1. INTRODUCTION AND EXPLANATORY NOTES

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PRECRUISE PLANNING

Leg 33 of the Deep Sea Drilling Project was the fourth of five cruises planned for the 1973-1974 drilling program of the *Glomar Challenger* in the Pacific. The main purpose of this leg was to investigate the geologic history of one of the linear submarine ridge and island chain systems that have given rise to so much speculation from the days of J.D. Dana to the present.

Leg 33 grew out of a proposal to the JOIDES Planning Committee for a "Leg Hot Spot" (Schlanger, Winterer, and Lancelot, memo. 1971). At that time Morgan (1971, 1972a, b) had extended Wilson's (1963) hypothesis that linear island chains and aseismic ridges were formed above fixed hot spots in the mantle, and that, when viewed from a time framework, these chains mapped plate motion. Morgon (1971, 1972a, b) proposed that such chains were fed by thermal plumes, and that their bends, or elbows, marked changes in plate direction. He specifically included the Line Islands-Tuamotu Chain as having resulted from one of his fixed plumes. The original "Leg Hot Spot" proposal was designed to test these ideas by drilling along the flanks of islands, seamounts, and ridges in the Line Islands and the Tuamotus. Site 165, drilled on Leg 17, in a turbidite apron northwest of Kingman Reef in the Line Islands showed that such flank sites revealed a great deal about the history of nearby islands. The turbidites contained skeletal debris of reefal and shallower water ridge crest origin and volcaniclastic sequences that marked the history and cessation of volcanism at that point along the island chain. Since the original proposal was written, many new data have been assembled by a number of workers, giving new insights into what now appears to be a much more complicated linear island chain generation mechanism than was originally envisioned by Morgan and Wilson. Shaw and Jackson (1973), for example, believe that these chains are localized by gravitational anchors rather than by thermal plumes. Many of these newer ideas on linear island chain generation are based on data from the Hawaiian-Emperor Chain; very little new data have been produced from the Line Islands-Tuamotu Chain, the longest of the so-called bent island chains in the Pacific Basin.

The primary objectives of Leg 33 were:

1) To determine the ages and geologic histories of segments of the Line Islands-Tuamotu Chain by drilling into the turbidite fans that drape around them. Based on such new data, we considered it possible to determine whether the two chain segments are indeed temporarily linked at an elbow, whether they overlap in age, or whether they are two separate "subchains."

2) To determine the extent and rate of the vertical motions undergone by these islands through time as they traveled away from the site of generation.

3) To gain a better understanding of the development of the sedimentary aprons that surround the islands.

4) To add to our information on the origin and geologic history of oceanic plateaus and rises by drilling the Manihiki Plateau.

Secondary objectives of Leg 33 included:

5) Petrologic objectives.
6) Paleooceanographic objectives.
7) Biostratigraphic objectives.
8) Geophysical objectives.
9) Operational objectives.

Six primary sites and several alternate sites were originally selected (Figure 1 and Table 1). One primary site, 33-1, provided a location close to Honolulu for the proposed first sea trials of the heave compensation system which was, among other things, designed to improve the quality of cores recovered in soft sediments and to extend bit life. Four primary sites, 33-2, 33-3, 33-4, and 33-6, were selected to test ideas relevant to linear island chain formation; and one primary site, 33-5, was selected to solve problems relevant to oceanic rise and plateau genesis.

Cruise Objectives

Linear Island Chain Genesis and Age

Since Morgan's (1971, 1972a, b) proposals, Jackson et al. (1972) showed that volcanism along the southeastern Hawaiian Islands has been episodic. Shaw (1973) calculated the volumes of the Hawaiian Islands, showed them to correlate with the episodic ages, and predicted even greater episodicity among undated seamounts in the northwestern part of the chain. Winterer (1973) pointed out discrepancies between the rate of movement of the equatorial sediment bulge and the apparent rate of movement of the Hawaiian Chain. Clague and Jarrard (1973a) compiled a list of minimum ages of most Pacific Island chains, and found them partially at variance with the Morgan hypothesis. Clague and Dalrymple (1973) dated Kōko Seamount, and, although aware of the episodic nature of the volcanism, predicted an age of 42-44 m.y. for the Hawaiian-Emperor bend. Scholl et al. (1971) reported the age of Meiji Seamount, which may be the northernmost of the Emperor seamounts as 72 m.y. Using these values and volumetric

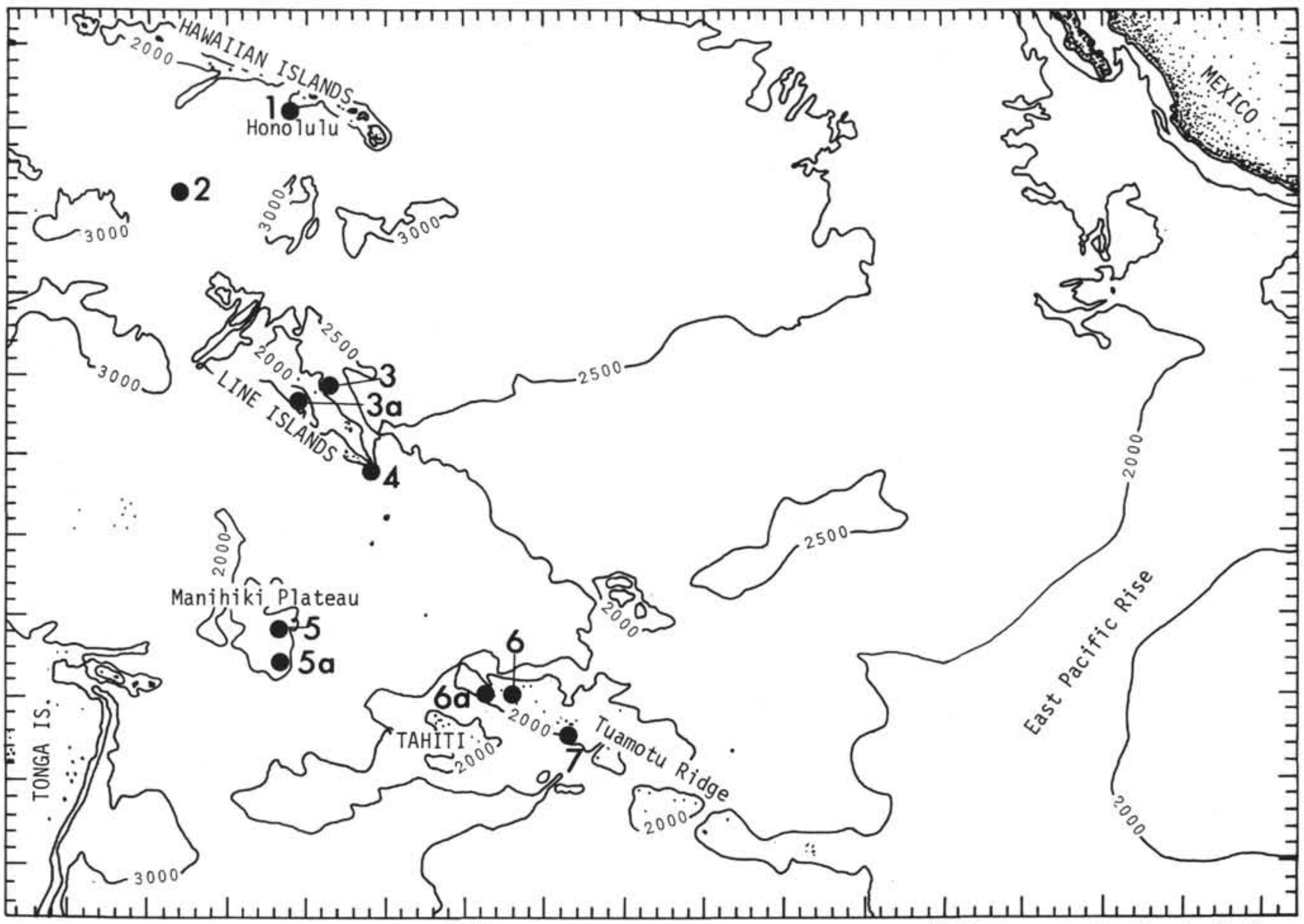


Figure 1. *Location of proposed sites to be drilled during Deep Sea Drilling Project, Leg 33.*

data, Bargar and Jackson (1975) calculated the eruption rate along the Emperor segment as 0.012 km^3/yr and of the Hawaiian segment 0.018 km^3/yr. There are growing data that suggest that "hot spots" are not fixed in time, as Wilson and Morgan contended, but that they move slowly with time (Clague and Jarrard, 1973a; Molnar and Atwater, 1973). Shaw and Jackson (1973) proposed that linear island chains in the Pacific are stabilized by gravitational anchors rather than thermal plumes, anchors that would move slowly with time, and that the apparent periodicity of volcanism is caused by shear melting above an anchor free to flow or counterflow in the asthenosphere. Thus, while data principally derived from the Hawaiian-Emperor Chain proliferate, and are being extended to other linear island chains, little was known about the Line Islands proper or their relation to the Tuamotus. Clague and Jarrard (1973b) pointed out that the Line Islands do not lie exactly on the great circles of the Emperors or the Marshall-Gilbert-Ellice chains to which they are supposedly related. They are complicated by the "Line Cross," a bathymetric feature of obscure origin. Clague and Jarrard (1973b) reported only five ages from the entire Tuamotu-Line Chain, some of them questionable. These dates, which range from 37.5-80 m.y., are not consistent with an even rate of progression of volcanism along the chain. We planned to devote four continuously cored holes (33-2, 33-3, 33-4, and 33-6) to the Line-Tuamotu Chain toward resolving this inconsistency.

History of Vertical Motion of the Islands

Previous studies on the diagenetic history of the limestone columns that underlie atolls show that their emergence-submergence history is preserved in the form of alternating zones of aragonite-free, calcite-rich rocks and aragonite-rich rocks separated by "solution unconformities" (Schlanger, 1963). The diagenetic state of the skeletal debris of shallow-water and reefal origin present in the turbidite facies to be drilled at Sites 33-2, 33-3, 33-4, and 33-6 was planned to indicate periods of emergence (uplift) and submergence (subsidence) of the adjacent island chain.

Sedimentary Fan Development

The central part of the Line Islands Ridge is marked by a spectacular development of sedimentary fans both to the east and west of the main ridge. Seismic profiles show that up to 800 meters of well-stratified sediment are present above acoustic basement. At Site 165 on Leg 17 it was found that much of this fan material shows

TABLE 1
Proposed Sites for Leg 33 – Central Pacific

Site	Area	Coordinates	Water Depth (m)	Drilling Depth (m)	Priority	Major Objectives
1	Kaula Island Fan	21°N 161°W	4500	300	1	Sea trial of heave compensator; geologic history of Kaula Island
2 (314)	Johnston Island Trough	16°N 168.5°W	5100	600	1	Geologic history of Johnston Island; turbidite fan sedimentology
3 (315)	Fanning Island Fan East	4.2°N 158.4°W	4200	720	1	Geologic history of central Line Islands; turbidite fan sedimentology
3a	Fanning Island Fan West	3.3°N 160.5°W	4500	630	2	Geologic history of central Line Islands; turbidite fan sedimentology
4 (316)	Line Islands South	0.8°S 156.1°W	4700	650	1	Geologic history of southern Line Islands
5 (317)	Manihiki Plateau	11°S 162.2°W	2560	900	1	Geologic history of a major rise; facies comparison with Shatsky and Magellan rises; heat flow measurements
5a	Manihiki Plateau	12.8°S 162.3°W	2400	800	1	Geologic history of a major rise; facies comparison with Shatsky and Magellan rises; heat flow measurements; this site is alternate for Site 33-5
6 (318)	Tuamotu Ridge	15.2°S 146.8°W	2600	670	1	Petrology of Tuamotu basalts; geologic history of Tuamotu atolls
6a	Tuamotu-NW	15.5°S 149°W	4200	225	2	Petrology of Tuamotu basalts; geologic history of Tuamotu atolls
7[a]	Tuamotu Trough	17.8°S 144°W	4000	460	2	Geologic history of central Tuamotu Chain

[a]May be drilled on Leg 34.

cyclical sedimentation units of probable turbidite origin. Site 33-3 was planned for maximum penetration and core recovery of a fan so that its sedimentological history could be studied.

Oceanic Plateau and Rise Genesis

Manihiki Plateau, Shatsky Rise, and Magellan Rise represent three major geologic features that are anomalous in terms of a simple ridge-crest model of sea-floor generation. The age and mode of formation of such features will have to be included in any sophisticated theory of sea-floor evolution. Therefore, it was important to completely sample the sedimentary cap and core the basement basalt of these rises and plateaus. Adequate coring of the Magellan Rise on Leg 17 resulted in the documentation of its Late Jurassic to Quaternary history of pelagic sedimentation. A complete penetration of Shatsky Rise was planned for Leg 32. An evaluation of the Manihiki Plateau was planned for Leg 33.

Petrologic Objectives

The thickness of sediment which overlies basalt at Leg 33 drill sites posed a problem. It was postulated that the entire Line Islands Chain had passed through nutrient-rich equatorial waters, and that the individual edifices were partially blanketed by thick sediment sequences which must be penetrated before basalt could be cored. At Sites 33-1, 33-3, and 33-4, it was recognized that if basalt were recovered, it would be difficult to say whether it represented derivation from shield-shaped edifices or was older ocean floor. It was decided that, unless coring or seismic profiling gave new information, drilling into basalt at these sites would be minimized. Site 33-2, on the other hand, appeared to overlie older oceanic crust, and, time permitting, we planned to drill basalt until bit failure. At Site 33-5, on the Manihiki Plateau, basalt again would be drilled as time permitted. Finally, at Site 33-6, previous seismic profiles seemed to clearly indicate edifice material at the drill site, and an effort needed to be made to recover as much volcanic rock as possible. We expected typical deep-sea basalt at Sites 33-2 and 33-5, although it was thought it might be much altered (Salisbury and Christensen, 1972; Bass et al., 1973). At Site 33-6 it was thought to be interesting to note whether or not we encountered alkalic rocks typical of Hawaiian-type shields, or Hawaiian-Icelandic-type tholeiite.

Paleooceanographic Objectives

The complete penetration of the Magellan Rise on Leg 17 (Site 167) revealed that the 1185-meter-thick sedimentary cap contains an almost uninterrupted pelagic record spanning Late Jurassic to Quaternary time.

At the time Leg 33 was planned, Leg 30 was engaged in drilling the Ontong-Java Plateau, Leg 32 had proposed to drill Shatsky Rise, and, together with our proposed Site 33-5 on the Manihiki Plateau, would provide four relatively complete stratigraphic sections of the major Pacific plateaus. Their sediments would represent deposition covering a broad latitudinal span. The paths of these rises through the various water masses of the Pacific since late Mesozoic time should be reflected in (1) the lithofacies sequences developed on each in the stratigraphic column, and (2) in the differences in lithofacies within isochronous zones between each column. Further, these thick pelagic sections offer excellent material for isotope studies (Coplen and Schlanger, 1973) that are beginning to show the existence of worldwide isotope events having possible paleotemperature significance.

Biostratigraphic Objectives

No sites had been selected primarily for biostratigraphic objectives although charting latitudinal aspects of fossil assemblages was an important consideration for the Manihiki Plateau drill site. In addition, the turbidite fan sites would penetrate intervals where pelagic faunal and floral elements have been cosedimented with both the reefal and bank facies as well as ridge crest elements, thereby increasing our knowledge of the correlations between planktonic and benthonic fossils.

Geophysical Objectives

Heat flow measurements were needed to establish additional reliable oceanic control points, to determine if heat flow varies with depth, and to establish the temperature regimes of diagenesis in pelagic sediments. Prior to Leg 33 (R.P. von Herzen, letter dated 24 July 1973), a maximum of only three to four reliable downhole temperatures had been obtained for any DSDP site. Rather than collect scattered data, Leg 33 agreed to attempt to obtain 8 to 10 downhole measurements at one site, 33-5, on the Manihiki Plateau, but heat flow instrumentation was not onboard the *Challenger* when the leg left Honolulu.

Operational Objectives

Due to delays in the installation of the heave compensation unit, we were informed that its testing would occur on Leg 33. Site 33-1 was selected as a test locality based on considerations of water depth, closeness to Honolulu, and sediment thickness. The site, while not part of the original cruise proposal for Leg 33, would provide valuable data on the evolution of the Kaula-Nihoa-Kauai triplet in the Hawaiian Island Chain, and thus contribute data to the problem of linear island chain formation.

CRUISE RESULTS

Geologic Results

Glomar Challenger steamed from Honolulu on 2 November 1973, drilled eight holes at five sites (Figure 2), and docked at Papeete, Tahiti, on 17 December, to complete Leg 33 of the Deep Sea Drilling Project. Preplanned Site 33-1 was abandoned because of initial operational problems (see following section) and the *Challenger* proceeded directly from Honolulu to the Johnston Island Trough. The drilling and coring summary of Leg 33 is summarized in Table 2.

Preplanned Site 33-2 (Site 314)

Site objectives were reduced on leaving Honolulu (due to a substantially shortened leg that resulted from delays in the installation of the heave compensator) to a spot-coring program in order to penetrate the estimated 650 meters of sediment overlying basement at this site. Actual penetration at the site was 45 meters; drilling difficulties culminated in the bending of the bumper subs of the bottom-hole assembly and the site was abandoned. The section from the mudline to 17.5 meters, and most likely to a depth of 35 meters, consisted of brown zeolitic clay rich in phillipsite and containing abundant reworked late Neogene, Paleogene, and Cretaceous faunal elements. This soft clay overlay harder claystone and porcellanite probably of middle to late Eocene age that was found at 35 to 45 meters depth. The porcellanite was diagenetically produced from an originally foraminiferal and nannofossil-bearing sediment. The relict carbonate, in the form of nannofossils and recrystallized (possibly planktonic) foraminifera in the porcellanite, indicated that the Johnston Island Trough may have been shallower than the foraminiferal solution depth during middle to late Eocene time (the present depth is 5225 m).

By way of contrast, at Site 164 (present depth 5499 m) the stratigraphically equivalent section was probably deeper than the carbonate-compensation depth or was beneath a region of extremely low fertility. At Site 68 (present depth 5467 m) the situation was similar to that at Site 164. It seemed therefore reasonable to propose that the bottom of the Johnston Island Trough was already shallower by middle-late Eocene time than the basin to the east, in which Sites 165 and 68 are located.

Preplanned Site 33-3 (Site 315)

After four cores were cut in Hole 315, in the interval from 0.0 to 37.5 meters subbottom depth, and 17.2 meters of core consisting of Pleistocene to lower Pliocene oozes were recovered, the drill string had to be pulled because the ship had moved too far away from the beacon. Hole 315A was respudded at the same location and water depth: total depth of this hole was 1034.5 meters, of which 323.0 meters was cored and 130.5 meters recovered. The section consisted of (1) cyclically bedded foraminiferal and nannofossil ooze from 0 to 56 meters, of Quaternary through Pliocene age within which a Pliocene hiatus was found; (2) variegated purple, white, and green nannofossil ooze from 56 to 710 meters, which became chalky near a depth of 370 meters, of Oligocene to late Miocene age, and which contained a Miocene hiatus at a depth of about 454-512 meters; (3) Eocene through upper Campanian claystone, chert, and limestone from 710 meters to 844 meters, a section whose base was dated as near the middle-upper Campanian boundary, and which contained a unit of reefal debris at about 800 meters; (4) middle and upper Campanian volcaniclastic sandstones and micritic claystones that extended from 844 to 901 meters and displayed a wide variety of turbidite structures; the base of this unit appeared to be close to the Campanian-

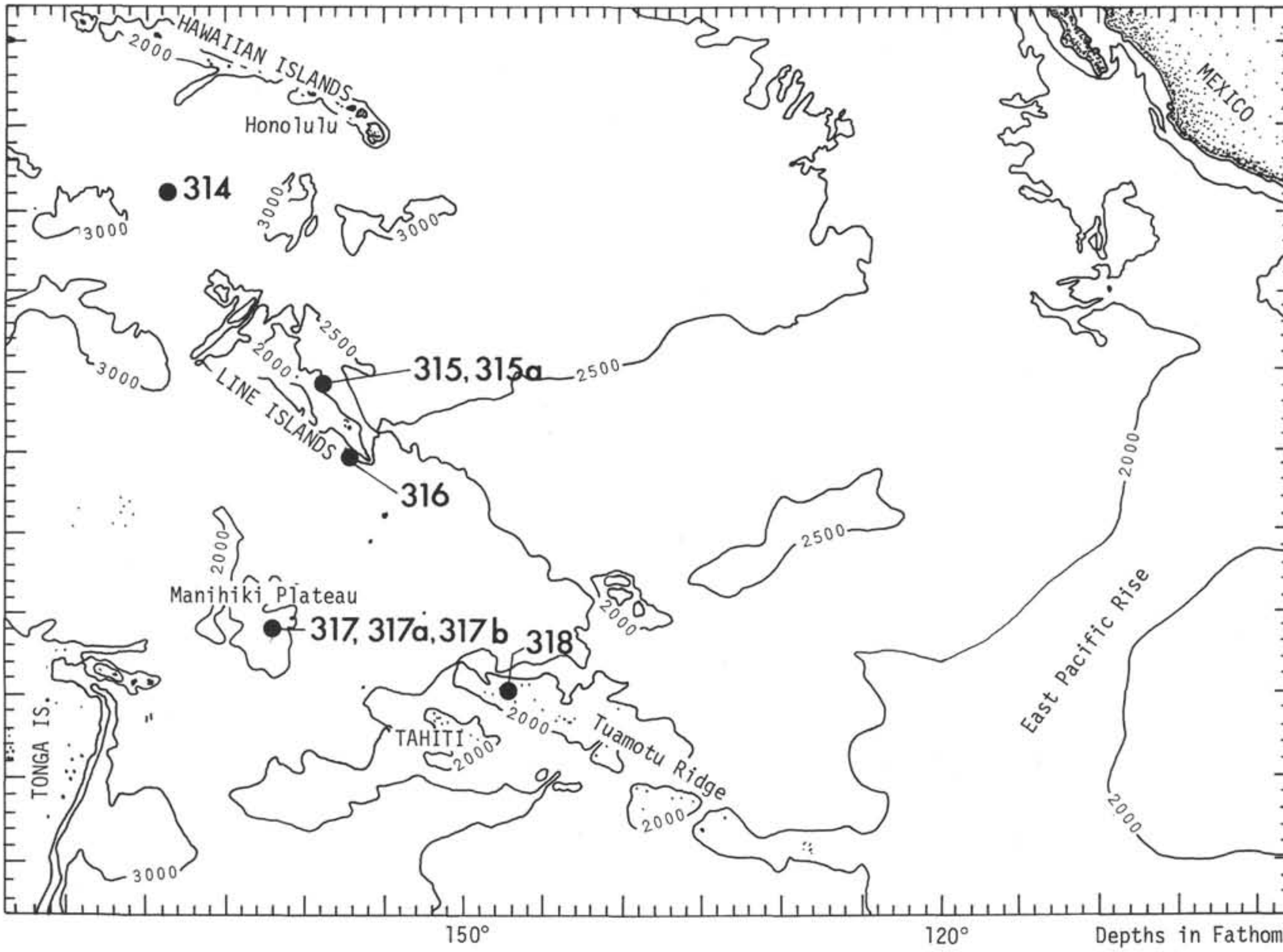


Figure 2. *Location of holes drilled during Leg 33.*

TABLE 2
Deep Sea Drilling Project Site Summary, Leg 33

Hole	Latitude	Longitude	Water Depth (m)	Number of Cores	Cores With Recovery	Percent With Recovery	Cored (m)	Recovered (m)	Recovered (%)	Drilled (m)	Total Penet. (m)	Avg. Rate Penet.	Time On Hole (hr)	Time On Site (hr)
Johnston Island Trough														
314	15° 54.76'N	168° 28.07'W	5225.5[a]	3	0	0	17.5	<1.0	<1.0	27.5	45.0	165.0	42.5	42.5
Fanning Island Fan East														
315	4° 10.26'N	158° 31.54'W	4164[a]	4	2	50	37.5	17.2	59.6	47.5	85.0	98.0	32.0	
315A	4° 10.26'N	158° 31.54'W	4164[a]	34	31	91	323.0	130.5	40.5	711.5	1034.5	26.0	124.5	156.5
Line Islands South														
316	0° 05.44'N	157° 07.71'W	4464.5[a]	30	29	97	285.0	102.8	36.4	552.0	837.0	21.0	115.0	115.5
Manihiki Plateau														
317	11° 00.09'S	162° 15.78'W	2625[a]	3	3	100	28.5	19.2	67.7	323.0	351.5	13.0	26.5	
317A	11° 00.09'S	162° 15.78'W	2622[a]	34	33	97	313.5	163.3	51.7	630.0	943.5	10.5	89.5	
317B	11° 00.09'S	162° 15.78'W	2622[a]	45	42	93	424.5	308.0	71.6	0	424.5	6.3	67.0	183.0
Tuamotu Ridge														
318	14° 49.63'S	146° 51.51'W	2659[a]	32	32	100	298.5	147.1	49.3	446.5	745.0	25.7	77.0	77.0
Total				185	172	93	1728.0	888.1	51.5	2747.5	4466.0	29.0	574.0	574.0

[a]Drill pipe depth.

Santonian boundary; (5) ferruginous claystones and graded volcanogenic sandstones in the interval 911-996 meters, of Santonian age. Beneath these sediments 38 meters of basalt was cored but less than 8 meters was recovered. Parts of at least six flow units, each ranging from 1.5 to 2.0 meters thick, were recognized in the cores. All the basalt was highly altered, and it could not be determined whether it had tholeiitic or alkalic affinities (see Jackson et al., this volume). It is suspected that at least some of the units were alkalic. Based on extrapolated sedimentation rates, we concluded that volcanism ceased at Site 315 about 85 m.y. ago (see Lanphere and Dalrymple, this volume).

Preplanned Site 33-4 (Site 316)

The section consisted of (1) cyclically bedded white foraminiferal-nannofossil ooze of Quaternary age between 0.0 and 2.0 meters depth, (2A) Quaternary through middle Miocene varicolored foraminiferal-nannofossil oozes between 2.0 and 267 meters depth, (2B) middle through lower Miocene varicolored chalk between 267 and 380 meters depth, (3) lower Miocene through Paleocene interbedded chalks and cherts (locally dolomitic) between 267 and 580 meters depth, and (4) interbedded chalk, limestone, and chert, underlain by volcanogenic debris, from 580 meters to the bottom of the hole at 837 meters, which ranged in age from middle Maestrichtian to early Campanian. Again, based on extrapolated sedimentation rates we concluded that volcanism ended here about 81-83 m.y. ago.

Preplanned Site 33-5 (Site 317)

In order to avoid using reentry techniques and minimize bit wear, a drilling strategy was adopted that involved (1) washing down to hard rock, (2) coring continuously to and into basement, (3) pulling the drill string, respudding with a fresh bit, and (4) continuously coring the upper ooze and chalk section. Hole 317 was terminated at 351.5 meters below the bottom because a bolt accidentally fell down the drill pipe and prevented recovery of the core barrel. Hole 317A was then spudded and was successfully completed in basalt at 943.5 meters. Hole 317B, drilled to sample the previously bypassed upper section, was continuously cored until a fragment of a pump was washed into the drill pipe and prevented retrieval of the core barrel at a depth of 424.5 meters; that left a gap of 129.5 meters between the deepest cores of 317B and the shallowest level of the continuously cored part of 317A. The section at Site 317, as reconstructed from all three holes, consisted of (1) grayish-orange, white, and bluish-white nannofossil and foraminiferal ooze, firm ooze, and chalk, of Quaternary to middle Oligocene age, from 0.0 to 303.5 subbottom depth; (2) light-colored foraminiferal nannofossil ooze, chalk, and chert, of middle Oligocene to Aptian age, from 303.5 to 647 meters depth which contained only rare benthonic forams in its lower part; and (3) greenish-black to red volcanogenic sandstones, siltstones, and mudstones of Early Cretaceous age, from 647 to 910 meters in depth, which were very poor in fossils except for some Aptian fossils in the uppermost part of the section. Between 600 and 700 meters depth, including parts of Units 2 and 3 above, well-preserved pelecypods were observed. Among these some shallow-water forms were thought to exist, although they were not identified or dated with certainty aboard ship. Below 910 meters, basalt was encountered directly beneath the volcanogenic sediments. Parts of 10 basalt-flow units lay between 910 and 943.5 meters, the deepest level reached in drilling. Thin, baked volcanogenic siltstones lay between four of the uppermost flow units. The flow units appeared to be of the oceanic tholeiite type; their exceedingly vesicular character suggests original deposition in shallow water, or very high original gas content. The deepest volcanogenic sediments and the basalts beneath them were older than 107 m.y. B.P. and could, we felt, be as old as 120 m.y. B.P.

The heave compensator was tested at this site and was used in coring the greater part of Hole 317B. Recovery with the heave compensator was as good as that usually obtained in comparable lithologies. However, from these preliminary tests, cores taken with the compensator at this site appeared to be about as much deformed as those taken without it.

Preplanned Site 33-6 (Site 318)

Unfortunately time on this site was limited and basement was not reached. The section at Site 318 consisted of five lithologic units: (1) nannofossil foraminiferal ooze from 0 to between 35.5 and 64.5 meters subbottom depth, of Quaternary to late Pliocene age, including graded layers of shallow-water reefal debris; (2) foraminiferal-nannofossil firm ooze to soft chalk, from between 35.5 and 64.5 to between 245 and 264 meters depth, of late Pliocene to middle Miocene age, including a few layers of sand-size altered volcanogenic glass; (3) firm, nannofossil-foraminiferal chalk, from between 245 and 264 to between 416 and 435 meters depth, of early Miocene (with a minor hiatus) to early Oligocene age, also contained some volcanogenic and skeletal debris; (4) nannofossiliferous and foraminiferal limestone with common chert nodules and lenses, from between 416 and 435 to between 530 and 549 meters, of early Oligocene through late Eocene age, which contained some volcanogenic debris, and, near its base, skeletal debris of shallow-water origin; this unit contained a middle to early Oligocene hiatus; and (5) green and gray clayey limestones, siltstones, and sandstones, as graded beds, from between 530 and 549 to 745 meters, of middle and early Eocene age. The heave compensator was left in the drill string, and alternate cores throughout the section were taken with it locked out for one core and in operation for the next. This program was followed through the first 20 cores taken at the site. Initial comparative results again indicated that core recovery and deformation appeared unchanged with the heave compensator.

Conclusions

The precruise planning for Leg 33 was in part based on the results from Site 165. Sites 314, 315, and 316 were selected to provide, along with Site 165, four "cessation of volcanism" ages along the entire Line Islands Chain. Unfortunately, Site 314 failed to provide data relative to the hot-spot problem. However, Sites 165, 315, and 316 did provide some evidence that the Line Island Chain did not fit into a simple hot-spot model (see Dalrymple and Lanphere, this volume, and Jackson and Schlanger, this volume, for a postcruise evaluation of this problem).

Site 315 bore a strong resemblance to Site 165 except that the Eocene section at Site 315 proved to be much thicker than the Eocene section at Site 165 and that the equivalent of the very thick Miocene and post-Miocene section present at Site 315 had apparently been eroded at Site 165. The date of cessation of flow-type volcanism at the two sites appeared to have been nearly identical, even though they are nearly 800 km apart along the Line Islands Chain. We concluded that if the Line Islands edifices or their debris were sampled at only these two sites, then volcanism along the chain would have to be interpreted as either grossly episodic or coeval.

The section encountered at Site 316 was quite similar to that found at Site 315, except that the pre-Eocene section at Site 315 was much thinner than that at Site 316, and the post-Eocene section much thicker (see Cook, this volume). Acoustic profiles between the two sites suggested that the post-Eocene section thinned gradually, rather than abruptly, from Site 315 to Site 316 (see Schlanger and Winterer, this volume).

The ages of basaltic flows that underlie Sites 165, 315, and 316, determined by means of extrapolation based on the oldest fossils found and sedimentation rate data, indicated a total possible range of cessation ages of basalts ranging from 79 to 85 m.y. B.P.; these ages appeared to be coeval within the limits of the uncertainties involved in the extrapolations. The "basement" ages did not appear to follow a simple pattern; at Site 315, in the central part of the chain, the basement was thought to be older than it was at the northern and southern ends of the chain. The cessation of major erosion of the volcanic basement, as determined by fossil ages in volcaniclastic sediments, was also nearly identical in age at Sites 165, 315, and 316. Indeed, the maximum thickness of volcanogenic sediments at the three sites occurred in sediments of middle Campanian to middle Maestrichtian (see Cook, this volume) age. If the thick section of volcanogenic debris at all three sites represented the simultaneous growth and erosion of nearby Line Islands edifices, then it seemed apparent that the cessation of volcanism at the three sites was roughly coeval, and the chain did not young to the south, at least over 1270 km along the chain spanned by the three sites. In fact, the geological histories of all three sites appear to have been nearly identical from early Campanian time to the present (see Cook, this volume). Included in the chain's history is a Campanian-Maestrichtian reefal phase on isolated edifices on the ridge as evidenced by shallow-water reefal debris of this age found at all three sites (see Beckmann, this volume). In our opinion, no hypothesis that requires systematic movement of the Pacific plate over a fixed "hot-spot" beneath it could account for the geochronology of Line Islands volcanism, and it seemed apparent that these islands and seamounts were formed by a mechanism different from that postulated to explain the volcanic history of the Hawaiian-Emperor Chain (see Winterer, this volume, and Jackson and Schlanger, this volume, for postcruise evaluations).

The Manihiki Plateau (Site 317) appeared to occur in a different geological setting from that of a linear island chain (see Winterer, this volume, and Jackson and Schlanger, this volume). The history of the plateau, as derived from the drilling, began with the extrusion of extremely vesicular tholeiitic basalts of probably oceanic ridge rather than of oceanic island type (see Jackson et al., this volume). A section of pelecypod-bearing, but undated on shipboard (see Kauffman, this volume), sediments 240 meters thick lay between the basalt and calcareous sediments dated as Aptian. If these relatively barren sediments were weathered ash, eruptive volcanism could have persisted to Aptian time; if the barren section consisted of originally volcanogenic material eroded from previously erupted rocks, active volcanism could have ended earlier (see Jenkyns, this volume). After the eruptive phase, the terrain appeared to have been eroded (see Jenkyns, this volume), after which the plateau subsided and became the site of pelagic sedimentation. The lack of any shallow-water in-place or transported fauna in the basal sediments was somewhat puzzling aboard ship because the vesicular nature of the basalt suggested relatively shallow water, and therefore some parts of the plateau should have had seamounts projecting above the general level of the flows. Subsequent study (see Kauffman, this volume; Jenkyns, this volume) revealed macrofossils indicative of shallow-water deposition. The islands around the rim of the plateau, such as Manihiki and Suvarov, kept pace with the rising sea level and became atolls.

The Manihiki Plateau section drilled appeared to compare much more closely to the Ontong-Java Plateau section than to sections from the Magellan Rise or the Shatsky Rise. Both the Manihiki and Ontong-Java plateaus had younger basement ages (Aptian-Barremian[?]) than Magellan and Shatsky (Tithonian-Berriasian). Neither the Manihiki (see Cockerham and Jarrard, this volume) nor the Ontong-Java plateaus appeared to have passed through equatorial waters; the Magellan Rise, on the other hand, probably crossed the equator 25-30 m.y. ago, and the Shatsky Rise is reported to have crossed about 90 m.y. ago. The presence of a thick Cretaceous volcanogenic sedimentary section at Manihiki contrasts with the thin tuffaceous section that lies above basalt at Ontong-Java, but we had no reason to suppose the Manihiki volcaniclastics were not locally derived (see Jenkyns, this volume).

The geological history of the area around Site 318 in the Tuamotu Islands could be only partly reconstructed because basement was not reached. The deepest sediments penetrated were volcanogenic debris rich in shallow-water skeletal fragments, mainly large benthonic forams (see Beckmann, this volume); associated nannofossils yielded a latest early Eocene age (see Martini, this volume). Volcanic edifices in the general area of the site evidently were built, eroded, and had developed reefs by that time. Using a minimum age of 50 m.y. ago for the end of flow volcanism at Site 318, and considering such other ages as were available, it was possible to interpret the progression of Tuamotuan volcanism, like the Hawaiian, as irregular rather than linear. Furthermore, a minimum age of 50 m.y. for the Tuamotu Chain in the area we drilled was greater than the most recent estimate of the age of the Hawaiian-Emperor bend (42 m.y.). After major erosion and reef formation, nearly continuous pelagic sedimentation took place at the drill site, although several hiatuses were present, during the period from early Eocene to Quaternary time. However, abundant reefal debris was deposited as turbidite units during middle Eocene and early Miocene time.

Operations

A summary of operations, total time distribution on Leg 33, and on-site time distribution are given as Table 3 and Figures 3 and 4, respectively.

Heave Compensator

The heave compensation system was installed and partially tested at dockside during the Honolulu port call. Installation was complete except for the stabilizer arms which were fabricated by the drill crew while underway. Installation time was underestimated by the contractor and 23 days were required for installation. Welding and installation of high pressure piping remained on the critical path during installation. Except for minor leaks, which were readily repaired, the system passed Coast Guard Certification tests.

Following crew orientation and system checkout, the compensator was tested at dockside. Test loads of 415,000 pounds and 600,000 pounds were pulled against substructure beams and the compensator was stroked using the drawworks to simulate heaves to 12 feet. Data were incomplete because test time was reduced to permit ship departure for Leg 33 on 2 November. The data obtained, however, showed good correlation with predicted performance and indicated the system had the potential to meet design specifications of ±0.625% load variation at 400,000 pound drill-string load.

A GMI and a Brown Brothers engineer were aboard for Leg 33 to provide service and analyze system performance. Testing, trouble-shooting, and field modifications were made while underway with minimum interference to normal drilling operations. The fabrication of stabilizer arms proved time consuming and delayed operational testing of the system until Site 316.

After field modifications of the raise-lower circuit and locking latches and troubleshooting of the Olmstead safety valve, the crew received familiarization training at Site 317. At Sites 317B and 318, the system was tested and monitored for performance. Performance data were obtained by recording instrumentation from remote transducers and visually recording drill data from the driller's console. For example, with a total hook load of 285,000 pounds, bit weight of 20,000 pounds and heaves to 6.5 feet, the system compensated with an average weight fluctuation of ±1500 to ±3200 pounds. For analytical and testing purposes, a partial air bank using only 28% of the available air volume was used, and per-

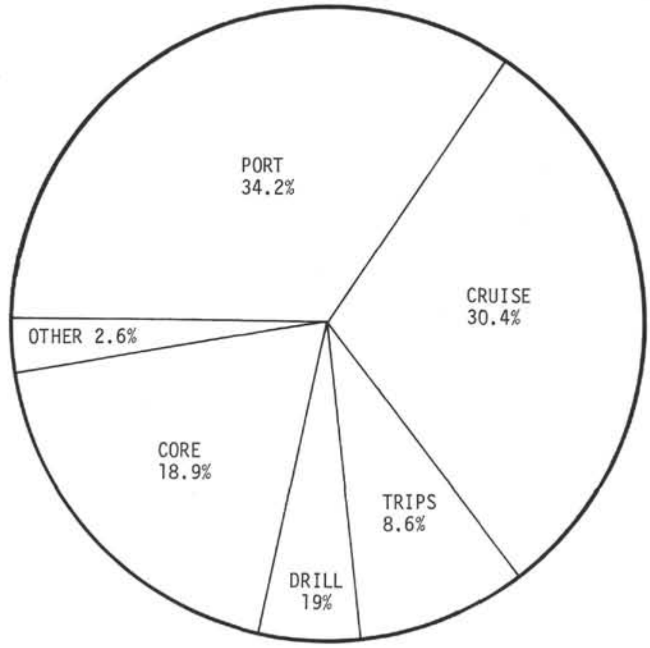


Figure 3. *Time distribution for the whole of Leg 33.*

TABLE 3
Summary of Operations

Total days Leg 33 (10 October–17 December 1973)		67.7
Total days in port		23.7
Total days cruising		20.5
Total days on site		24.1
Trip time	5.8	
Drilling time	3.6	
Coring time	12.8	
Mechanical downtime	0	
Waiting on weather	0	
Other miscellaneous time	1.9	
Total distance traveled (nautical miles)		4004.0
Average speed		8.3
Sites investigated		5
Holes drilled		8
Number of cores attempted		185
Percent of cores with recovery		172
Total penetration		4466.0
Total meters drilled		2747.5
Total meters cored		1728.0
Total meters recovered		888.1
Percent of core recovered		51.5
Percent of total penetration cored		38.5
Maximum water depth (m)		5225
Minimum water depth (m)		2622

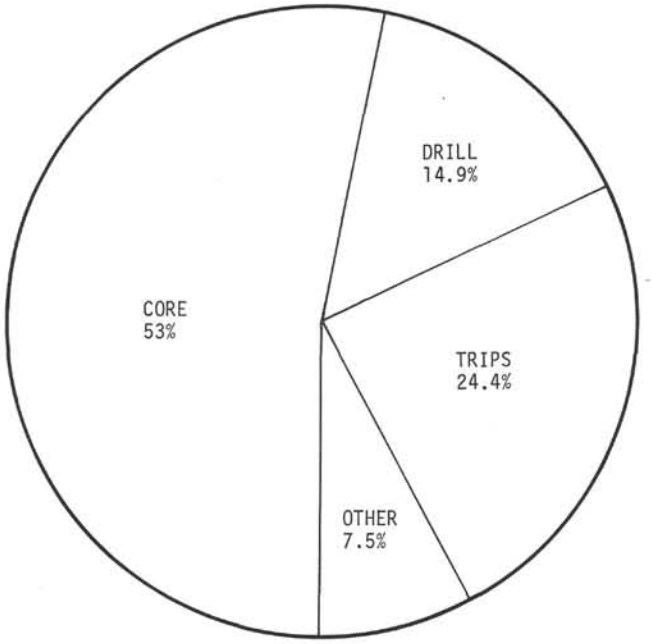


Figure 4. *On-site time distribution, Leg 33.*

formance is expected to improve with full bank operation and minor system adjustments. Performance data are being analyzed for conformance to specifications and for contractual acceptance of the system.

Project capability was increased by the installation and use of a heave compensation system which is expected to increase bit life as well as core recovery and quality. At Site 318 the heave compensator was placed in the drill string and used to total depth. In soft sediments, alternate cores were taken with the unit compensating. Starting at a penetration of 606 meters, hard rock requiring bit weights of 18 to 22,000 pounds was encountered, and the heave compensator was used continuously to minimize bit wear. Silicified limestones and hard, dense siltstones slowed drilling to as low as 16 minutes a meter. The compensator kept variation in bit weight to ± 1000 pounds in the mild seas. (Details on heave compensation are in a succeeding section.) The bit was in excellent condition considering the drilling conditions. Cones were tight, only one insert was broken, and the teeth were graded at T-3.

Drill Pipe Pinger

Sea-floor depths for coring are routinely found by PDR and drill-pipe measurement when actual cores are recovered. In very soft sediments, accuracy decreases and coring attempts may begin several tens of meters above or below the mudline. To improve this accuracy, DSDP has been developing a drill pipe pinger which was successfully used to locate bottom at Site 314. In 5225 meters of water, the pinger found bottom with a resolution of ± 3 meters. Water depth was 5221 meters of PDR and 5225 meters by drill pipe. The test of the pinger at Site 314 is described further in Chapter 2 (this volume).

The pinger incorporates a 12-kHz transducer and a self-contained electronics package made up to a special piston core barrel which can retrieve a 7.5-meter core. In use, the self-contained pinger was placed and locked in the outer core barrel with the transducer protruding 0.3 meters below the core catcher. As the assembly was lowered, direct and reflected waves were traced on a Gifft recorder. Convergence of the two waves fixes the location of the sea floor. The direct wave clearly shows each time a stand of pipe is made up to the drill string and lowered. Pulse rate of the pinger is 2 sec and the recorder is operated on a 1-sec sweep.

The piston corer assembly is actuated by latching onto the pinger fishing neck and shearing a releasing pin. This action releases the pinger assembly from the outer core barrel. By maintaining a tension on the pinger and simultaneously lowering the drill string, a piston core can be taken. At Site 314, sea-bottom sediments were too indurated for piston coring, and no recovery was obtained on one attempt.

Drilling and Coring Bottom-Hole Assemblies

The bottom-hole assembly normally used is made up with a bit, float sub, core barrel, three 8-1/4 in. drill collars, two bumper subs, two 8-1/4 in. drill collars, one 7-1/4 in. drill collar, and one joint of 5-1/2 in. heavy-weight drill pipe. At Sites 317 and 318, where the heave compensator was used, the bottom-hole assembly was modified by removing one of the lower two bumper subs. The upper two bumper subs remained in the assembly. With this assembly, drilling could continue to the objective even if the heave compensator should fail. In the event of a malfunction, the heave compensator could be locked up and removed from the drill string. When experience demonstrates the reliability of the compensator, the only bumper subs needed in the drill string will be those providing jarring/bumping action in the case of stuck pipe. At present, with the heave compensator in the string (assuming drilling in hard formations which requires the working of both sets of bumper subs), there is insufficient clearance between the water table and the connector block to pull the bit off bottom when making a connection. However, with one bumper sub out of the assembly when using the compensator in hard formation, it is possible to be 5 feet off bottom during a connection. This still maintains 5 feet between the water table and the block with the compensator fully extended.

Bits

All bits were of the journal-bearing, four-cone, medium-tooth insert type. Bit performance was excellent and no drilling was prematurely terminated because of bit failures. Typically, the bits were pulled with one loose cone after penetrating some 250 meters of hard strata requiring 20,000 pounds or more of bit weight to drill. A summary of bit performance is given in Table 4.

Usually, bearing failure was further advanced than cutting structure failure. Sediment sequences varied at different sites, but in general the lithologic sequence was composed of an upper 500 meters of ooze and chalk drilled with up to 10,000 pounds of weight, 150 meters of chalk and chert requiring 10 to 20,000 pounds of weight and a hard limestone, siltstone, and basalt interval of some 200 meters requiring 20 to 22,000 of weight. As might be expected, sound velocity in the hard strata correlated well with drilling time. Correlations between lithology, sonic velocity, rate of penetration, and bit weight were used to evaluate bit performance.

The bit at Site 318, where the heave compensator was used, was in exceptionally good condition. Graded at T-3, B-3, the bearings were still tight and inserted in excellent condition after a penetration of 745 meters. Hard rock, including silicified limestone, was drilled. Of the 745 meters penetration, 158 meters required bit weights of 15 to 22,000 pounds to penetrate.

Coring Assemblies

The "hard formation" slip-type core catcher with hard facing proved effective and is recommended for use in hard rock sections. On eight cores, plastic socks had torn, and patches of plastic had plugged the check valve in the core. Recovery in these instances varied from zero to about 50%. Consideration should be given to a stronger sock material. Two swivel assemblies were retired because of normal wear and tear. One of the swivels was bent below the bearing assembly, probably during repeated joint breakout and was replaced. The second swivel had a failure of grease seals.

TABLE 4
Deep Sea Drilling Project Bit Summary, Leg 33

Hole	Mfg.	Size	Type	Serial Number	Cored (m)	Drilled (m)	Total Penet. (m)	Hours on Bit	Condition	Remarks
314	Smith	10-1/8	F94C 4-CTR	PC204	17.0	27.5	44.5	0.5	T-1, B-1	Suitable for rerun – excellent condition
315	Smith	10-1/8	F94C 4-CTR	NW800	28.0	57.0	85.0	0.4		Broke bottom-hole assembly – lost
315A	Smith	10-1/8	F94C 4-CTR	PC205	323.0	711.5	1034.5	39.8	T-8, B-8	One cone loose – 3 medium tight – few inserts broken
316	Smith	10-1/8	F94C 4-CTR	NW801	285.0	552.0	837.0	39.9	T-5, B-5	One cone loose
317	Smith	10-1/8	F940 4-CTR	NW802	28.5	323.0	351.5	1.5	No Wear	
317A	Smith	10-1/8	F94C 4-CTR	NW802	313.5	630.0	943.5	31.0	T-2, B-2	In gage – no loose cones
317B	Smith	10-1/8	F94C 4-CTR	PC204	424.5	0	424.5	6.3	T-3, B-4	Suitable for rerun – cones medium tight – in gage
318	Smith	10-1/8	F94C 4-CTR	PC206	298.5	446.5	745.0	28.9	T-3, B-3	Used compensator – no loose cones – center inserts good condition

Sinker bars were shortened up by 10 feet to allow head room for running into the connector block. To improve action, the jars were moved to a point below the sinker bar.

Positioning

A summary of the dynamic positioning on Leg 33 is given as Figure 5, and a beacon summary is given in Table 5.

Performance of the dynamic positioning system was satisfactory except at Site 315 where failure of the digital-to-analog converter resulted in the loss of the bottom-hole assembly.

Weather was not a major factor on this leg, although some acoustic interference was anticipated due to choppy seas generated by 25-35 mph trade winds. The hydrophones were lowered 10 feet at Sites 315, 316, 317 and completely eliminated acoustic losses. Thruster noise levels became quite high at times. Despite this, good acoustics were maintained at all times.

At Site 314, automatic positioning was used for the duration except for two instances about 12 hr apart when the display, main shafts, and thruster commands became slightly erratic. Each time this happened, switching modes from auto to semi-auto and back to auto cured the problem. This did not interrupt drilling as the erratic behavior was not overly pronounced and was of less than 5 min duration each time.

At Site 315, positioning was initially good in automatic. Failure of several cards in the digital-to-analog converter caused loss of the bottom-hole assembly due to erroneous display signals after about 14 hr on site. Maximum excursion was about 1000 feet.

At Site 315A on 16 November, erratic loss of acoustics with drastic changes in thrust direction and magnitude occurred. The ship moved about 400 feet off the hole before the positioning system could recover. High sustained thrust requirements necessitated going to semi-auto as thrusters were overloading the generators. At daylight, it was discovered that the convergence of the equatorial current and counter-current had passed under the ship with a great deal of turbulent water and opposite current flow on either side of the line of convergence. After the current stabilized, positioning was returned to auto with no further problems on this site.

Positioning on Site 317 was in auto with the exception of about 15 min in semi-auto when failure of the pitch gyro amplifier caused the main shafts to be commanded full astern from 100 rpm ahead. The amplifier was replaced and the system returned to auto for the duration. Positioning was excellent for the remainder of the leg with no further problems of any kind.

EXPLANATORY NOTES

Organization and Subdivision of the Report

This Initial Report volume is divided into three parts. Part I consists of an Introduction and Explanatory Notes chapter and Site Reports based mostly on the work accomplished during shipboard studies at sea. Part II, Special Studies, contains chapters on paleontology, geochemistry, petrology, mineralogy, and geophysics which were written by members of the shipboard party or interested specialists both within and without the Deep Sea Drilling Project. The chapters in Part II include interpretations based on information that was available at the time the chapters were submitted. Part III consists of chapters dealing with regional geology, stratigraphy, and sedimentology which were written by the shipboard scientists.

Material in the Site Report chapters is arranged in a standardized order as follows (authorship of various sections within the Site Reports is indicated in parentheses):

Site Data: Location, dates occupied, position, water depth, total penetration, number of cores taken, total length of recovery, deepest unit recovered, and principal results (Jackson and Schlanger).

Background and Objectives: Reason for drilling, geophysical data, presite surveys, description of available data, and objectives (Winterer, Schlanger, and Jackson).

Operations: Site approach and profiler records, sonobuoy surveys, drilling and coring program, drilling

TABLE 5
Deep Sea Drilling Project Beacon Summary, Leg 33

Site	Make	Freq. (kHz)	Serial Number	Site Time (hr)	Remarks
314	ORE	16.0	242	42.5	Very strong signal
315	ORE	16.0	260	32.0	Very strong signal – long life
315A	ORE	16.0	260	124.5	Very strong signal – long life
316	ORE	13.5	209	9.5	Signal dropped by 25 db – dropped replacement
316	ORE	16.0	248	105.5	Very good signal
317	ORE	16.0	257	26.5	Very good signal
317A	ORE	16.0	257	89.5	Very good signal
317B	ORE	16.0	257	67.0	Very good signal
318	ORE	13.5	286	77.0	Good signal

operations, and coring summary (Schlanger and Jackson).

Lithology: Description of column starting at the top (basalt section by Jackson), stratigraphic column, barrel sheets, lithologic summary (Cook, Kelts, Jenkyns, Winterer).

Physical Properties: Density, porosity, sonic velocity (Boyce).

Geochemistry: $CaCo_3$ "bomb" (Dootson).

Biostratigraphy: Calcareous nannoplankton (Martini), foraminifera (McNulty and Kaneps), Radiolaria (Johnson).

Sedimentation Rates: (Kaneps, Schlanger, Jackson).

Correlation of Seismic Reflection Profiles With Drilling Results: (Winterer and Schlanger).

Summary and Conclusions: (Jackson and Schlanger).

References: Includes references for entire Site Report.

Data presentations given for each site chapter include:

1) Core forms with detailed presentations of the lithology, physical properties, and biostratigraphy of each core recovered (Winterer, Cook, Kelts, Jenkyns, Kaneps, Johnson, Martini, Boyce). Symbols used on these forms are explained in another section of this chapter (Conventions and Symbols).

2) Physical properties graphic log with a plot of density, porosity, and sonic velocity.

3) Core photographs (black and white) are arranged in order by hole, core, and section.

Survey and Drilling Data

The survey data used in precruise planning for specific site selections are given in each Site Report chapter. We depended heavily on records obtained from the Lamont-Doherty Geological Observatory (Columbia University), Scripps Institution of Oceanography (UC San Diego), and the Hawaii Institute of Geophysics (University of Hawaii). Short surveys were made by *Glomar Challenger* before dropping the beacon. We found excellent correspondence between profiles from the above institutions and *Glomar Challenger* records.

Steaming between sites, continuous observations were made of water depth, the magnetic field, and subbottom stratigraphy and structure. Underway depths were recorded on a Gifft precision depth recorder; the depths were read on the basis of an assumed 800 fathoms/sec sounding velocity. The sea depth (in m) at each site subsequently was corrected (1) according to the tables of Matthews (1939) and (2) for the depth of the hull transducer (6 m) below sea level. In addition, any depths referred to the drilling platform were calculated under the assumption that this level is 10 meters above the water line.

The magnetic data were collected with a Varian proton magnetomater with the sensor towed 300 meters behind the ship. The readings, for shipboard use, were taken from an analog recorder every 5 min.

The seismic profiling system consisted of two Bolt airguns, a Scripps-designed hydrophone array, Bolt amplifiers, two bandpass filters, and two EDO recorders (filter settings, airgun sizes, etc., are shown on the individual profiles).

Basis for Numbering Sites, Cores, Sections

Each drilling site accomplished by DSDP is assigned a number, for example, Site 314. The first hole at each site carries the site number, i.e., Hole 314; additional holes at the same site have a letter following the number. For example, Hole 317A is the second hole drilled at Site 317 and Hole 317B would have been the third hole drilled at this site.

The cores from each hole are numbered successively in the order in which they were taken: Core 1, Core 2, etc. A core was taken by dropping a core barrel down the drill string, and coring for 9 meters as measured by the lowering of the drill string. Sediments were retained in a plastic liner about 9.3 meters long inside the core barrel and in a 0.40-meter-long core catcher assembly below the liner. Generally, the liner was not completely full.

When the core barrel was recovered on deck, the core catcher was removed from the barrel, and any material in the catcher (as much as 25 cm in length) was labeled "core catcher," or CC. The plastic core liner was withdrawn from the steel barrel and cut into 150-cm lengths called sections, beginning at the lower end of the barrel. A liner (average length about 9.3 m) can be cut into six such sections, with a short section about 30 cm in length left over at the top end. The numbering scheme for the sections depends on how much material is recovered. In a full barrel, the short top section is called the "zero" section, and the first 150-cm section below that is Section 1, the next, Section 2, etc. When the barrel is only partly filled, the cutting of the plastic liner proceeds as usual, starting from the bottom of the liner.

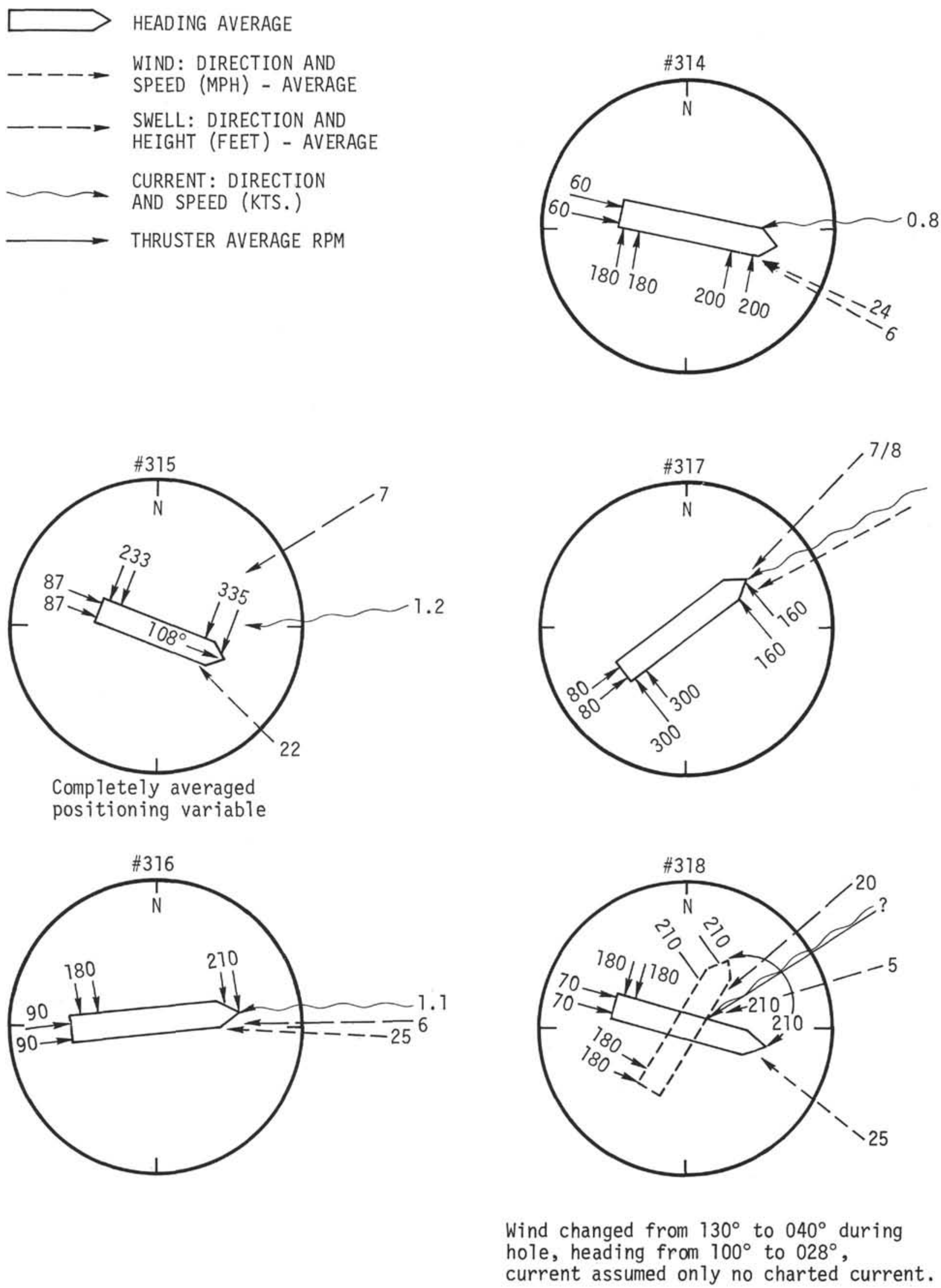
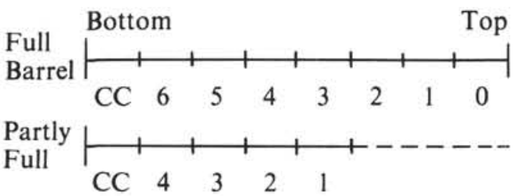


Figure 5. *Summary of dynamic positioning at Leg 33 sites.*

The labeling, however, begins with the uppermost 150-cm section in which there is core material. That section, even if only partly full, is Section 1; the next below is Section 2, etc. The following diagram illustrates the two cases.



Within each section, individual samples or observations are located in centimeters down from the top of the section. This is true even when a section is not full of material, either because of original lack of material (a short Section 1, for example), or because of voids produced by compaction or shrinkage.

To designate a sample, a shorthand numbering system is used. Briefly, a sample designated as 317-15-2, 50-52 cm is from the 50-52 cm interval below the top of Section 2, in Core 15 of Hole 317, that was drilled during Leg 33. Generally, the leg number is left off the sample designations.

Sometimes the core barrel will jam up with hard sediment after coring a few meters; the core will then really represent only the first few meters penetrated. At other times, the circulation of water may wash away the upper softer part of a core and recovery will represent the lower part. Separated lengths of core in a core liner may come from the drill bit being lifted away from the bottom of the hole during coring in rough sea conditions. Similarly, there is no guarantee that the core-catcher sample represents the material at the base of the cored interval. The labeling of samples is therefore rigorously tied to the position of the sediment or rock within a section as the position appears when the section is first cut open and is logged in the visual core description sheets.

Handling of Cores

The first assessment and age determination of the core material was made on samples from the core catcher as soon as possible after the core was brought on deck. After a core-section had been cut, sealed, and labeled, it was brought into the core laboratory for processing. The core-section was first weighed for mean bulk density measurement. Then GRAPE (Gamma Ray Attenuation Porosity Evlaution) analysis was made for detailed density determinations.

After the physical measurements were made, the core liner was cut on a jig using Exacto-type blades and the end caps cut by knife. The core was then split with a cheese cutter if the sediment was soft. When compacted or partially lithified sediments were included, the core had to be split by a band saw or diamond saw.

One of the split halves was designated a "working" half. Sonic velocity determinations using a Hamilton frame were made on pieces from this half. Numerous samples were measured both parallel and perpendicular to bedding as part of a seismic anisotropy study. Samples, including those for grain size, X-ray mineralogy, interstitial water chemistry, and total carbonate content, were taken, labeled, and sealed. The working half was then sent to the paleontology laboratory. There, samples for shipboard and shore-based studies of nannoplankton, foraminifera, and radiolarians were taken.

The other half of a split section was designated an "archive" half. The cut surface was smoothed with a spatula to bring out more clearly the sedimentary features. The color, texture, structure, and composition of the various lithologic units within a section were described on standard visual core description sheets (one per section) and any unusual features noted. Smear slides were made and examined with a petrographic microscope. The archive half of the core-section was then photographed. Both halves were sent to cold storage onboard after they had been processed.

Material obtained from the core catcher and not used up in the initial examination was retained in freezer boxes for subsequent work. Hand sediments were handled as follows:

Pieces were removed from the core catcher and placed in short piece of the half liner, maintaining proper sequence and orientation. These pieces were placed in the bottom of the liner of the lowest section recovered, and the entire core moved upward by the length of the core-catcher material. Pieces were labeled on the outside of the core with an arrow pointing up and provisional number to maintain sequence. Core-catcher material was split on a diamond saw, making certain each piece had a label. Core material recovered in the core liner was labeled and split; when split pieces were replaced in half-liners, room was left at the bottom of the lowest section for core-catcher material, and other pieces moved up accordingly. From this point on, the core is handled as any other sediment core.

All sediment samples from Leg 33 are now deposited in cold storage at the DSDP West Coast Repository at the Scripps Institution of Oceanography, La Jolla, California.

Visual core descriptions of igneous rocks, including basalts, were simply continued on the visual core description sheets, rather than placed on a separate form, as has been done heretofore. Color index, rock type, textures, percent of phenocrysts, percent and size of vesicles, structures, and alteration were routinely noted. The sampling procedure for basalts was different from that of sedimentary rocks in that oriented 1-in. plugs were drilled from sections in the round. In general one plug was cut from each flow unit in the two holes where basalt was cored, and thin sections were made aboard ship for confirmatory descriptions. Thin sections of igneous rocks were described on the visual core descriptions of the igneous rocks form. In general, the names of igneous rocks are based on the textural and mineral proportion data of Macdonald and Katsura (1964) where rocks were not so altered as to preclude identification.

The basalt samples are stored in a dry, nonrefrigerated container.

Drilling Disturbances

When the cores were split, many of them showed signs of postdepositional disturbance. Such signs were the concave downwards appearance of originally plane bands, the haphazard mixing of lumps of different lithologies, and the near-fluid state of some sediments.

During drilling, six basic parameters (bit type, weight on the bit, pipe revolutions per minute, torque, pump pressure, and pump strokes per minute) reflect the conditions at the contact between bit and sediment. When a core is being cut, water circulation is reduced to a minimum, or zero, and bit weight is normally kept to lower values and increased more steadily than during drilling. Invariably, however, some short periods of circulation are required, and it is then that softer sediments may be washed away from the bit or that water may be forced up inside the core liner, turning the sediment into a slurry. The washing away of softer sediment during periods of circulation can lead to the recovered cores being unrepresentative samples of the drilled strata. This is especially true when alternating hard and soft beds are cut. The heave of the bit while coring during rough weather may also lead to fluid cores.

Four degrees of drilling deformation were recognized in the sediments as follows: (a) slightly deformed, (b) moderately deformed, (c) highly deformed, and (d) soupy. The criteria used in defining these degrees of deformation was that slightly deformed sediments exhibit a small bending of bedding contacts, whereas extreme bending defines moderate deformation. For highly deformed strata, bedding is completely disrupted and/or at times has vertical attitudes. Soupy intervals usually are water saturated and lose practically all aspects of bedding. In intervals of alternating hard and soft beds, such deformation will be characterized by brecciated fragments of the former, surrounded by viscous to soupy flowage of the latter.

Physical Properties

A thorough discussion of physical properties is presented by Boyce (this volume). It covers equipment, methods, errors, correction factors, presentation, and coring disturbance relative to the validity of the data. Only a brief review is given here.

The physical properties are presented in graphical form and discussed in each site chapter. Some explanation of the measuring techniques and data processing follows.

1) Sediment water content (W): The water content (W) is defined as the weight of water in the sediment divided by the weight of the saturated wet sediment. The former is obtained by heating a 0.5-ml cylindrical sample (taken with a syringe) to about 110°C for 24 hr and weighing the sample before and after heating. The water content (%) is thus:

$$W = \frac{100\ (\text{weight of wet sediment} - \text{weight of dry sediment} + \text{salts})}{\text{weight of wet sediment}}$$

No corrections were made for the salts, but the values are thought to be accurate to within ±3%.

2) Sediment porosity (ϕ): The porosity (ϕ) is defined as the volume of pore space divided by the volume of the wet saturated sample and is expressed as a percentage. Porosities calculated from W are not plotted. The continuous plots of porosity (site summaries only) are obtained from the GRAPE densities (see below) assuming a mean grain density of 2.67 g/cm^3 and a water density of 1.024 g/cm^3.

3) Wet bulk density (p): The wet bulk density (p) is defined as the weight in grams per cubic centimeter of the wet saturated sediment, i.e.:

$$p = \frac{\text{weight of wet sediment}}{\text{volume of wet sediment (cm}^3\text{)}}$$

The densities of the seawater-saturated cores were measured in three ways: (1) by weighing each 1.5-meter core-section, giving a mean density for the whole section; (2) from the water content W (syringe samples); and (3) by continuous measurement along the length of the core-section with the GRAPE using as standards, water (1.024 g/cm^3) and aluminum (2.6 g/cm^3). It is noted that because of the possible presence of drilling disturbances, low values are suspect and emphasis should be placed on the maximum densities (minimum porosities).

4) Compressional wave velocity (Vp): The sonic velocity (Vp) is obtained by timing a 400-kHz sonic pulse across two transducers and measuring the distance across the sample with a dial gauge (Hamilton frame method). Measurements were made at laboratory temperature and pressure, a time delay of about 4 hr being allowed for the cores to reach equilibrium.

5) Specific acoustic impedance (Zp): This is defined as density multiplied by compressional wave velocity. The parameter is of value in the interpretation of seismic reflection profiles.

Shore-Based Studies

Grain-Size Analyses

Grain-size distribution was determined by standard sieving and pipette analysis. The sediment sample was dried and then dispersed in a Calgon solution. If the sediment failed to disaggregate in Calgon, it was dispersed in hydrogen peroxide. The sand-sized fraction was separated by a 62.5 μm sieve, with the fines being processed by standard pipette analysis following Stokes settling velocity equation, which is discussed in detail in Volume IX of the Initial Reports of the Deep Sea Drilling Project. Step-by-step procedures are covered in Volume IV. In general, the sand-, silt-, and clay-sized fractions are reproducible within ±2.5% (absolute) with multiple operators over a long period of time. A discussion of this precision is in Volume IX.

Carbon and Carbonate Analyses

The carbon-carbonate data were determined by a Leco induction furnace combined with a Leco acid-base semiautomatic carbon determinator. Normally, the more precise seventy-second analyzer is used in place of the semi-automatic carbon determinator.

The sample was burned at 1600°C, and the liberated gas of carbon dioxide and oxygen was volumetrically measured in a solution of dilute sulfuric acid and methyl red. This gas was then passed through a potassium hydroxide solution, which preferentially absorbs carbon dioxide, and the volume of the gas was measured a second time. The volume of carbon dioxide gas is the difference of the two volumetric measurements. Corrections were made to standard temperature and pressure. Step-by-step procedures are in Volume IV of the Initial Reports of the Deep Sea Drilling Project and a discussion of the method, calibration, and precision are in Volume IX.

Total carbon and organic carbon (carbon remaining after treatment with hydrochloric acid) are determined in terms of percent by weight and the theoretical percentage of calcium carbonate is calculated from the following relationship:

Percent calcium carbonate ($CaCO_3$) =
(%total C -%C after acidification) $\times 8.33$

However, carbonate sediments may also include magnesium, iron, or other carbonates; this may result in "calcium" carbonate values greater than the actual content of calcium carbonate. In our determinations, all carbonate is assumed to be calcium carbonate. Precision of the determination is as follows:

Total carbon (within 1.2%-12%)	= ±0.3% absolute
Total carbon (within 0%-1.2%)	= ±0.06% absolute
Organic carbon	= ±0.06% absolute
Calcium carbonate (within 10% - 100%)	= ±3% absolute
(within 0% - 10%)	= ±1% absolute

X-Ray Methods

Samples of sediment were examined using X-ray diffraction methods at the University of California at Riverside, under the supervision of H.E. Cook.

Treatment of the raw samples included washing to remove seawater salts, grinding to less than 10 μm under butanol, and expansion of montmorillonite with trihexylamine acetate. The sediments were X-rayed as randomized powders. A more complete account of the methods used at Riverside is found in Appendix III of Volume IV of the Initial Reports.

Rules for Naming Common Pelagic Sediments

Nomenclature proposal for Leg 33

Rule 1. The word order for names is:
color - constituent(s) - induration modifier(s)

Rule 2. Color is determined using GSA color chart names followed by color code number in (parentheses).

Rule 3. A constituent should be >5% to be included in a name.

Rule 4. Only two constituents appear in a name.

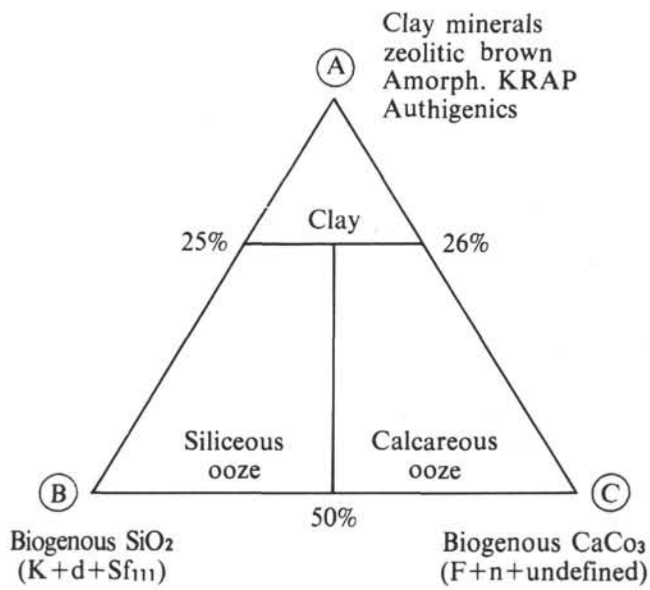
Rule 5. Ranges used for smear-slide descriptions are:

<5%	rare (R)
5%-25%	common (C)
25%-50%	abundant (A)
>50%	dominant (D)

Rule 6.[1] If (A) is >75%: called clay with a preceding constituent modifier; if (A) <75% called ooze with appropriate constituent modifiers discussed below.

Rule 7. If any single biogenous constituent is dominant (D); that constituent is used as last modifier in name.

Rule 8.[1] If no constituent is >50% then
(a) Σ (B) biogenous siliceous constituent > Σ (C) calcareous constituents called siliceous ooze.
(b) Σ (C) > Σ (B): called calcareous ooze. Second most abundant constituent used as the first modifier.



Rule 9. Induration rule chart

Induration Increasing Downward	Constituents		
	Calcareous (C)	Siliceous (B)	(A)
	ooze	ooze	clay
	firm ooze	firm ooze	
	chalk	porcellanite	claystone
	limestone	chert	

Rule 10. Unusual or nonpelagic sediments not covered by the above classification are to be named in a (geologically) logical manner.

Hypothetical sediments—without color designation:

30% Forams	60% Forams
40% Rads	20% Rads
20% Nannos	10% Zeolitic clay
10% Clay	10% Nannos
→Radiolarian Calcareous Ooze	→Radiolarian Foraminiferal Ooze

[1]Rules 6 and 8 pertain to the construction of a triangular diagram.

60% Clay	75% Zeolitic clay
40% Rads	20% Rads
→Clayey	5% Nannos
Radiolarian Ooze	→Radiolarian
	Zeolitic Clay

Graphic symbols for lithology as used on core and site logs are shown in Figure 6.

Basis for Age Determination

The integrated biostratigraphic framework for foraminifers, nannofossils, and radiolarians as used on Leg 33 is shown in Figure 7. A scale of absolute age, based on that of Berggren (1972) for the Cenozoic and DSDP Leg 17 (Winterer, 1973) for the Cretaceous, is also given.

The planktonic foraminifer zonation for mid-Eocene and younger sediments is that of Blow (1969) with the exception of the Oligocene and Pleistocene. For the Oligocene, the zonation of Bolli (1970) was found to be more suitable, and the Pleistocene was subdivided into two zones on the basis of the extinction horizon of *Globoquadrina pseudofoliata* Parker, which has been estimated by Thompson and Saito (1974) to have an age of about 220,000 yr. For pre-mid-Eocene sediments the zonation of Blow and Berggren (Berggren, 1972) was used. In the Cretaceous, relatively few planktonic foraminifer zones could be recognized. Those for the Upper Cretaceous follow the definitions of Cita and Gartner (1971), while those for the Lower Cretaceous are as defined by van Hinte (1971).

For Cenozoic nannofossils, the standard zonation (Martini, 1971), as emended by Martini (this volume), was used. In the Cretaceous, a composite system of zones by various authors was employed (see Martini, this volume).

The radiolarian zones recognized are those of Sanfilippo and Riedel (1973) and Foreman (1973a) for the upper Paleocene and lower Eocene; those of Riedel and Sanfilippo (1970), as modified by Foreman (1973b), for the middle and upper Eocene; those of Riedel and Sanfilippo (1971) for the Oligocene through Pliocene; and those of Nigrini (1971) for the Quaternary.

In addition, reference is made to the chapters in this volume by Martini (silicoflagellates), Takayanagi and Oda (Cenozoic foraminifers), Beckmann (large foraminifers), Schrader (diatoms), Bukry (nannofossils), and Kauffman (mollusks) for additional data on the age of sediments recovered during Leg 33.

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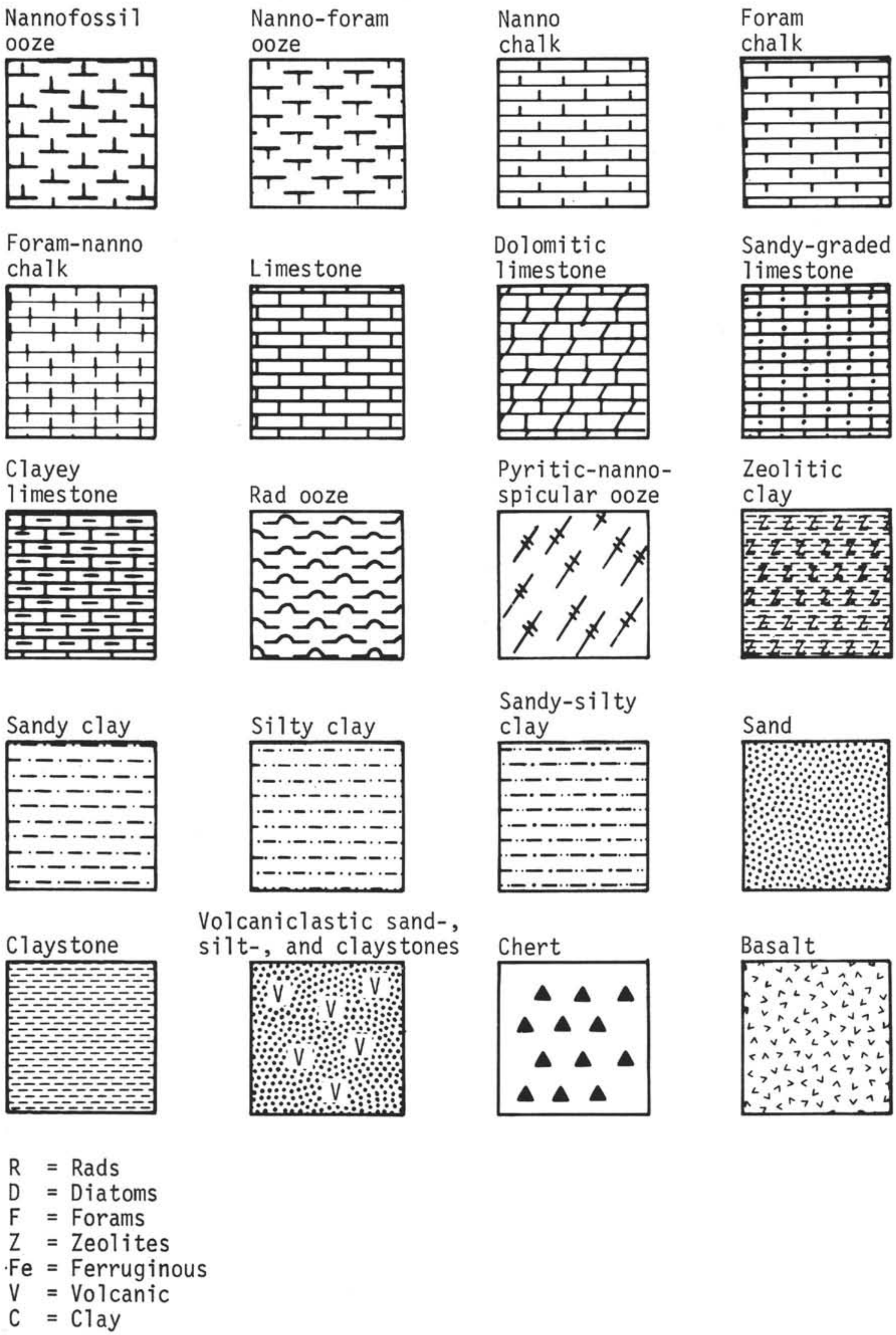

Figure 6. *Graphic lithological symbols employed on core and site logs, Leg 33.*

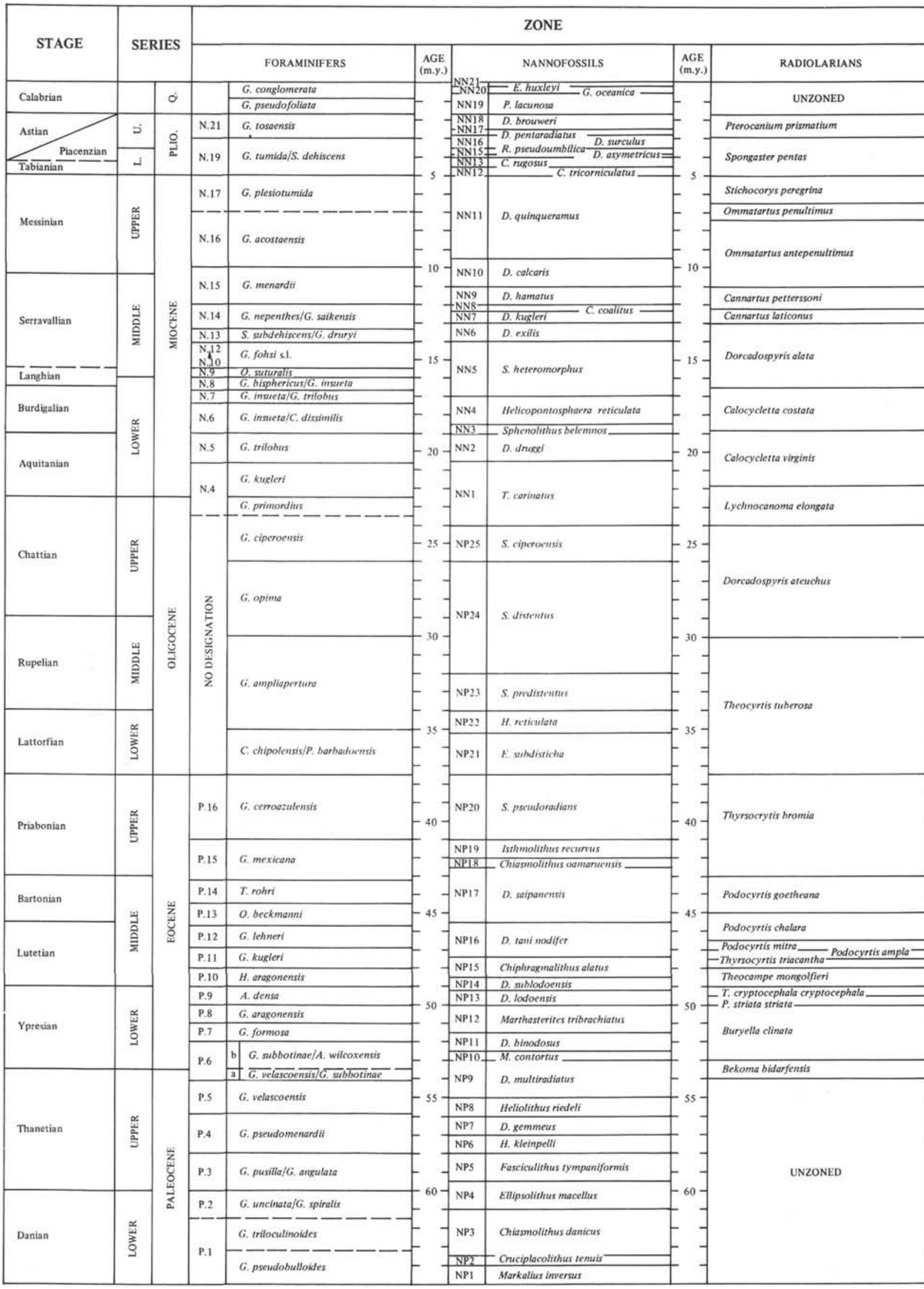

Figure 7. *Biostratigraphic framework and time scale used during Leg 33 (see text for explanation).*

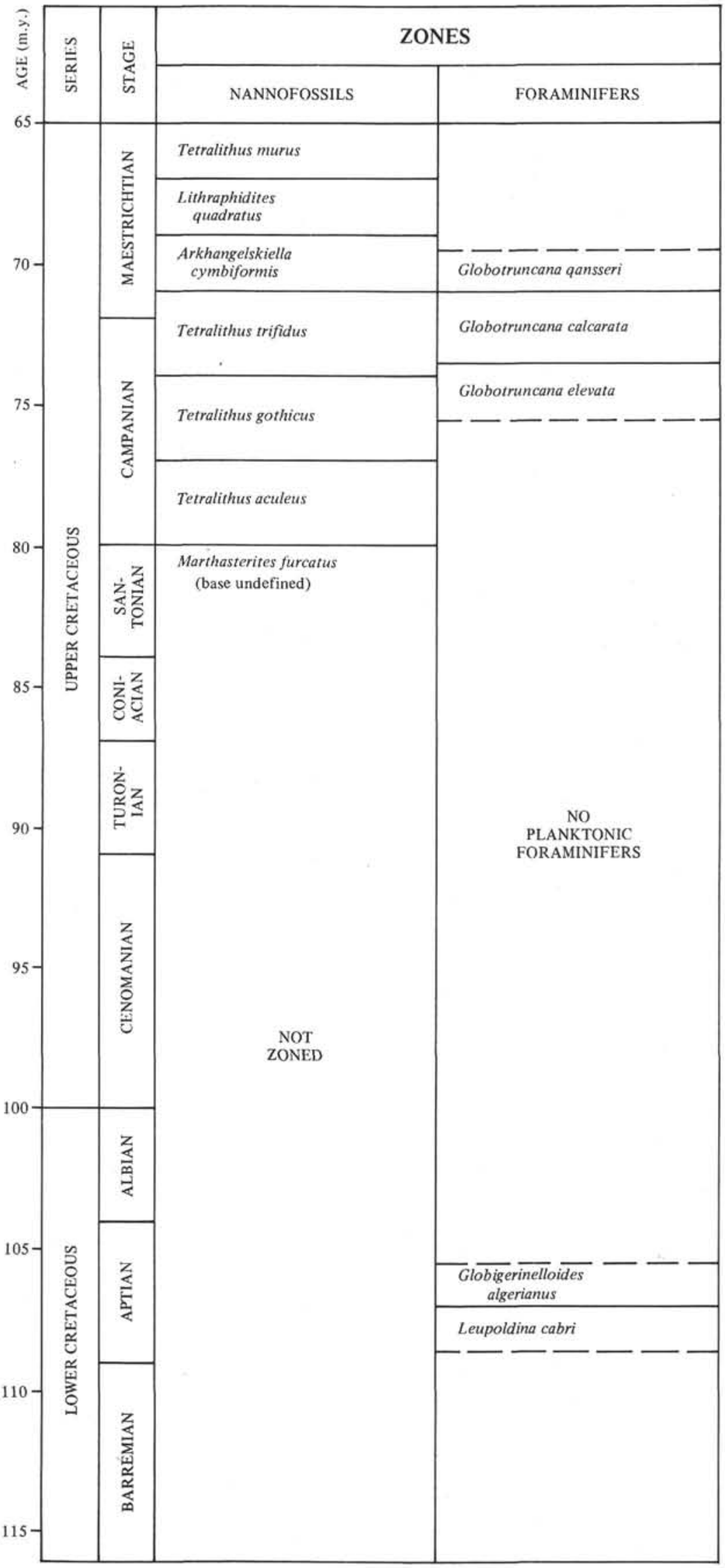

Figure 7. *(Continued).*

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