful framework for future studies of tropical microfossils. Moreover, the several nearly continuous sections we obtained will be important in understanding the geologic history of the eastern equatorial Pacific.

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TECTONIC CONSIDERATIONS

Latitudinal Plate Motions

The influence of the equatorial high productivity is manifest in the sediments not only by their contained microfossils but also the sediment thickness. Ewing and others (1968) show in an extensive seismic reflection survey of the Pacific that a belt of thick sediments underlies the equatorial region. In general the crest of this lens of sediment (greater than 600 meters thick) underlies the equator; however, at 150° West longitude it lies about three degrees North of the equator and gradually converges with the equator eastward. The sediment lens is broken by the East Pacific Rise at about 102° where the sediments thin to less than 100 meters in thickness. East of 170° West longitude the sediments are acoustically highly stratified while to the west they are acoustically transparent (Ewing *et al.*, 1968). The upper layers in the highly stratified section thin and sometime disappear to the north of the crest of the sediment lens, while the deeper layers appear to be continuous from south to north, coming to the surface north of the Clipperton Fracture Zone. A similar thinning is evident in some areas on the southern flank of the lens (Ewing *et al.*, 1968). This pattern of outcropping sediments results in the common occurrence of Tertiary sediments within easy reach of the piston corer a few degrees North of the equator (Hays and others, 1969).

The high degree of correspondence between the axis of this equatorial sediment lens and the equatorial zone of high productivity has led a number of workers to conclude that whatever relative motion the Pacific plate may have to other plates, its motion relative to the equator must be nearly east-west; otherwise the sediment lens would be considerably offset from the equator or spread over a much larger area. Others, however, have pointed to the other evidence for a northward motion of the Pacific plate (Pitman *et al.*, 1968). Riedel and Funnell (1964), Burckle *et al.*, (1967), Riedel (1967), and Hays *et al.*, (1969) have all pointed out the peculiar area of broad outcropping older sediments along the northern flank of the sediment lens. More recently, Francheteau and others (1970) have re-examined earlier evidence and suggested on the basis of 49 seamount magnetization vectors that the Pacific plate has moved northward some 30° of latitude since the Cretaceous. The sediment thickness data and the seamount magnetic data appear to be mutually contradictory, so Leg 9 of *Challenger* set as one of its objectives the gathering of data that might help resolve this apparent contradiction of evidence. We adopted the following line of reasoning: Since the rate of accumulation of the highly biogenous sediments of the equatorial Pacific is dependent on the productivity of the overlying surface waters, and this productivity is highest at the equatorial divergence and drops off to the north and south, then the rates of accumulation should be greatest under the equator and decrease to the north and south. This has already been shown to be true from piston core data (Hays *et al.*, 1969). This being so, then the rates of accumulation of equatorial Pacific sediments should be highly sensitive to any latitudinal motion of the Pacific plate. The beauty of this approach is that it is not dependent on relative motions between plates but dependent solely on the motion of the Pacific plate relative to the axis of rotation of the earth. One of our primary objectives, then, was to monitor closely the accumulation rates of the sediments we penetrated.

East-West Motions

Although some of the earliest studies of sea floor spreading through the interpretation of magnetic anomaly patterns were from the Pacific (Vine, 1966) and numerous other studies have followed (McKenzie and Parker, 1968; Pitman and others, 1968; Herron and Hays, 1969; Atwater and Menard, 1970; Atwater, 1970; Hays and Pitman, 1970; to name a few), little has been done with the magnetic anomaly pattern of the equatorial region (20° to 30°S). The low inclination of the magnetic field of the earth in this area of an east-west spreading ridge makes recognition of anomalies difficult. As with tracks of other ships through this area, the amplitude of the anomalies recorded by *Challenger* were too low to be interpreted.

The paucity of information that can be derived from the magnetic anomalies in this region makes the determination of basement age by *Challenger* drilling even more important than in other areas, where drilling serves to confirm the ages predicted from the magnetic anomalies.

The sediment thickness data of Ewing and others (1968) offers suggestive evidence that the rate of lateral spreading of the East Pacific Rise may not have been constant during the Tertiary. They show that the sediments are very thin between the rise crest and about 108°W, at which point they thicken abruptly. Having noticed similar phenomena on other ridge crests they suggest that this sediment thickness change was caused by a pause in spreading for about 30 to 40 million years before the Mid-Miocene. A site on Leg 9 was scheduled to investigate one of the places where an abrupt increase in sediment thickness occurs. If the interpretation of Ewing and others (1968) is correct, the basement should be considerably older just to the west of the zone of thickening than would be predicted by constant sea floor spreading from the rise crest.

Assorted Problems

Several other important problems can be added to the list of previously described considerations. In a study of cores from the crest of the East Pacific Rise, Boström and Peterson (1966), found that sediments in a narrow zone contain anomalously high concentrations of iron, manganese and other heavy metals. They reasoned that these heavy-metal concentrations resulted from hydrothermal emanations from the ridge crest and the leaching of the heavy metals from these emanations by the thin cover of sediments on the ridge crest. They reasoned that if their explanation is correct and this is a continuing process associated with the ridge crest then one would expect to find similar heavy-metal concentrations at and just above the contact between basement basalt and sediment at drill sites well removed from the rise axis. Investigation of such deposits was one of the Leg 9 objectives.

Hays and others (1969) correlated varying concentrations of calcium carbonate in equatorial Pacific sediments with climatically induced faunal fluctuations and O^{18}/O^{16} fluctuations in Caribbean and equatorial Atlantic cores. Following the reasoning of Arrhenius (1952) they argued that during cold periods the strength of the trade winds was enhanced, causing increased upwelling at the equatorial divergence and, consequently, higher productivity. This resulted in concentrations of calcium carbonate higher in glacial than in interglacial or warmer intervals. Great importance is attributed to determining whether the calcium carbonate cycle is confined to the late Cenozoic, or whether it is a process that has been going on for a much longer interval of time. It was therefore important to look for carbonate cycles in sediments older than the Pliocene.

A final problem that drilling Leg 9 might help to resolve is the amount and sense of displacement on the Clipperton Fracture Zone. Two holes were scheduled to the north and south of this feature.

In order to accomplish our objectives we recognized from the start that it would be necessary to obtain a number of continuous sections. Although there is still some controversy about the advantages of continuous coring the members of the scientific staff of Leg 9 were unanimous in their desire to continuously core as much as possible. Our policy throughout the cruise was to do as complete a job at each site as possible, recognizing that this might mean sacrificing sites at the end of the leg. Due to constantly threatening problems with the tunnel thrusters this policy seemed not only scientifically justified but highly practical. Moreover, we had the option of changing the sites drilled if our accumulating information on the equatorial sediments justified it. As a consequence of these policies, we continuously cored four of our eight sites (Sites 77, 78, 83 and 84) which were at the western and eastern extremities of our leg; and heavily cored, although not continuously, one other site (80).

Along the route (Figure 1) nine sites and seventeen holes were drilled recovering 1538 meters of sediment (Table 1) along an east-west track. Basalt (Basement) was penetrated on eight of the nine sites drilled. The sediment overlying the basalt in every case showed evidence indicating the basalt is probably intrusive. At the one site that failed to reach basement (Site 76) the bit was stopped by silicified turbidites probably of Pliocene age. With the exception of the first site, all sites are related in that they all sampled the thick units of ooze deposited under the zone of high productivity centered along the equator. Without exception, the sediments contain abundant remains of coccoliths, diatoms, foraminifers and Radiolaria.

The details of our findings are contained in the Site Report section of the volume and summaries of these details are presented in several synthesis chapters at the end of the report. Syntheses of the biostratigraphic studies are found in two chapters, one by Jenkins and Orr and the other by Goll. Results that bear on the tectonics of the area, sediment cyclicity and the sediment-basement contact are found in a chapter entitled Geologic History. We take considerable pride in the large sediment recovery of Leg 9, not for naive reasons of competition with the other legs of the project, but because we feel that the detailed history contained in our continuous sections will be of great value to future researchers. The scientific findings contained in this report are only a small beginning to the information that can be gleaned from our cores by future workers. It is our hope that this report will serve as a useful guide to these future workers.

Summary of Leg 9 Operations

Leg 9 was the final leg of the initial phase of the drilling program and was the fifth leg of this phase in the Pacific. During this 56 day cruise, nine sites and seventeen holes were drilled in the equatorial Pacific between 146° West Longitude and 83°W. Five of the nine sites were continuously or nearly continuously cored and several others closely cored. This resulted in a recovery of 199 cores of the 202 attempted–a 90.9 per cent recovery rate–and 1538 meters of sediment recovered. Basement was reached and basalt recovered at all sites except the first (Site 76), where penetration was halted by shallow cherts of Pliocene age. The coring results at each site are summarized in Table 1 and general operational statistics in Table 2.

A variety of formations was encountered, varying from soft oozes through volcanic ash and firm chalks to limestone, chert and basalt. Core recoveries were equally good in all formations. Basement samples were usually broken into small pieces except for the first one obtained with the roller bit on the second site, and the last one taken with the massive set diamond on the last site.

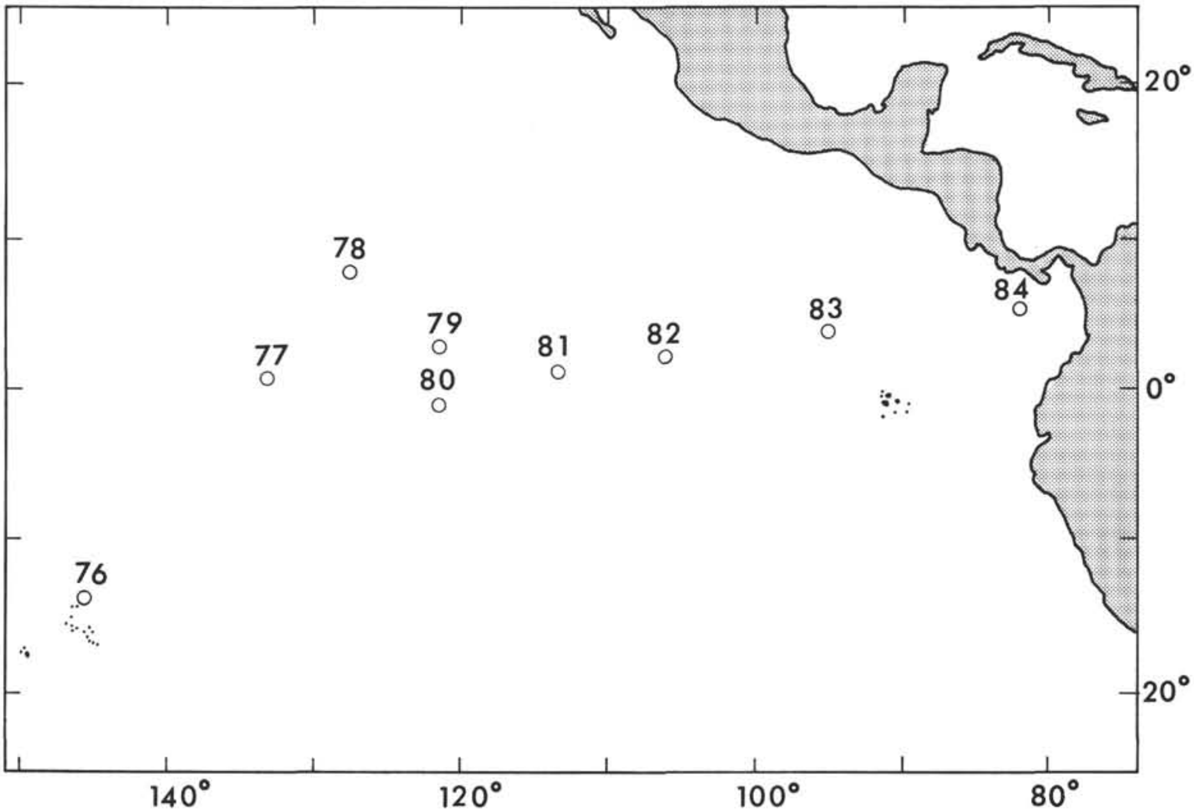

Figure 1. *Location of sites drilled on Leg 9.*

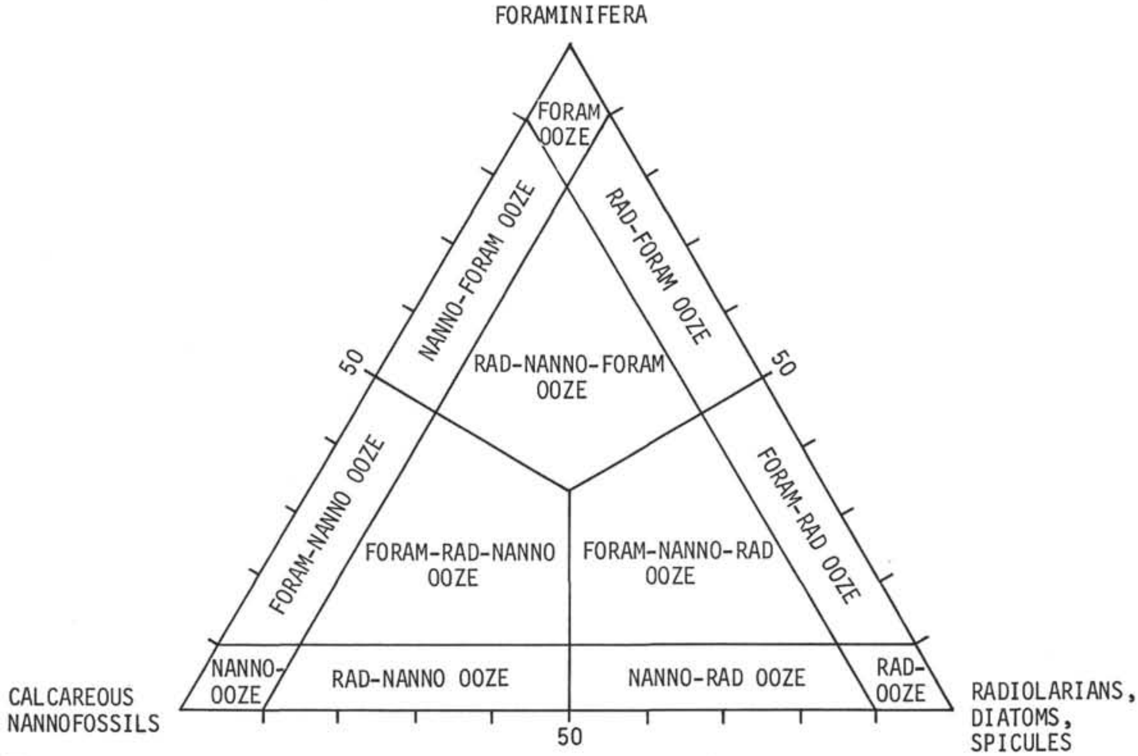

Figure 2. *Lithologic classification developed by Leg 3 geologists for oozes and chalks.*

TABLE 1
Operational Statistics for Leg 9, Deep Sea Drilling Project

Hole Number	Latitude	Longitude (W)	Water Depth (Feet)	Water Depth (Meters)	Penetration (Feet)	Penetration (Meters)	Number of Cores	Cored (Feet)	Cored (Meters)	Recovery (Feet)	Recovery (Meters)	Per Cent Recovery
76	14° 05.90′S	145° 39.64′	15,085	4597.92	90	27.43	1	30	9.14	30	9.14	100.00
76A	14° 05.90′S	145° 39.64′	15,085	4597.92	90	27.43	2	60	18.28	55	16.77	91.66
77	00° 28.90′N	133° 13.70′	14,077	4290.68	30	9.14	1	30	9.14	1	0.30	3.33
77A	00° 28.90′N	133° 13.70′	14,077	4290.68	60	18.28	2	60	18.28	30	9.14	50.00
77B	00° 28.90′N	133° 13.70′	14,077	4290.68	1579	481.28	54	1549	472.13	1436	437.69	92.70
77C	00° 28.90′N	133° 13.70′	14,077	4290.68	330	100.58	1	30	9.14	25	7.62	83.33
78	07° 57.00′N	127° 21.35′	14,363	4377.85	1051	302.34	37	1051	320.34	990	301.75	94.19
79	02° 33.02′N	121° 34.00′	15,006	4573.84	1359	414.22	17	437	133.20	396	120.70	90.61
79A	02° 33.02′N	121° 34.00′	15,006	4573.84	944	287.73	4	120	36.58	114	34.75	95.00
80	00° 57.72′S	121° 33.22′	14,472	4411.07	655	199.64	6	139	42.37	131	39.93	94.24
80A	00° 57.72′S	121° 33.22′	14,472	4411.07	388	118.26	5	150	45.72	150	45.72	100.00
81	01° 26.49′N	113° 48.54′	12,681	3865.18	1343	409.34	7	129	39.31	129	39.31	100.00
82	02° 35.48′N	106° 56.52′	12,161	3706.68	703	214.27	7	165	50.29	151	46.02	91.51
82A	02° 35.48′N	106° 56.52′	12,161	3706.68	1364	110.94	3	90	27.43	87	26.52	96.66
83	04° 02.8′N	9 95° 44.25′	11,961	3645.72	792	241.40	9	201	61.26	153	46.63	76.12
83A	04° 02.8′N	95° 44.25′	11,961	3645.72	720	219.45	16	480	146.30	464	141.42	96.66
84	05° 44.92′N	82° 53.29′	10,159	3096.47	833	253.90	30	833	253.90	703	214.26	84.39
Total			230,881	70,372.68	11,331	3435.63		5554	1692.81	5045	1537.67	90.81

TABLE 2
Leg 9 – Deep Sea Drilling Project Summary of Operations
(Papeete to Balboa)

Total days Leg 9 (December 2, 1969 to January 27, 1970)	56.24
Total days cruising	24.55
Average speed	9.36 kts.
Total miles traveled	5669.00
Total days on sites	25.90
Survey time	1.43
Port time	4.36

Trip time	147.50 =	6.14
Drilling time	28.00 =	1.18
Coring time	377.75 =	15.62
Other		1.53
Survey time		1.43
Total		25.90

Sites drilled	9
Holes drilled	17

Number of cores attempted	202.0
Number of cores recovered	199.0
Percentage of cores with recovery	98.6
Total footage cored	5554.0
Total footage recovered	5050.0
Percentage footage recovered	90.9
Total penetration	11,472.0
Percentage cored of total penetration	48.6
Number of sites on which basalt was recovered	8.0

The configuration of the bottom hole assembly was not changed throughout the leg and was the same as was used successfully on the latter part of Leg 8. From the bit up it consisted of the outer core barrel, three 8.25-inch drill collars; two bumper subs, six 8.25-inch drill collars; one bumper sub, two 8.25-inch drill collars, one 7.25-inch drill collar and one joint of heavy-weight drill pipe. The two bumper subs were run four collars above the bit with the thought that light bit weights could be controlled with more accuracy since the total weight of four collars amounted to 13,900 pounds in sea water. It was felt that weights on the order of 10,000 pounds should be run to establish a pattern in hard formations before full drill collar weight was applied. This procedure worked well in all cases except the one cited below.

Chert was encountered on the first hole after 90 feet of penetration and coring with light bit weight for 70 minutes resulted in no apparent penetration, although a small piece of chert was recovered. After coring the second hole and rotating for 30 minutes on a hard spot encountered 16 feet higher than in the first hole, a failure occurred in the drill collar tool joint which was at the mud line. The recording weight indicator showed a surge to 35,000 pounds at this point and probably caused the unsupported bottom hole assembly to fail from column buckling. It would appear that if the neutral point of the bottom hole assembly can be kept below the mud line, this type of failure can be eliminated.

Two types of bits were used on this leg and each performed satisfactorily. A new four cone tungsten carbide insert roller bit was used to core the second and third sites (77 and 78), and a total of 2484.5 feet of core was recovered. Coring on basalt was attempted for three hours on the second site and for one and one-half hours on the third site before a cone partially locked and rapid oscillation of the drill string caused termination of the drilling operations. Drilling weights on basement ranged from 10,000 to 30,000 pounds with rotations per minute from 35 to 52. All cones had peening marks due to ship heave, and the poor condition of the bearings was also attributed to this motion.

The other type bit used was a light set diamond with a crown at the center for coring hard formations. Two of these 250-carat bits were used and each recovered basalt on two separate sites. A massive set 500-carat diamond was used on two other sides–recovering basalt on both –and still has approximately 90 per cent salvage.

Dynamic Positioning

The ship positioning system operated very well, holding the vessel within a 180 foot radius of the beacon. On the second site a burned-out relay in the computer allowed a 1000-foot excursion before it was repaired. At the time of the computer failure a core had been retrieved from 15,357 feet and the barrel dropped for the next core. The string was rotated slowly and circulation maintained off the bottom until repairs were effected and the ship repositioned. The time included was approximately 30 minutes and no unusual hole conditions were noted. Coring was resumed in a normal manner after repositioning. Burnett 16.0 kHz beacons were used exclusively and all but one operated satisfactorily. This beacon had a change in pulse repetition rate from 2.1 seconds at the surface to 2.3 seconds after landing on bottom. This exceeded the tolerance of the computer and required that a change in location be made to avoid interference before another beacon could be dropped. It was discovered on the fifth location that two more beacons were not performing to specifications at the surface, and these were set aside for return to the manufacturer. The balance of the beacons aboard was checked and found to be within operating tolerances.

A problem with the number one bow thruster developed while on the third location when the D. C. motor bearings became overheated and smoke came billowing from the forward hatchway. The location was completed using only one forward thruster.

It was decided that shipboard repairs were impractical, and the leg was completed using the remaining bow thruster for positioning.

Overall performance of the coring equipment was excellent and no major problems were encountered. Wire line speeds for retrieving cores increased from 296 ft/min on the first hole to 440 ft/min on the fourth hole with a subsequent decrease of trip time from 102 minutes per core to 68 minutes per core in the same depth of water. Part of the decrease in the time required to recover cores was a result of cutting off 8000 feet of worn line, thus allowing the balance of the line to spool more evenly. The balance of the decrease was due to increased efficiency of the crews as a routine was established. The balance of the holes maintained a 400 to 440 ft/min wire line speed which allowed minimum wear on wire line packing and little loss of fluids to be blown over the ship. The core barrel was stuck one time and was released by setting the drill string on bottom and maintaining 5000 pounds tension above weight of line until it came free. The barrel was apparently jammed at the lower end, since working and pulling for 30 minutes prior to setting the string on bottom had not accomplished a release.

The practice of dropping the core barrel while drilling the last connection before coring was initiated about midway during the leg and reduced waiting time for the barrel to reach bottom by about 20 per cent. This procedure can be used when the formations are soft but should not be attempted when the drilling time for a connection is nearly the same or exceeds the falling time of the core barrel.

EXPLANATORY NOTES

Lithology

Color

The Geological Society of America Rock-Color Chart terminology and numbers are used throughout this study. Where a sediment color was between two colors an interpolated name and number was used. For example, a color between very pale orange (10YR8/2) and pale yellowish brown (10YR6/2) was called pale orange (10YR7/2).

Lithologic Classification

Because one person aboard Leg 9 described all of the cores, except those at one site, it was possible to maintain a high degree of uniformity in core descriptions, fossil identifications, estimation of percentages of biogenous constituents, and sediment classification.

All sediment names consist of three parts in the following order: Color–biotic and mineralogic constituents and their approximate percentages–degree of induration. For example, an unconsolidated, very pale orange ooze made up of foraminifera, radiolarians, and calcareous nannofossils might be very pale orange (10YR8/2) foraminiferal (10 to 20 percent)–radiolarian (20 to 30 percent)–calcareous nannofossil (50 to 70 percent) ooze. This classification scheme (Figure 2) is one developed by Leg 9 geologists.

The terms ooze and chalk are used to designate different degrees of induration. Thus, in our terminology, the different degrees of increasing induration go from ooze to chalk ooze to ooze chalk to chalk.

Relative constituent percentages were visually estimated from smear slides. These numbers serve as a quick visual basis for characterizing the different formations and to show overall downhole fluctuations and trends. All accessory percentage curves plotted on the Hole Summaries are based on smear slide data. These curves include percentages of calcium carbonate, foraminifera, Radiolaria, calcareous nannofossils, and clay.

The lithologic symbols used on Leg 9 to graphically illustrate the sediment types are the same as those used on Leg 8. We have added a few new symbols to illustrate sediment types which were not encountered on Leg 8 (Figure 3).

Stratigraphic Nomenclature

Because Leg 9 recovered over 1500 meters of core at 9 sites, we had a good opportunity to apply classical stratigraphic concepts to deep marine sediments. We continuously cored Site 77 and recovered about 480 meters of sediment. This site was divided into several stratigraphic units which served as a standard of reference with which to compare other Leg 9 sites and Leg 8 sites.

The most obvious and objective criteria to differentiate these stratigraphic units is color and, to a lesser degree, bedding characteristics. In the equatorial Pacific sediments of Leg 9 we found a wide spectrum of sediment colors, including white (N9), dusky brown (5YR2/2), dusky green (5G3/2), very dusky purple (5P2/2) and various intermediate shades.

A cooperative examination of logs and colored strip photographs of Leg 8 and Leg 9 cores was made by Jon Galehouse of Leg 8 and Harry E. Cook of Leg 9 in order to develop a uniform nomenclature for this region. In naming these sediments Legs 8 and 9 follow the code of the American Commission on Stratigraphic Nomenclature (1961) rather than the recommendation of J. Andrews and K. J. Hsu (1970). The units are designated as deep sea geologic formations, using the drill sites as type sections and applying names from nearby islands and submarine fracture zones. Even though the drill sites are 200 to 800 kilometers apart, the consistent sequence in stratigraphic position in the Leg 8 and 9 sediments led us to adopt four deep sea formations. Three of these formations, the Clipperton, Marquesas, and Line Islands Oceanic Formations were defined by the Leg 8 scientific staff (Tracey *et al.*, 1971). We named one new formation, the San Blas Oceanic Formation, at Sites 81 through 84, which is lithologically distinct from its stratigraphic equivalents at Sites 77 through 80. These formations and their depths below the sea floor are listed in Table 3.

The word 'Oceanic' is included in the formal formation name to stress that these are deep sea formations. Note that while the word always appears in the text discussions, it sometimes does not appear in illustrations. This is because much of the artwork had been done in final form before this convention was adopted, and correction would have delayed publication of this volume.

Disturbance of Cored Sediment During Drilling

Coring disturbs primary sedimentary structures in unconsolidated sediments to varying degrees. Because of this, much potentially useful information on the types and distributions of sedimentary structures is never recovered.

The degree of disturbance, as determined mainly by disruption of different colored laminations and beds, appears to be related to several parameters; these include degree of induration, type of sediment, grain size, drilling rate, and sea state. Core bit design and diameter may be a factor but we were unable to reach any conclusion on this.

Disturbance of sediments varies from a slight upward bowing of laminations, to virtually complete homogenization of sediments. Sediment disturbance decreases stratigraphically downward as the sediments gradually change from oozes to more indurated chalks. In addition, sediment type and grain size are important variables in affecting sediment disturbance. Unconsolidated sediments rich in clay minerals and sediments with large percentages of sand-size foraminifera and radiolarians were much less disturbed than sediments composed dominantly of clay-sized calcareous nannofossils. Drilling rate probably fluctuates during rough seas and even well-indurated chalks can be crushed and mixed with varying amounts of sea water. We attempted to evaluate core bit design by coring the same stratigraphic interval in two different holes with different bits. No apparent differences in the degree of core disturbance were recognized.

Intensely disturbed core sections were avoided for physical property measurements. Usually at least part of each of the disturbed sections was only moderately disturbed so that a reliable lithologic column could be reconstructed at each site.

Physical Properties

Bulk Density

The bulk density test is a quick, easy means of measurement that gives a relatively good value for the density of a sample having no voids. It does, however, have the disadvantage of not being applicable to a partially filled core, due to the unknown volume of voids. The

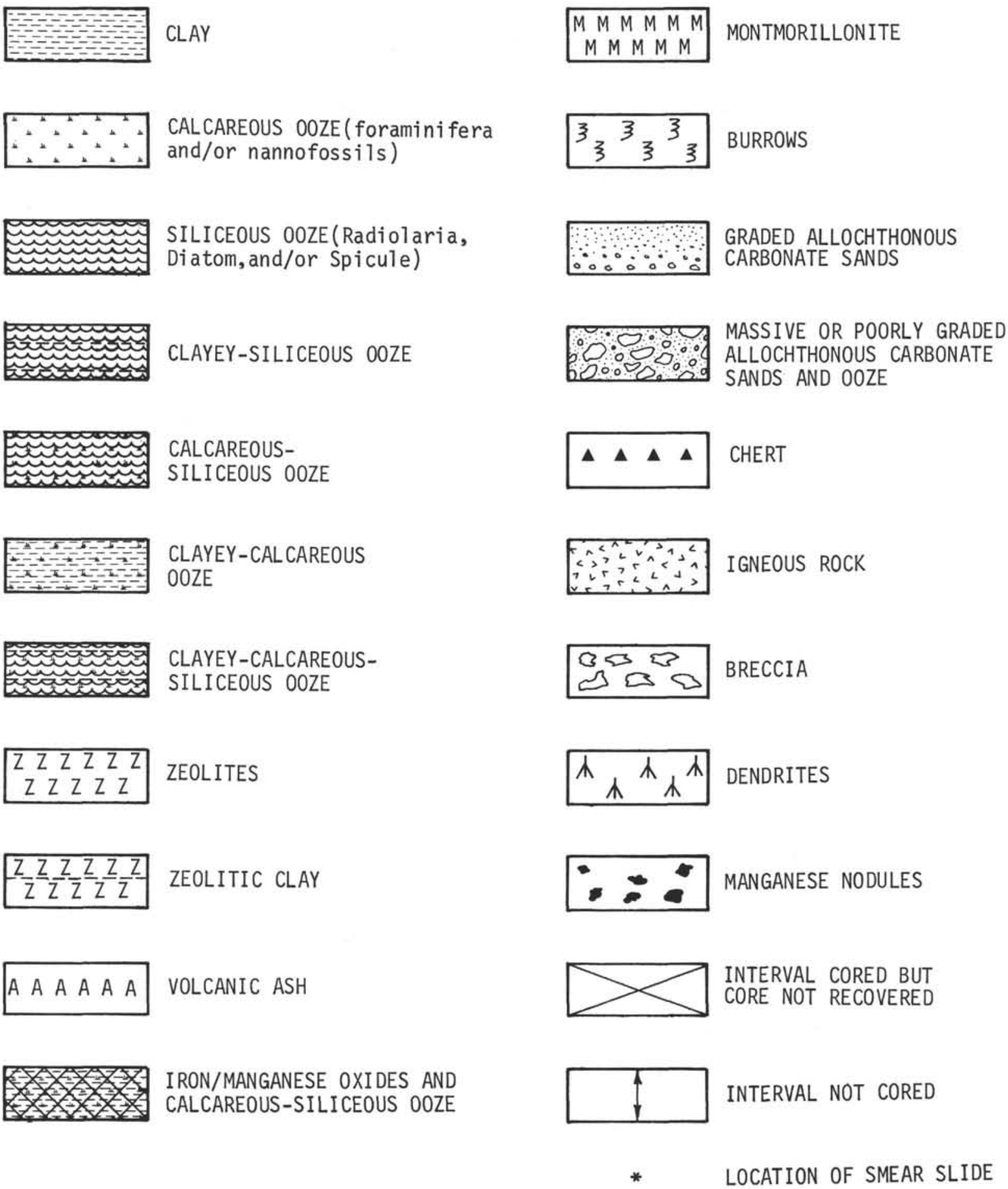

Figure 3. *Lithologic symbols used for hole, core, and section logs on Leg 9.*

Series Subseries	Planktonic Foraminiferal Zones	Definition of Zonal Boundaries IA = Appearance E = Extinction	Bolli (1957 a, b, c, 1966, 1970 in press Bolli & Bermudez 1966	Banner & Blow (1965) Parker (1967) Blow (1969)
Pleistocene	*Pulleniatina obliquiloculata*	← *G. fistulosus* (E)	*G. truncatulinoides truncatulinoides*	N-22-23
Upper Pliocene	*Globigerinoides fistulosus*	← *G. fistulosus* (IA)	*G. truncatulinoides tosaensis*	N-21
Lower Pliocene	*Sphaeroidinella dehiscens*	← *S. dehiscens* (IA)	*G. exilis/G. miocenica*	N-19-20
Upper Miocene	*Globorotalia tumida*	← *G. tumida* (IA)	*G. margaritae*	N-18
	Globorotalia plestiotumida	← *G. plesiotumida* (IA)	*G. dutertrei* *G. obliquus extremus*	N-17
Middle Miocene	*Globoquadrina altispira*	← *G. fohsi lobata* (E)	*G. acostaensis* *G. fohsi lobata*	N-12-16
	Globorotalia fohsi lobata	← *G. fohsi lobata* (IA)	*G. fohsi lobata*	N-10-11
	Globorotalia fohsi fohsi-Globorotalia peripheroacuta	← *G. peripheroactua* (IA)	*G. fohsi fohsi* *G. fohsi barisanensis*	
	Globorotalia peripheroronda *Praeorbulina glomerosa curva* Subzone	← *P. glomerosa curva* (E) ← *P. glomerosa curva* (IA)		N-9
Lower Miocene	*Globigerinoides bisphericus* Subzone *Globoquadrina venezuelana*	← *G. bisphericus* (IA) ← *G. dissimilis* (E)	*G. insueta*	N-8 N-7
	Globigerinita dissimilis	← *G. kugleri* (E)	*C. stainforthi* *C. dissimilis*	N-5-6
	Globorotalia kugleri	← *G. kugleri* (IA)	*G. kugleri*	N-4
Upper Oligocene	*Globigerina angulisuturalis*	← *G. opima* (E)	*G. ciperoensis ciperoensis*	N-3
	Globorotalia opima	← *C. cubensis* (E)	*G. opima opima*	N-2
	Chiloguembelina cubensis	← *C. opima* (IA)		
	Globigerina ampliapertura	← *P. barbadoensis* (E)	*G. ampliapertura*	N-1
Lower Oligocene	*Pseudohastigerina barbadoensis*	← *G. insolita* (E)	*C. chipolensis* *H. micra*	P-18-19
Upper Eocene	*Globorotalia insolita*		*G. cerroazulensis*	P-17

Figure 4. Correlation of foraminiferal zones.

Series	Foraminifera	Nannoplankton	Radiolaria
Pleistocene	*Pulleniatina obliquiloculata*	*Gephyrocapsa "oceanica" Ceratolithus cristatus* Subzone	No zonal name
		Gephyrocapsa "oceanica" C. leptoporus macintyrei S.Z.	*Pterocanium prismatium*
Upper Pliocene	*Globigerinoides fistulosus*	*G. "oceanica"-C. carteri* S.Z.	
		Discoaster brouweri Cyclococcolithus leptoporus Subzone	*Spongaster pentas* East
Lower Pliocene	*Sphaeroidinella dehiscens*	*Ceratolithus rugosus*	
Upper Miocene	*Globorotalia tumida*	*Ceratolithus tricorniculatus*	West *Stichocorys peregrina*
	Globorotalia plesiotumida		
		Discoaster variabilis Discoaster challengeri S.Z.	*Ommatartus penultimus*
	Globoquadrina altispira	*D. variabilis D. hamatus* S.Z.; *D. variabilis C. eopelagicus* S.Z.; *D. variabilis D. exilis* Subzone	*Ommatartus antepenultimus*
Middle Miocene			*Cannartus* (?) *petterssoni*
	Globorotalia fohsi lobata	*Discoaster exilis Discoaster kugleri* Subzone	*Cannartus laticonus*
	Globorotalia fohsi fohsi Globorotalia peripheroacuta	*D. exilis-Cyclococcolithus neogammation* S.Z.	
		S. heteromorphus T. rugosus S.Z.	*Dorcadospyris alata*
	Globorotalia peripheroronda Praeorbulina glomerosa curva Subzone	*Sphenolithus heteromorphus Helicopontosphaera ampliaperta* S.Z.	*Calocycletta costata*
Lower Miocene	*Globigerinoides bisphericus* Subzone *Globoquadrina venezuelana*	*Triquetrorhabdulus carinatus Sphenolithus heteromorphus* S.Z.	
	Globigerinita dissimilis	*T. carinatus S. belemnos* S.Z.	*Calocycletta virginis*
		Triquetrorhabdulus carinatus Cyclococcolithus neogammation S.Z.	
	Globorotalia kugleri		*Lychnocanium bipes*
Upper Oligocene	*Globigerina angulisuturalis*	*T. carinatus C. bisectus var.* S.Z.	
		C. bisectus T. carinatus S.Z.	*Dorcadospyris papilio*
	Globorotalia opima	*C. bisectus S. distentus* Subzone	*Theocyrtis annosa*
	Chiloguembelina cubensis		
	Globigerina ampliapertura	*C. bisectus Helicopontosphaera compacta* S.Z.	*Lithocyclia angustum*
Lower Oligocene	*Pseudohastigerina barbadoensis*	*C. lucitanicas S. predistentus*	*Theocyrtis tuberosa*
		C. lucitanicas I. recurvus S.Z.	
Eocene	*Globorotalia insolita*	*Discoaster barbadiensis*	

Figure 5. Correlations and equivalents–foraminifera, nannoplankton, Radiolaria.

TABLE 3
Rock-Stratigraphic Nomenclature Used on Leg 9, Unit Thicknesses, and their Depths below the Sea Floor

Site 76 – 0 to 27.3 meters
Unit 1 – 0 to 9.1 meters
Unit 2 – 9.1 to 13.6 meters
Unit 3 – 13.6 to 17.9 meters
Unit 4 – 17.9 to 21.4 meters
Unit 5 – 21.4 to 27.3 meters
- Contact Sharp
Chert

Site 77 – Clipperton Formation – 0 to 172.5 meters (172.5 meters)
Cyclic Unit – 0 to 42.4 meters (42.4 meters)
- Contact Transitional
Varicolored Unit – 42.4 to 172.5 meters (130.1 meters)
- Contact Transitional
Marquesas Formation – 172.5 to 470.8 meters (298.3 meters)
Gray Unit – 172.5 to 252.6 meters (80.1 meters)
Brown Unit – 252.6 to 280.3 meters (27.7 meters)
Gray Unit – 280.3 to 408.1 meters (127.8 meters)
Brown Unit – 408.1 to 426.6 meters (18.5 meters)
Gray Unit – 426.6 to 470.8 meters (44.2 meters)
- Contact Sharp
Line Islands Formation – 470.8 to 481 meters (10.2 meters)
- Contact Sharp
Basalt

Site 78 – Clipperton Formation – 0 to 51.7 meters (51.7 meters)
Cyclic Unit – 0 to 51.7 meters (51.7 meters)
- Contact Transitional
Marquesas Formation – 51.7 to 310.5 meters (258.8 meters)
Brown Unit – 51.7 to 101.1 meters (49.4 meters)
Gray Unit – 101.1 to 272.4 meters (171.3 meters)
Brown Unit – 272.4 to 310.5 meters (38.1 meters)
- Contact Transitional
Line Islands Formation – 310.5 to 320.3 meters (9.8 meters)
- Contact Sharp
Basalt

Site 79 – Clipperton Formation – 0 to 305 meters (305 meters)
Cyclic Unit – 0 to 45 meters (45 meters)
- - - - - - - - - - Contact Uncored
Varicolored Unit – 45 to 305 meters (260 meters)
- Contact Uncored
Marquesas Formation – 305 to 413.7 meters (108.7 meters)
Brown Unit – 305 to 352.6 meters (47.6 meters)
Gray Unit – 352.6 to 379.2 meters (26.6 meters)
Brown Unit – 379.2 to 413.7 meters (34.5 meters)
- Contact Sharp
Basalt

TABLE 3 – *Continued*

Site 80 – Clipperton Formation – 0 to 90.6 meters (90.6 meters)	
Varicolored Unit – 0 to 90.6 meters (90.6 meters)	
	Contact Sharp
Marquesas Formation – 90.6 to 185 meters (94.4 meters)	
Brown Unit – 90.6 to 185 meters (94.4 meters)	
	Contact Uncored
Line Islands Formation – 185 to 202.6 meters (17.6 meters)	
	Contact Uncored
Basalt	
Site 81 – Clipperton Formation – 0 to 60 meters (60 meters)	
Cyclic Unit – 0 to 2.3 meters (2.3 meters)	
Varicolored Unit – 2.3 to 60 meters (57.7 meters)	
	Contact Uncored
San Blas Formation – 60 to 385 meters (325 meters)	
	Contact Uncored
Line Islands Formation – 385 to 409.1 meters (24.1 meters)	
	Contact Sharp
Basalt	
Site 82 – Clipperton Formation – 0 to 5.8 meters (5.8 meters)	
Cyclic Unit – 0 to 5.8 meters (5.8 meters)	
	Contact Transitional
San Blas Formation – 5.8 to 202.6 meters (196.8 meters)	
	Contact Sharp
Line Islands Formation – 202.6 to 223.0 meters (20.4 meters)	
	Contact Sharp
Basalt	
Site 83 – Clipperton Formation – 0 to 12.6 meters (12.6 meters)	
Cyclic Unit – 0 to 12.6 meters (12.6 meters)	
	Contact Sharp
San Blas Formation – 12.6 to 222 meters (209.4 meters)	
Unit 1 – 12.6 to 49.6 meters (37 meters)	
Unit 2 – 49.6 to 150 meters (100.4 meters)	
Unit 3 – 150 to 222 meters (72 meters)	
	Contact Uncored
Line Islands Formation – 222 to 233 meters (11 meters)	
	Contact Sharp
Basalt	
Site 84 – San Blas Formation – 0 to 253.9 meters (253.9 meters)	
Unit 1 – 0 to 39.6 meters (39.6 meters)	
Unit 2 – 39.6 to 87.4 meters (47.8 meters)	
Unit 3 – 87.4 to 128 meters (40.6 meters)	
Unit 4 – 128 to 234.6 meters (106.6 meters)	
Unit 5 – 234.6 to 253.9 meters (19.3 meters)	
	Contact Sharp
Basalt	

bulk density measurement is simply an average density of the core taken as a whole. To obtain the bulk density, the 150-centimeter core section is placed on a balance and weighed to the nearest 10 grams. The tare weight of the core tube and end caps—which is assumed to be constant—is then subtracted from the overall weight, leaving the weight of the sample only (assuming that there are no voids). The volume of the sample is known to be 3040.5 cubic centimeters, based on a 2-inch diameter for the core liner. The bulk density is then calculated as follows:

$$\text{Core section bulk density} = \frac{\text{(total core section wt)} - \text{tare wt of liner \& caps}}{\text{volume of plastic liner}}$$

It is essential that there be no voids in the core, as they will cause a lower apparent bulk density if they are not subtracted from the total volume. Owing to the difficulty of measuring the exact volume of the voids, as a general procedure the bulk density of a section was not measured if voids were present.

Gamma Ray Attenuation Porosity Evaluation (GRAPE)

The Gamma Ray Attenuation Density Scanner is a machine which is used to obtain a continuous analog plot of the density and porosity of a core. The basic principle of the machine is that when a pencil-thin beam of gamma radiation is projected through a core, the intensity of the radiation is reduced according to the following formula:

$$I = IoE^{Pb\ ud}$$

where

I = intensity of gamma ray beam penetrating the core

Io = source intensity

Pb = bulk density in gm/cm^3

u = mass absorption coefficient in cm^2/gm

d = diameter of sample in centimeters

In porous materials, the following equation holds true:

$$Pb = Pg\,(1 - 0) + Pf\,(0)$$

where

Pg = matrix or grain density

Pf = density of fluid filling the pore space

0 = porosity of the material

Combining the above two equations yields the following:

$$0 = \frac{Pg - \dfrac{\ln (Io/I)}{ud}}{Pg - Pf}$$

The unknowns in this equation are the grain density, the absorption coefficient, and the fluid density. The absorption coefficient is constant for most geologic materials at about 0.1 cm^2/gm, and both the grain density and the fluid density may be estimated with reasonable accuracy for a given type of sediment. Since both the source intensity and the transmitted intensity can be measured, the equation may then be solved for the porosity of the sample.

The density of the sample is measured directly by GRAPE through the scattering of the gamma ray beam caused by the sediment sample.

The machine itself consists of several sections. A gamma ray source of 5 to 10 millicuries of Ba^{133} with the appropriate shielding and collimation is used to produce a parallel beam of approximately 0.5-centimeter diameter. Opposite the source is a shielded scintillation counter and an optical caliper to measure sample thickness. The sample travels at speeds up to 9 cm/min in a carriage which moves on a track between the source and the counter.

The rest of the machine consists of a power supply case, a computer case, and strip-chart recorder. The computer case contains a small analog computer to evaluate the final equation for the porosity and density of the sample. The computer operates on all of the input variables from the different sections of the device and uses them to calculate the equation. The outputs from the computer and the optical caliper are recorded by the strip-chart recorder.

The variables recorded by the strip-chart recorder are: in green, the density of the core from 1.0 to 3.5 gm/cc; in blue, computed porosity with scaling of 0 to 100 percent; in red, core diameter; 0 to 5 inches. The linear scale on the recording is 1:1. That is, the length on the strip-chart is the same as the actual length of core. In practice, the calibration of the device is checked at the beginning of the processing of each core by running through the machine four cores of material of known density and porosity.

These materials are as follows:

water	density = 1.0 gm/cc	porosity = 100%
Karo syrup	density = 1.36 gm/cc	
sediment	density = 1.25 gm/cc	
aluminum	density = 2.5 gm/cc	porosity = 0%

To read the GRAPE records, one must make use of the calibration checks to establish a proper scale for that particular core or series of cores.

The GRAPE machine is used to give a continuous profile of the density, porosity, and diameter of a particular core section. This information may be used in several ways. The records may be compared to the core to study density or porosity changes and to direct a program of sampling for more detailed tests.

Natural Gamma Emission

Included in the composition of the rocks and sediments are certain minerals containing elements which naturally emit gamma radiation; that is, they emit the radiation with no external stimulus, such as X-ray bombardment, etc. The elements usually responsible for gamma ray emission are: isotopes of the uranium series and the thorium series, potassium minerals, and phosphates. In general, high radiation is emitted from clays, potassic zeolites, potassic feldspars and volcanic ash. This natural gamma radiation can be measured, recorded and used in several ways. The measuring system on board the *Glomar Challenger* consists of the following:

1. *Detectors*–Four shielded 3 inch by 3 inch scintillation detectors at 90° in a plane perpendicular to axis of core sample.
2. *Transport Mechanism*–A conveyor mechanism to move the samples incrementally through the scintillation counter, the increment normally being 1.6 cm/75 sec.
3. *Analyzer and Recorder Unit*–The analyzer unit includes two dual imput, single channel analyzers to accumulate total count rate, a multi-channel analyzer to accumulate gamma ray spectra from each of four detectors, and a timing unit to regulate counting times and core movements. The recorder unit includes a digital-to-analog convertor unit to supply information to two analog recorders, one running on a 1:1 correspondence with the core and the other running on a scale of 5 centimeters equal to 10 meters of core. There is also a digital printout of the total count for each increment. In practice, the core is put onto the conveyor and initially advanced about 20 centimeters into the counter. The unit is turned on and the counters started. The core is then automatically advanced every 75 seconds and the gamma ray emission counted. At the end of the core, the unit is stopped and an alarm bell sounded.

Natural gamma measurements of sediments are a means of determining lithologic changes either in the core or in the walls of the hole if downhole logging equipment is used. If both the cores and the walls of the hole are scanned, the location of the core within the hole may be obtained by comparing and matching the curves obtained from the core and those from the hole. As there is a great deal of noncontinuous coring done in the Deep Sea Drilling Project, downhole logging might aid in making lithologic correlations. There was no downhole Natural Gamma Ray logging on Leg 9.

Sonic Velocity

In taking the sonic velocity of the sediment cores, the general principle used is to measure the difference in the travel time of a pulse through a known material and through an unknown material of the same length. This is done by measuring the difference between the transmission time through the core sample and the transmission time through the reference core of distilled water.

The system itself consists of a pulse generator followed by a pulse amplifier. These units use a 250v pulse of 0.5 microsecond to excite the barium titanate transducer crystals at their natural frequency of 400 kHz. Transducer crystals, held rigidly by a steel frame at a fixed distance from the receiving crystals, are contained in an oil-filled soft rubber head that conforms to the shape of the core and connects them acoustically to the core.

The pulse that travels through the core is picked up by an identical transducer unit, amplified by a Scott 140B decade amplifier, and displayed on a Tektronix oscilloscope.

The procedure for measuring the sonic velocity is initiated by first inserting the reference core section, filled with distilled water, into the transducer head. The pulses are then transmitted through the water, picked up, and displayed on the oscilloscope as a series of sharp peaked waves. The centering adjustment of the oscilloscope is then used to center one of the peaks on a reference line on the oscilloscope tube. The reference core is removed and the specimen core inserted into the transducer head.

To insure a good acoustic coupling, a mixture of glycerine and water is applied to the junction of the transducer head rubber and the plastic core liner. The signal being transmitted through the core will again be displayed as a series of sharp peaks, offset either to the left or right of their original position with the reference core in place. The time delay adjustment of the oscilloscope is then used to bring the same peak as initially centered, back to the center of the tube. This difference between the reference time and the sample time is the time delay. This time delay is used in the following formula to determine the sonic velocity of the sample:

$$Cs = \frac{Cw}{\frac{1 - Cw(Tw - Ts)}{d}}$$

where:

Cs = sediment sound speed

Cw = reference sound speed (distilled water

Tw = transit time through reference (including liner core)

Ts = transit time through sediment sample

d = inside diameter of core liner

In practice this equation was solved by a computer for the standard operation and presented as a table of sonic velocities designated by the time delay and the temperature of the sample. The procedure in testing was to record the standard reference time delay of the sediment sample, and record the temperature. The reference and the sample time delay were then subtracted and the difference looked up in the tables under the proper temperature to obtain the sonic velocity. The estimated accuracy is about ± 0.5 per cent.

The sonic velocity measurement is of importance in that a great deal of study on deep-sea sediments is based on sonic or seismic means and, consequently, the knowledge of the sonic velocities in sediments will aid in the interpretation of the data received. Sonic velocity changes may also indicate changes in porosity and density.

Penetrometer

The penetrometer test is a relative measure of induration and is used to supplement the core description. It is not a true test of sediment strength as it produces no measurement in units of soil strength.

A true test of sediment strength would probably not be worthwhile due to extreme sediment disturbance that occurs during the coring of unconsolidates oozes.

The test itself, following ASTM Designation D-5-65 consists of dropping a needle of a specified form under a given load into the sediment and measuring the distance of penetration, giving this as the result of the test.

The test unit is a soil test AP210 penetrometer consisting of a shaft into which a "standard" needle is mounted, the shaft being held at a uniform height above the core and released by a clutch. The amount of penetration is measured on a 4-inch dial graduated in tenths of a millimeter.

The points tested were at 37.5 centimeters, 75 centimeters, and 112.5 centimeters in the section core unless lithology changes or other irregularities, such as extreme fluidity, dictated a change in location.

Sampling Procedure

Paleontology

Sampling requirements and procedure differed substantially from that of other legs because of the composition of the paleontologic staff participating on Leg 9. Time limitations on many previous legs precluded working on any more than core catcher samples for the initial correlations while on shipboard. The versatility of the Leg 9 paleontologic staff made possible shipboard correlations on frequently as many as all six sections per core. These correlations were effected within a very short time of the actual recovery of the core, and usually included corroborative data from all three fossil groups (foraminifera, Radiolaria and calcareous nannofossils).

Probably the most significant procedural departure from previous legs was the practice of routinely obtaining samples from various sections of the core prior to splitting the core. Plug samples were obtained from the ends of the sections at the time the core was cut into sections on the catwalk. Samples were taken in this way for Radiolaria, foraminifera, and calcareous nannofossils. In most cases the tops of Sections 1, 3 and 5 were sampled. When continuous cores were being taken, the top of Section 1 was not sampled. This is equivalent to a sample every four meters under continuous coring conditions. The advantage of this technique is that it permits the paleontologists to proceed with detailed correlations at the same rate as the coring process. When sections are available about two days after the core was taken, the zones and ranges established on a four-meter stratigraphic interval were usually further refined by additional sampling. At this time an effort was made by the paleontologists to obtain samples from midway between the previous samples. By obtaining three additional samples per barrel, the final control in most cases was based on a two-meter stratigraphic interval. Departures from this sampling procedure were usually in situations where lithologic changes or incomplete core recovery precluded routine sampling.

In order to maintain some degree of consistency, the shore laboratory samples were obtained from Section 4 for most cores. Within this section, shore laboratory samples were carefully taken from lithologies adjudged to be in keeping with the requirement of the shore laboratory operators.

Sampling Procedure

Lithology

After the initial paleontological samples were taken at the core receiving area, the capped 150-centimeter long sections were taken into the core laboratory and split longitudinally with a Skil saw and laid open. Half of each section, labeled the archive half, was described and had smear slides made from the various lithologies. These smear slides were examined under a petrographic microscope and a descriptive lithologic name was given to the sediments. These names were based on the sediment classification scheme developed on board Leg 9, as previously mentioned (Figure 1).

Samples were obtained by pushing a cylindrical plastic tube down through the sediments. The tube and sediment were then sealed in a plastic vial and sorted under refrigeration to preserve moisture content. X-ray mineralogy samples of 10 cubic centimeters for the shore laboratory were obtained at 5 to 7 centimeters and 20 to 22 centimeters from the top of each opened section and at any significant lithologic change. Grain-size analysis samples of 10-cubic centimeters for the shore laboratory were also taken at 10 to 12 centimeters from the top of each opened section and at any obvious grain size changes. Three 10-cubic centimeter paleomagnetic samples were taken during the Leg 9 cruise. Collecting more paleomagnetic samples was not considered advisable due to sediment disturbance. Two-cubic centimeter calcium carbonate samples were routinely taken at 16 to 17 centimeters from the top of each opened section. The 0.5-cubic centimeter interstitial water samples were obtained with a syringe at 17 centimeters from the top of each opened section unless the sediments were obviously filled with water from drilling procedures.

Every effort was made to open all sections unless the backlog of cores or excess water in the core liner made it impractical.

Biostratigraphic and Age Considerations

After drilling the second site (77) on Leg 9 through to the Upper Eocene, it was readily apparent that in spite of the fact that planktonic foraminifera were abundant, the zonal scheme proposed by Blow as outlined in the Biostratigraphy Manual (Part VII) was completely unworkable. The failure of Blow's zonal scheme in the southeast Pacific is due largely to the fact that he has completely overlook the particular susceptibility of certain planktonic foraminifera to destructive solution in the deep seas. We see then that although Berger (1967, 1968 ab) has listed *Globigerinoides, Orbulina* and *Globigerina* as highly susceptible genera to solution, Blow has used these species as zonal indices in several places. Even where solution was not prevalent in the cores, Blow's number and letter zonal scheme frequently was unworkable because of the poor definition of his zonal boundaries. To remedy these problems, and in order to effectively contribute foraminiferal correlations to the cruise effort, the Leg 9 foraminiferal workers devised their own zonal scheme for the southeast Pacific which is shown in Figure 4. This foraminiferal zonal scheme is based wherever possible on solution-resistant genera such as *Globoquadrina, Globorotalia* and *Pulleniatina* (see Synthesis Section–Foraminifera). A more thorough discussion as well as the complete definition for each of these new zones may be found in the Leg 9 Synthesis Section.

For the Neogene radiolarian zonation we have followed the scheme established by Riedel and Sanfilippo (1970). This zonation has been modified by the inclusion of four additional zones in the Oligocene. Three of these zones, the *Theocyrtis annosa* Zone, *Hexaspyris papilio* Zone, and the *Lychnocanium bipes* Zone, were defined by T. C. Moore (in press) and used in the Leg 8 volume. The fourth zone, the *Lithocyclia angustum* Zone, is provisionally named here and occurs between the *Theocyrtis tuberosa* Zone and *Theocyrtis annosa* Zone.

Comparison of the nannofossil zonation to the foraminifera and radiolarian zonations is shown in Figure 5.

Paleontological data for each site are displayed by means of two types of biostratigraphic charts. Each of the three major fossil groups, planktonic foraminifera, Radiolaria and nannofossils, have been alloted a separate set of charts depicting species ranges, and zonations plotted against drilling depth. These charts are simply titled Biostratigraphic Charts Radiolaria, etc., and each set is arranged in a series of pages with 200 feet of drilled depth below sea floor on each page. Charts such as these are common in biostratigraphic practice and, with one exception, require no explanation. Cores thirty feet long or shorter are illustrated at a uniform scale. Difficulties arise where recovery exceeds the drilled interval at sites which were continuously cored. It was necessary to use a smaller scale to fit these anomalous cores into the required thirty-foot interval. Such cores are marked by an asterisk following the core designation.

A fourth set of biostratigraphic charts is included with each site report. Titled Biostratigraphic Comparison Charts, they serve to compare the zonations and zonal index taxa of the three fossil groups. These charts are illustrated at a scale of 165 meters per page.

The absolute ages used in this report are generally derived from Berggren (1969) and bear the following relationship to our zonation.

The youngest absolute data used on Leg 9 was the upper Pliocene/Pleistocene boundary at 1.85 million years (Hays *et al.,* 1969). Elsewhere the Pliocene/Pleistocene boundary has been defined on the evolutionary transition of the planktonic foraminiferer *Globorotalia tosaensis* into *Globorotalia truncatulinoides* (Berggren *et al.*, 1967). In the southeast Pacific this zonal species proved to be very susceptible to solution (see Jenkins and Orr, Synthesis (Foraminifera), but the extinction of *Globigerinoides fistulosus* was found to represent the same horizon in the area we studied. This level marks the boundary between the *Pulleniatina obliquiloculata* and *Globigerinoides fistulosus* foraminiferal zones. The boundary between the *Ceratolithus rugosus and* the *Ceratolithus tricorniculatus* nannofossil zones defines the upper Miocene/lower Pliocene boundary and is synchronous with the Miocene/Pliocene boundary of Saito based on foraminiferal criteria and dated at 5 million years B.P. (Saito, personal communication). This boundary falls within the upper half of the *Globorotalia tumida* foraminiferal zone, but no other microfossil zonal boundaries correspond to this interface.

The Upper Miocene/Middle Miocene boundary is defined in this report as the zonal interface between the *Ommatartus antepenultimus* and the *Cannartus petterssoni* radiolarian zones. This interface was further corroborated by the extinction of either of the two nannofossil species *Discoaster hamatus* or *Discoaster exilis.* Our boundary falls somewhat above the boundary used by Berggren and dated at 10+0.5 million years B.P.

The early Miocene/middle Miocene boundary was recognized by the boundary between the *Praeorbulina glomerosa curva* and *Globigerinoides bisphericus* foraminiferal subzones with an age of 14 million years (Berggren 1969). This boundary was further defined as the *Triquetrohabdulus carinatus* nannofossil extinction. The Lower Miocene/Upper Oligocene boundary was recognized at the boundary between the *Globorotalia kugleri* and the *Globigerina angulisuturalis* foraminiferal zones with an age of 22.5 million years (Berggren 1969).

The final absolute date employed on Leg 9 was the Lower Oligocene/Upper Eocene boundary at 36 million years (Berggren 1969). This interface falls just above the top of the *Globorotalia insolite* foraminiferal zone, but is defined as the boundary between the *Cyclococcolithus lustanicus/Sphenolithus predistentus* and the *Cycloccoccolithus lusitanicus/Ithmolithus recurvus* nannofossil subzones.

Site Report Introduction

Our Site Reports are organized so as to provide the reader with the maximum amount of information at a glance but also provide additional detail for those who wish it. The beginning of each site report contains a sketch of the seismic reflection record across the site accompanied by the intervals cored, lithologies of those intervals and biostratigraphic series boundaries. The accompanying text includes a review of the main geological findings at the site and an operational summary. This section should provide the reader with enough information so that he can decide if this site will be useful to him in his particular research endeavor. This capsulated summary of the site is followed by more detailed discussion of the lithology, biostratigraphy and physical properties of the sediments.

The biostratigraphic data are presented in a series of species range charts for each group (foraminifera, Radiolaria and nannofossils), and comparison charts that present in comparative format the ranges of key species from each group.

The page-sized figures in each site report are arranged to progress toward increasing detail. The text is followed by the Site Summary which is followed by the Stratigraphic range charts (foraminifera, Radiolaria and nannofossils). These, in turn, are followed by the biostratigraphic comparison charts, the core summaries and, finally, selected section summaries complete the page-sized figures included with each site report.

References

Andrews, J. and Hsu, K., Jinghwa, 1970. Note 38-a recommendation to the American Commission on Stratigraphic Nomenclature concerning nomenclatural problems of submarine formations. *Bull. Am. Assoc. Petrol. Geol.* **54**, 1746.

Arrhenius, G., 1952. Sediment cores from the East Pacific. *Repts. Swedish Deep-Sea Expedition.* **5**, 85 p. (Goteborg).

Atwater, T., 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. *Bull. Geol. Soc. Am.* **81**, 3513.

Atwater, T. and Menard, H. W., 1970. Magnetic lineations in the Northwest Pacific. *Earth & Planetary Sci. Letters.* **7**, 445.

Berggren, W. A., 1969. Cenozoic chronostratigraphy, planktonic foraminiferal zonation and the radiometric time scale. *Nature.* **224**, 1072.

Burckle, L. H., Ewing, J., Saito, T. and Leyden, R., 1967. Tertiary sediments from the east Pacific. *Science.* **157**, 537-540.

Ewing, J., Ewing, M., Aitken, T. and Ludwig, W., 1968. North Pacific sediment layers measured by seismic profiling. In *The Crust and Upper Mantle of the Pacific Area.* L. Knopoff, C. Drake and P. Hart (Eds.) *Am. Geophys. Union Mono.* 12.

Francheteau, J., Harrison, C. G., Sclater, J. G. and Richards, M., 1970. Magnetization of Pacific seamounts: a preliminary polar curve for the northeastern Pacific. *J. Geophys. Res.* **75**, 2035.

Hayes, D. E. and Pitman, W. C., III, 1970. Marine geophysics and sea floor spreading in the Pacific-Antarctic area: a review. *Ant. J. U.S.* **5**, 70.

Hays, J. D., Saito, T., Opdyke, N. and Burckle, L., 1969. Pliocene/Pleistocene sediments of the equatorial Pacific: their paleomagnetic, biostratigraphic and climatic record. *Bull. Geol. Soc. Am.* **80**, 1481.

Herron, E. M. and Hayes, D. E., 1969. A geophysical study of the Chile Ridge. *Earth Planet. Sci. Letters.* **6**, 77.

McKenzie, D. and Parker, R. L., 1967. The North Pacific, an example of tectonics on a sphere. *Nature.* **216**, 1276.

Parker, F. L., 1967. Late Tertiary biostratigraphy (planktonic Foraminifera) of tropical Indo-Pacific deep sea cores **In** *Am. Paleont. Bull.*, **52**, pp. 115-203.

Pitman, W. C., III, Herron, E. M. and Heirtzler, J. R., 1968. Magnetic anomalies in the Pacific and sea floor spreading. *J. Geophys. Res.* **73**, 2069.

Ried, J. L., 1962. On circulation, phosphate phosphorous content, and zooplankton volumes in the upper part of the Pacific Ocean. *Limnol. and Oceanog.*, **7**, pp. 287-306.

Riedel, W. R., 1957. Radiolaria: a preliminary stratigraphy **In** *Swedish Deep Sea Expedition Reports,* **6**, pp. 61-96.

Riedel, W. R., 1959. Oligocene and Lower Miocene Radiolaria in tropical Pacific sediments. *Micropaleontology,* **5** , pp. 285-302.

Riedel, W. R., 1967. Radiolarian evidence consistent with spreading of the Pacific floor. *Science,* **157**, pp. 540-542.

Riedel, W. R., 1971. The occurrence of pre-Quaternary Radiolaria in deep-sea sediments. **In** *The Micropaleontology of Oceans.* Funnel, B. M. and Riedel, W. R. (Eds.) Cambridge Univ. Prep., 567-594.

Riedel, W. R. and Funnel, B. M., 1964. Tertiary sediment cores and microfossils. from the Pacific Ocean floor. *Geol. Soc. London Quart. J.* **120**, 305.

Riedel, W. R. and Sanfilippo, A., 1970. Radiolaria, Leg 4, Deep Sea Drilling Project. **In** Badez, R. G. *et al.,* 1970. *Initial Reports of the Deep Sea Drilling Project, Volume IV.* Washington (U. S. Government Printing Office). 503.

Vine, F. J., 1966. Spreading of the ocean floor: new evidence. *Science.* **154**, 1405.