1. INTRODUCTION AND EXPLANATORY NOTES

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PURPOSE OF STUDY AND GOALS

The marginal seas, volcanic island arcs, and deep-sea trenches rimming the western Pacific Ocean have attracted the attention of geoscientists for well over a century with the region ultimately evolving into a veritable geological testing ground as noted in a colorful review of Coleman's (1973) recent compendium on this topic. The tectonic evolution of this area of extremely complex geology has been attacked with renewed vigor by students of global plate tectonics with major questions revolving around the age and origin of marginal seas forming the boundaries between continent and ocean basin. The prime focus of the 31st voyage of *Glomar Challenger* was to probe the history of the West Philippine Basin and the Sea of Japan (Figures 1 and 2), two classic examples of these enigmatic pieces of sea floor. These areas display many of the geophysical characteristics of deep-sea crust, but are situated within island arcs of transitional to continental character. These two areas are particularly attractive because the former represents a well-defined example, which, if understood, would greatly enhance our knowledge of the origin and development of marginal basins. Alternately, the Japan Sea appears to represent the first stages of arc-continent separation within an area notable for the existing large body of geological, geophysical, and paleontologic data.

Significantly, the tectonic and volcanic history of this region has been overprinted by an equally complex paleooceanographic, paleoclimatic, and resulting biostratigraphic history. Thus, drilling in the marginal western Pacific afforded an excellent opportunity to obtain tropical to subtropical biostratigraphic reference sections deposited beneath the western equatorial water mass and the Kuroshio Current as well as sections containing the lesser known temperate and subarctic planktonic biofacies within the Sea of Japan.

Major Goals of Leg 31

The major purpose of Leg 31 was the scrutiny of tectonic, sedimentologic, volcanic, paleontologic, and paleooceanographic processes operative in arc-marginal basin complexes along with a deciphering of basin history. The following major goals were outlined on the basis of precruise analyses of the area:

1) Testing of the various proposed origins of the West Philippine Basin and the basins of the Sea of Japan.

2) Dating the major geologic events in and surrounding the Philippine Sea to better understand the formation of arc complexes as developed in the western Pacific.

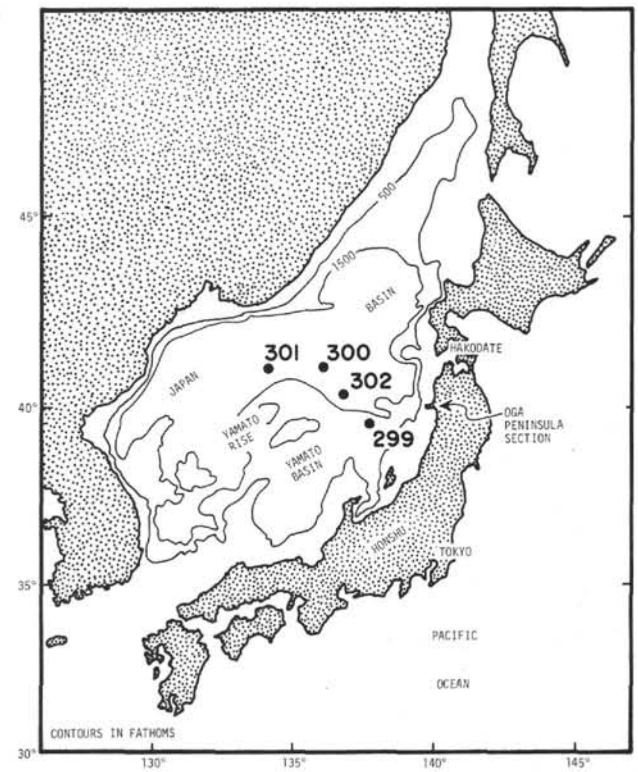

Figure 2. *Location of Leg 31 drilling sites in the Sea of Japan and position of the Oga Peninsula surface section commonly used as the standard biostratigraphic reference section in this area (Ingle, Chapter 41, this volume). (Figure 1 is in pocket at back of volume.)*

3) Documentation of Cenozoic planktonic biostratigraphy in areas influenced by tropical, transitional, and subarctic water masses in some marginal seas of the western Pacific and their correlation with key reference sections exposed in the Japanese Islands, Taiwan, and the Philippine Islands.

4) Analysis of variations in late Paleogene and Neogene planktonic biofacies in terms of major paleooceanographic and paleoclimatological events.

5) Scrutiny of sedimentary processes within marginal basins with focus on turbidite deposition and sediment provenance.

6) Investigating volcanogenic processes and post-depositional sediment alteration which might be operative in marginal basins.

SUMMARY OF DRILLING RESULTS

General

The 12 sites ultimately occupied during Leg 31 all yielded significant new data bearing on the nature and evolution of the West Philippine Basin, Shikoku Basin, and Sea of Japan. However, results in the Sea of Japan were less than expected due to early termination of drilling because of critical shows of ethane. Particularly noteworthy results were obtained at Site 292 on the Benham Rise (Figure 1), where a nearly complete equatorial late Eocene through Pleistocene stratigraphic reference section was recovered, and at Site 298 on the inner slope of the Nankai Trough where recently folded trench deposits representative of ongoing subduction were penetrated. Detailed drilling results for all sites are presented in Site Report Chapters 2 through 13, with overall syntheses of insular stratigraphy and the tectonic development of the Philippine Sea contained in Part IV (Chapters 41 and 42). The following summaries are presented as an introduction and brief review of Leg 31 results.

Philippine Sea Sites

Of the several major complexes of marginal basins in the western Pacific, the Philippine Sea seemed to show the most straightforward sequence of development. Active crustal extension is occurring in the first basin behind the Mariana Trench, and the basins become older and deeper, with generally decreasing heat flow, toward the west. Data supporting an eastward progression of extensional pulses were available from the two eastern basins, the Mariana and the Parece Vela, but the few pre-Leg 31 bits of information from the West Philippine Basin led to the proposal of a number of different modes of origin.

Drilling results of Leg 31 in both the West Philippine and Shikoku basins of the Philippine Sea support the concept of crustal extension and of arc migration east of the Palau-Kyushu Ridge, but imply a much more complex origin for the West Philippine Basin.

Site 290

Site 290 is located in the West Philippine Basin in a trough at the distal edge of the sedimentary apron along the west flank of the Palau-Kyushu Ridge. The major objective at this site, in conjunction with Sites 291, 292, and 293, was to test the mode and age of origin of the West Philippine Sea with emphasis on the nature of the Central Basin Fault. Two holes were drilled with the stratigraphic sequence encountered in Hole 290 consisting of 90 meters of Quaternary to late Oligocene brown clay overlying 49 meters of late Oligocene nannofossil ooze. Eighty-six meters of early Oligocene-late Eocene volcanic silts underlie this latter unit. The lowest sequence cored is a 30-meter-thick unit of late Eocene volcanic conglomerate and breccia.

Site 291

Site 291 was located on the flank of one of several N 20°-30°W trending benches near the crest of the outer swell of the Philippine Trench. The objectives at this site were identical to those at Site 290.

Two holes were drilled at Site 291 with the sediments being entirely pelagic down to basalt basement. The stratigraphic section consists of brown clay with increasingly frequent nannofossil interbeds below 50 meters based on seismic records or 69 meters where first cored. This section is Recent to late Eocene in age with nannofossil beds ending in early late Oligocene or later. The interval from 99 to 121 meters is a dark-brown ferruginous and zeolite clay with nannofossil and radiolarian-rich beds of late Eocene age. Holes 291 and 291A both bottomed in extrusive basalt with a glassy to very fine-grained surface.

Site 292

Site 292 was located on the southeastern portion of the Benham Rise a significant, if somewhat anomalous, high at the westernmost margin of the West Philippine Sea adjacent to Luzon Island. Prime objectives at this site were to recover a well-developed late Cenozoic biostratigraphic section deposited well above the CCD. Continuous coring revealed 154 meters of Pleistocene-late Oligocene nannofossil ooze, 71 meters of late to early Oligocene nannofossil ooze and chalk, and 142.5 meters of early Oligocene late Eocene ooze, chalk, and minor chert underlain by basalt. Multiple early to mid Miocene unconformities were detected at 101.5 and 111.0 meters. This sequence forms an outstanding tropical calcareous biostratigraphic reference section with an especially well-developed and apparently complete Oligocene interval. Basalt was penetrated from 367.5 to 443.5 meters, and radiometrically dated (K-Ar) as 38.2 ±1 m.y. and 37.1 ±2 m.y. (late Eocene).

Site 293

Hole 293 drilled into a thick apron of sediment lying north and east of Luzon and immediately west of the Central Basin Fault zone of the West Philippine Basin. The stratigraphic column penetrated consists of 244 meters of late Pliocene-Pleistocene sand-silt turbidites, 156 meters of Pliocene distal mudstone turbidites, 29 meters of brown mudstone with reworked late middle Eocene nannofossils overlying 46.5 meters (or more) of Miocene basaltic tectonic breccia. The breccia includes clasts of metabasalt and quartz-diorite gneiss.

Sites 294/295

Sites 294/295 were drilled far to the east of the Central Basin Fault zone in the thin sediment blanket covering deeper portions of the northeastern West Philippine Basin. The drilling represented an attempt to determine basement age in this portion of the sea. Hole 294 may have been sited near a small basement high, and after technical problems forced abandonment of this hole, a new hole (295) was drilled 1800 meters to the west. Drilling at both sites demonstrated that the entire 100-150 meter pelagic cover over the acoustic basement in this area consists of brown clay, which overlies basalt. Fossils were scarce in both holes; however, Eocene nannofossils and reworked Paleocene planktonic foraminifera were recovered from a slurry in the final core taken from Hole 295 near the basalt contact.

Site 296

Hole 296 was drilled on a sediment-covered terrace of the northern Palau-Kyushu Ridge. The primary objective was to recover a biostratigraphic reference section deposited beneath the transitional water mass of the northward-flowing Kuroshio Current. The latter objective was met admirably with the stratigraphic sequence consisting of 453 meters of Pleistocene to late Oligocene ash-bearing nannofossil oozes and chalks underlain by 634 meters of late Oligocene to early Oligocene volcaniclastics. The chalk-ooze interval contains an excellent record of evolution and productivity of calcareous planktonic microfossils in this area; unfortunately, a comparable siliceous record is missing. The boundary between Oligocene volcaniclastics and younger chalks may coincide with rifting of the ridge after initial opening of the Parece Vela Basin in the late Oligocene.

Site 297

Site 297 is located in the westernmost corner of the Shikoku Basin directly south of the Nankai Trough. Confirmation or reappraisal of the timing of a proposed Plio-Pleistocene pulse of subduction in the adjacent Nankai Trough was sought at this site, as well as evidence bearing on the age of the Shikoku Basin and development of the southwest Japan margin. The stratigraphic sequence encountered consists of 54 meters of Pleistocene diatom ash-rich clay, 36 meters of Pleistocene clay-rich nannofossil ooze, 240 meters of Pleistocene-late Pliocene claystone, 240 meters of late-early Pliocene claystone and turbidite sands and silts with displaced shallow-water foraminifera, and 127.5 meters of early Pliocene (?) to middle Miocene vitric ash and claystone. Cessation of turbidite deposition of continental material in early Pliocene likely marks the formation of the Nankai Trough.

A series of mechanical problems prevented the completion of both Holes 297 and 297A in basement.

Site 298

Site 298 was located on the lower inner slope of the Nankai Trough in order to probe the mechanism by which sediments of the trench floor are initially deformed and removed from the descending oceanic plate. This particular trench is unique because it is only 4500 meters deep, and yet a large number of high-magnitude shallow focus earthquakes suggest that the subduction rates are relatively high at the moment. The stratigraphic section consists entirely of a trench-floor turbidite sequence which becomes more fine grained with depth. The upper 136 meters are Holocene to late Pleistocene, and the lower 475 meters are late to early Pleistocene in age. The entire section is deformed to some degree, with the intensity of compaction, cleavage, and mesoscopic folding increasing downward.

Sea of Japan Sites

The Sea of Japan constitutes one of the most intensely studied of the many marginal seas rimming the western Pacific. Despite the relative abundance of geological information from the adjacent Japanese Islands and a recent flurry of geophysical measurements in the Sea of Japan, the age and origin of this feature remains controversial. The predominant view holds that the sea originated by tensional subsidence and rifting during the Oligocene-early Miocene interval as interpreted largely from rocks exposed in western Honshu. A second, and in some respects more speculative, origin involves a proposed proto-sea representing an extensional basin complex formed in the late Mesozoic-early Cenozoic interval. Unfortunately, shows of ethane and caving sand prevented penetration of the entire sedimentary sections in the Yamato and Japan basins, thus leaving the questions of ultimate age of the sea unanswered.

Site 299

Site 299 was located in the northwest portion of the Yamato Basin in the Sea of Japan. Objectives at this site were to determine basement age, obtain evidence of the subsequent filling of the basin, and recover biostratigraphic evidence detailing the paleooceanographic and paleoclimatic history of this portion of the sea. The stratigraphic sequence penetrated at Site 299 consists of 532 meters of late Pleistocene through early Pliocene sands, silts, clays, and claystones interpreted as a sequence of distal through proximal turbidite deposits covering an older unit of diatomaceous pelagic sediments. Unfortunately, an ethane gas show near the boundary between the turbidite unit and underlying pelagic unit forced abandonment of this hole before basement objectives were reached.

Sites 300 and 301

Hole 300 was drilled in the central portion of the Japan Abyssal Plain (or Basin) adjacent to the north end of the Yamato Rise. Difficulty was encountered in spudding Site 300 due to surface sand and gravel, with the hole finally washed to 117 meters through sand in order to seat drill collars. At this point the pipe and core barrel became badly stuck due to caving sand, and the hole was abandoned due to the prospect of further caving. The scant section penetrated represents late Pleistocene turbidites apparently derived from the Toyama Trough area.

Abandonment of Site 300 forced selection of an alternate site, Site 301. The hole was drilled in the Japan Abyssal Plain about 200 km southwest of Site 300 in a more protected area of the plain. Objectives at this site were focused on obtaining a record of the older sediments of the Japan Basin, as well as sampling the presumably colder planktonic biofacies present in this area. The stratigraphic section penetrated consists of 240.5 meters of Plio-Pleistocene distal turbidites, fine sands, silts, and clays underlain by 256 meters of Pliocene through early Pliocene or late Miocene (?) clayey diatomite and diatomaceous claystone with a few sandy interbeds representing an earlier interval of turbidite deposition. These sediments constitute a good late Miocene (?) to Pleistocene diatom reference section. Ethane gas shows forced abandonment of this site before target depth was reached.

Site 302

Due to the premature abandonment of Holes 299, 300, and 301, extra time was available in the schedule to select an additional drilling site in the Sea of Japan. Older *Vema* 28 (LDGO) seismic records and underway *Challenger* records illustrate that the flanks of the

Yamato Rise are covered by an undulating blanket of pelagic sediment which appears to be correlative in part with the ubiquitous diatomaceous unit underlying much of the sea. Hole 302 was drilled on a plateau-like area of the northern flank of the Yamato Rise in order to probe this pelagic unit and to penetrate any older sedimentary units present on the rise if possible. The stratigraphic section recovered consists of 33 meters of Pleistocene diatom ooze and ash, 38 meters of Pleistocene-late Pliocene zeolitic clay and micarb, 281.5 meters of late Pliocene-early Pliocene diatomaceous ooze, 254.5 meters of Miocene zeolitic clay, and 2 meters of unfossiliferous silty volcanic sand and green tuff of questionable early Miocene age. A good sequence of Radiolarians and silicoflagellates was recovered from the Plio-Pleistocene portion of this column. Due to a medical emergency this hole had to be completed rapidly, ahead of schedule, with only three cores pulled in the lower 275 meters of the hole.

LEG 31 OPERATIONAL SUMMARY

Leg 31 of the Deep Sea Drilling Project started on 13 June 1973 at Apra, Guam, and ended 52.3 days later at Hakodate, Japan, on 4 August 1973. *Glomar Challenger* traveled 4111 nautical miles and drilled a total of 17 holes at 13 sites in the Philippine Sea and the Sea of Japan (Figures 1 and 2). Water depths averaged 4453 meters (14,606 ft) and varied between 2399 meters and 6057 meters. Hole depths averaged 365 meters (1210 ft) and ranged between 98 and 1087 meters.

Weather was good during the leg. Typhoon Billie was in the embryonic stage while in the general area of the *Challenger* and had no effect on operations. Typhoon Ellen, more capricious than most and traveling in several different directions, including north, northwest, southwest, and west, deteriorated to a tropical storm and resulted in 12 hr downtime as a precautionary measure prior to spudding at Site 298.

The distribution of the 52.3 days total leg time was 61.4% site time, 34.8% cruise time, and 3.8% port time. Total site time of 32.1 days was divided into 52.7% coring, 7.8% drilling, 30.8% trips, and 8.7% other. A total of 6272.5 meters of ocean sediments and rocks was penetrated, of which 42% was cored. The average hole program consisted of taking 4.5 cores per 100 meters, with usable recovery obtained on 93% of the 285 cores attempted, and total recovery of 47% (Table 1).

For the 17 holes drilled, 12 were abandoned earlier than anticipated: 2 due to increasing gas shows, 7 from deteriorating hole conditions, 1 from failure of the Bowen subhydraulic system, and 1 due to a medical emergency which resulted in Leg 31 being terminated 2.5 days early. Equipment losses were limited to a bit and two drill collars and four bumper subs at Sites 290A and 298A. Mechanical downtime of 10 hr accrued from problems with the Bowen subhydraulic system. Dynamic positioning worked well during the leg, but trouble with computer interfacing required the semi-automatic mode of operation during the last two sites. No problems resulted, however.

EXPLANATORY NOTES

Responsibilities for Authorship

The authorship of site chapters is collectively the shipboard scientific party, with ultimate responsibility lying with the two chief scientists. D.E. Karig is senior author for Sites 290, 291, 293, 294/295, 297, and 298; J. C. Ingle for Sites 292, 299, 300, 301, and 302, with combined responsibility for Site 296.

Chapters 2 to 13 present data and discussions on the holes drilled. Each site chapter follows the same general outline with the respective authors listed in parentheses:

Site Data

Background and Objectives (Ingle and Karig)

Geological Setting

Objectives

TABLE 1
Summary of Pertinent Hole Statistics for DSDP Leg 31

Hole	Date (1973)	Latitude	Longitude	Water Depth (m)	Penetration (m)	No. of Cores	Cored (m)	Recovered (m)	Recovery (%)
290	June 18-20	17°44.85'N	133°28.08'E	6062	255.0	9	80.0	38.9	48.6
290A	June 20-21	17°45.05'N	133°28.44'E	6062	140.0	2	19.0	1.9	10.0
291	June 23-25	12°48.43'N	127°49.85'E	5217	126.5	5	41.0	10.0	24.4
291A	June 23-25	12°48.45'N	127°48.98'E	5217	114.5	2	16.5	1.4	8.5
292	June 26-30	15°49.11'N	124°39.05'E	2943	443.5	47	443.5	242.7	55.0
293	July 1-4	20°21.25'N	124°05.65'E	5599	563.5	23	202.5	78.8	38.9
294	July 7	22°34.74'N	131°23.13'E	5784	118.0	7	51.5	23.2	45.0
295	July 7-8	22°33.76'N	131°22.04'E	5808	158.0	3	28.5	19.8	69.0
296	July 10-14	29°20.41'N	133°31.52'E	2920	1087.0	65	612.0	312.1	51.0
297	July 15-18	30°52.36'N	134°09.89'E	4458	679.5	27	242.5	124.2	52.0
297A	July 18-19	30°52.36'N	134°09.89'E	4458	200.5	0	0.0	0.0	0.0
298	July 20-22	31°42.93'N	133°36.22'E	4628	611.0	16	145.5	66.8	45.8
298A	July 22-23	31°42.93'N	133°36.22'E	4628	98.0	1	9.5	0.4	4.2
299	July 26-28	39°29.69'N	137°39.72'E	2599	532.0	38	361.0	172.3	47.7
300	July 29-30	41°02.96'N	136°06.30'E	3427	117.0	2	10.5	0.0	0.0
301	July 30-Aug. 1	41°03.75'N	134°02.86'E	3520	497.0	20	183.5	49.9	27.2
302	Aug. 2-3	40°20.13'N	136°54.01'E	2399	531.5	18	164.5	91.0	55.3
Total					6272.5	285	2611.5	1233.5	47.0

Operations (Ingle and Karig)
  Presite Surveys
  Drilling Operations
  Postsite Surveys
Lithology (Bouma, Haile, MacGregor, Moore, and White)
  Lithologic Units (Descriptions of)
  Igneous Petrography (where applicable)
  Lithologic Interpretations
Physical Properties (Bouma, Moore, Yasui, and Watanabe)
  Density, Water Content
  Sonic Velocity
  Conductivity/Heat Flow (where applicable)
  Shear Strength (where applicable)
Geochemical Measurements (White)
Biostratigraphy (Ellis, Ingle, Koizumi, Ling, and Ujiié)
  Introduction
  Calcareous Nannofossils
  Foraminifera
  Radiolaria
  Silicoflagellates
  Diatoms
Summary and Interpretations (Ingle and Karig)
References
Appendix

The interpretations of individual authors have been retained in the section for which they were responsible. Therefore, conflicting interpretations are sometimes apparent between a particular section and the summary. Authorship of papers dealing with special topics (Chapters 14 to 40) and the Synthesis chapters (Part IV, Chapters 41 and 42) is cited in the text.

Part VI, Appendix I-IV, consists of organic geochemistry studies on samples obtained during DSDP Leg 29. Space limitations for Initial Reports Volume 29 did not allow their inclusion.

Survey and Drilling Data

The survey data used for specific site selections are given in each Site Report chapter. On passage between sites, continuous observations were made of depth, magnetic field, and subbottom structure. Short surveys were made on *Glomar Challenger* before dropping the beacon, using a precision echo sounder, seismic profiles, and magnetometer.

Underway depths were continuously recorded on a Gifft precision graphic recorder (PGR). The depths were read on the basis of an assumed 800 fathoms/sec sounding velocity. The sea depth (in m) at each site 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 have been calculated under the assumption that this level is 10 meters above the water line. Water depths cited for each hole were nearly always determined from the echo sounder since it was seldom possible to accurately determine the bottom with the drill string, or bottom-hole assembly.

The seismic profiling system consisted of two Bolt airguns, a Scripps-designed hydrophone array, Bolt amplifiers, two bandpass filters, and two EDO recorders, usually recording at two different filter settings.

Drilling Characteristics

Since the water circulation down the hole is an open one, cuttings are lost onto the sea bed and cannot be examined. The only information available about sedimentary stratification between cores, other than from seismic data, is from an examination of the behavior of the drill string as observed on the drill platform. The harder the layer being drilled, the slower and more difficult it is to penetrate. However, there are a number of other variable factors which determine the rate of penetration, so it is not possible to relate this directly with the hardness of the layers. The following parameters are recorded on the drilling recorder, and all influence the rate of penetration.

1) Weight on the bit. This can vary in three steps from zero when the bit is suspended up to 40,000 pounds when two of the three bumper subs are collapsed and the whole bottom assembly bears on the bit. The aim of the driller is to maintain constant bit weight by lowering the drill string when necessary. However, this is extremely difficult to do in conditions of swell, where the heave of the drill platform may exceed the available extension (15 ft) of the bumper subs.

2) Revolutions per minute. The revolutions per minute (rpm) is related to the torque applied to the top of the drill string, and a direct analysis of the two should give the resistance to drilling. However, the rpm record is not adequately expanded to do this. Nevertheless, visual observations of the drill rotation are useful in assessing the bit behavior. In particular, it can be seen that when the drill bit becomes jammed, rotation stops and then speeds up as the bit becomes free and the drill string untwists.

The Hole Summary Diagrams in the Site Report chapters (Chapters 2-13, this volume) contain a graphic plot of drilling/coring rates, as they relate to the lithologies encountered.

Drilling Disturbances

When the cores were split, many showed signs of the sediment having been disturbed since its deposition. Such signs were the concave downward appearance of originally plane bands, the haphazard mixing of lumps of different lithologies, and the near fluid state of some sediments recovered from tens or hundreds of meters below the sea bed. It seems reasonable to suppose that these disturbances came about during or after the cutting of the core. Three different stages during which the core may suffer stresses sufficient to alter its physical characteristics from those of the in situ state are: the cutting, the retrieval (with accompanying changes in pressure and temperature), and the core handling.

Shipboard Scientific Procedures

Basis for Numbering Sites, Holes, Cores, and Sections

A site number refers to a single hole or group of holes drilled in essentially the same position using the same acoustic beacon. The first hole at a site (for example, Site 290) was given the number of the site (for example, Hole 290). Second holes drilled by withdrawing from the first hole and redrilling were labeled "A" holes (Hole 290A).

A core was usually taken by dropping a core barrel down the drill string and coring for 9.5 meters as measured by lowering of the drill string before recovery. The sediment was retained in a plastic liner 9.28 meters long inside the core barrel, and in a 0.20-meter-long core-catcher assembly below the liner. The liner was not normally full.

On recovery, the liner was cut into sections of 1.5 meters measured from the lowest point of sediment within the liner (Figure 3). In general, the top of the core did not coincide with the top of a section. The sections were labeled from 1 for the top (incomplete) section to a figure as high as 6 for the bottom (complete) section, depending on the total length of core recovered (Figure 2).

In the event that there were gaps in the core resulting in empty sections, these were still numbered in sequence. Core-catcher samples are always considered to have come from the bottom of the cored interval regardless of the depth assigned to the adjacent section above. On occasions, over 9.5 meters of core were recovered. The small remainder was labeled Section 0 (zero) being above Section 1.

All samples taken from cores were numbered before being processed, according to the system described in the Shipboard Handbook for Leg 31. The label "31-290-3-2, 25 cm" thus refers to Leg 31, Hole 290, Core 3, Section 2, sampled 25 cm from the top of that section. The label "31-290-3, CC" refers to the core-catcher sample at the base of Core 3.

It is appreciated that with this labeling system, the top of the core material recovered may be located at 1.3 meters below the top of Section 1, and the bottom will be at 1.5 meters in Section 2 (if the total recovery is 1.7 m). In relating this to downhole depths, there is an arbitrariness of several meters. However, it is impossible to assess where exactly in the hole the sample came from. Sometimes the core barrel will jam up with a hard sediment after sampling a few meters, this will then really represent 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 off the bottom 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 samples within a section as the position appears when the section is first cut open and as logged in the visual core description sheets. The section labeling system implies that the top of the core is within 1.5 meters of the top of the cored interval. Thus, the downhole depth of 31-290-3-2, 25 cm is calculated as follows. The top of the cored interval of Core 3 is 189 meters. The top of Section 2 is 1.5 meters below top of the cored interval, that is, at 190.5 meters. The sample is 25 centimeters below the top of Section 2, that is, at 190.75 meters.

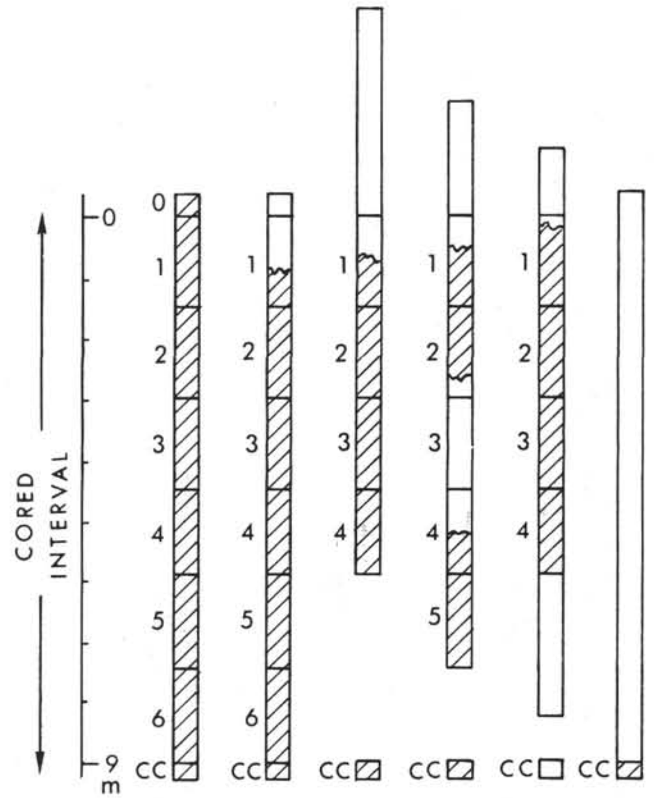

Figure 3. *Method of labeling sections of cores when recovery is complete, incomplete, and divided. The cores have been lined up so that the top of Section 1 is always coincident with the top of the cored interval, according to the method of calculating downhole depth of samples. Core-catcher samples are always considered to have come from the bottom of the cored interval regardless of the depth assigned to the adjacent section above.*

Handling of Cores

The first assessment of the core material was made rapidly on samples from the core catcher. An age by paleontology enabled rapid decisions to be made on whether to drill ahead or to take another core.

After a core section had been cut, sealed, and labeled, it was brought into the core laboratory for processing. The routine procedure listed below was usually followed:

1) Weighting of the core section for mean bulk density measurement.
2) GRAPE analysis for bulk density.
3) Sonic velocity determinations.
4) Thermal conductivity measurements.

After the physical measurements were made, the core liner was cut. The core could then be split into halves by a wire cutter, if the sediment was a soft ooze. If compacted or partially lithified sediments were included, the core had to be split by a machine band saw or diamond wheel.

One of the split halves was designated a working half. Samples, including those for grain size, X-ray mineralogy, interstitial water chemistry, and total carbonate content were taken, labeled, and sealed. Larger samples were taken from suitable cores for organic geochemical analysis, usually prior to splitting the core.

The working half was then sent to the Paleontology Laboratory. There, samples for shipboard and shore-based studies of nannoplankton, foraminifera, radiolarians, diatoms, and silicoflagellates or other microfossil groups were taken.

The other half of a split section was designated an archive half. The cut surface was smoothed with a spatula to emphasize 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. A smear slide was made, usually at 75 cm if the core was uniform. However, two or more smear slides were often made, for each area of distinct lithology in the core section. The smear slides were examined by petrographic microscope. The archive half of the core section was then photographed. Both halves were sent to cold storage onboard ship after they had been processed.

Material obtained from core catchers, and not used up in the initial examination, was retained for subsequent work in freezer boxes. Sometimes significant pebbles from the core were extracted and stored separately in labeled containers. On other occasions, the liners would contain only sediment-laden water. This was usually collected in a bucket and allowed to settle, the residue being stored in freezer boxes.

At several sites, hard cores were obtained either of basement or indurated sediment. Each separate core fragment was numbered and labeled consecutively from the top downwards and its orientation indicated by an upward-pointing arrow. Where possible, the fragments were arranged into their original relative orientation and were then sliced longitudinally for examination and separation into working and archive halves.

All samples are now deposited in cold storage at the West Coast Repository at Scripps Institution of Oceanography and are available to investigators.

Procedures Used in Physical-Chemical Properties Measurements and Sediment Analysis

Physical Properties

A thorough discussion of physical properties is presented by Boyce (1973) with regard to the 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. Explanation of some 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.

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/cc and a water density of 1.024 g/cc.

3) Wet bulk density (p): The wet bulk density (p) is defined as the weight in g/cc of the wet-saturated sediment i.e.,

$$p = \frac{\text{weight of wet sediment}}{\text{volume of wet sediment(cc)}}$$

The densities of the seawater-saturated cores were measured in three ways: (a) by weighing each 1.5-meter core section giving a mean density for the whole section; (b) from the water content W (syringe samples); (c) by continuous measurement along the length of the core section with the GRAPE using as standards, water (1.024 g/cc) and aluminium (2.6 g/cc). The GRAPE technique is described by Evans and Cotterell (1970) and Whitmarsh (1972). Because of the possible presence of drilling slurries and disturbances, low values are suspect and emphasis should be placed on the maximum densities (minimum porosities).

4) Compressional wave velocity: The sonic velocity is obtained by timing a 400-kHz sonic pulse across two transducers and measuring the distance across the sample with a dial gage (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. The accuracy is about ±2%. The values (km/sec) are plotted on Hole Summary Diagrams in the site summary chapters.

5) Thermal conductivity: The thermal conductivity is defined as the quantity of heat transmitted, due to unit temperature gradient, in unit time in steady conditions in a direction normal to a surface of unit area.

Thermal conductivities were measured with a von Herzen-Maxwell needle probe utilizing an improved instrumentation system developed by WHOI. Five fine needle probes were attached to the thermal conductivity measurement apparatus (K-box). The voltage drop in thermistors of the needle probes was alternately measured on 3-sec intervals by the digital voltmeter and punched on paper tape; the core section, number, and position of needle probes and other necessary information were recorded on a thermal conductivity measurement log.

Thermal conductivity measurements were carried out at Site 293 mainly to test the instrumentation system. Apparently uniform and undisturbed core sections were selected with four to five measurements being made on each section. Thermal conductivity measurements varied up to 0.3×10^{-3} cal/cm sec °C about the mean for a given section. Unhomogeneous lithologies rather than technical errors apparently account for these variations.

Thermal conductivity can be estimated from water content by Ratcliffe's formula:

$$\text{Thermal conductivity} = \frac{1}{\text{thermal resistance}} = \frac{1}{(168 \pm 14) + (6.78 \pm 0.31)\ W}$$

where W is water content in weight percent. Direct measurements of thermal conductivity and water content were not made at the same locations, therefore it is difficult to compare measured and calculated values of thermal conductivity. The averaged values for each core section are reasonable for partially consolidated sediment buried several hundred meters below the mudline.

6) Heat flow: Heat-flow measurements were made in situ in the sediment section at Sites 297, 298, and 301. The upward heat-flux measurements were computed from the temperature of the sediments measured at depth, using the downhole instrument (DHI) developed by WHOI. The instrument was mounted within the core barrel, which was lowered to the hole depth. No sediment cores were taken during this procedure.

In principle, the measurement was determined by the resistance of a thermistor in the heat probe. This resistance measurement which varied according to the ambient temperature, was converted to a frequency by a variable-frequency oscillator (VFO). The frequencies were recorded on tape. Temperature computations were computed using precalibrated relationships between temperature and resistance and frequency.

A check of the stability of the function of the VFO, was accomplished by four built-in (connected alternatively) precision resistors with values of 4, 7.5, 9, and 11 kohm. Frequency measurements at Site 297 for the precision resistors showed temporal shifts of more than 13% (= 850 Hz) during a 70-min measurement period. These values were far larger than those values shown on calibration tables experimentally calculated prior to the cruise. However, frequency shifts in the four calibration resistors were almost parallel to each other. It was found that at certain times, frequencies measured for the known resistors were linearly correlated with precalculated frequencies, although the two coefficients in the linear relationship varied from time to time.

It was concluded that in situ temperature could be determined with the preestablished calculation tables provided the frequency recorded was converted to an intermediate frequency. This was done by a linear formula established for the four known resistances at the closest period to the time of the measurement in the hole.

7) Shear strength: The C1-600 Torvane which was used onboard ship is a scientifically designed soil-testing instrument for the rapid determination of shear strength of cohesive soils, either in the field or in the laboratory. The instrument permits the rapid determination of a large number of strength values with different orientation of failure planes.

The shear strength of a cohesive soil is dependent upon many factors, including rate of loading, progressive failure, orientation of the failure plane, and pore water migration during testing. The instrument does not eliminate the effects of any of these variables. However, it does give repeatable values in a homogeneous clay, and extensive laboratory testing indicates excellent agreement between the unconfined compression test and the Torvane. The smallest division on the dial is in units of 0.05 tons per square foot (TSF) permitting visual interpolation to the nearest 0.01 TSF.

Measurements made on the working halves provided not only shear strength data, but also revealed the degree of coring disturbance through a core. For this reason alone the instrument is very useful, especially when no lithological or color differences are present to observe coring deformations. For shear strength values throughout the sediment of one hole, only the highest values (normally only obtained in the lowest section) should be used. Brief discussions of vane shear studies will be found in the Site Report chapters, with a more complete analysis and discussion to be found in Bouma and Moore, this volume.

Geochemical Measurements

Aboard ship, analyses for *p*H, alkalinity, and salinity are conducted routinely.

1) *p*H: *p*H is determined by two different methods. One is a flow-through electrode method, the other is a punch-in electrode method. *p*H is determined on all samples via the flow-through method, which is a glass capillary electrode in which a small portion of unfiltered pore water is passed. In the softer sediments a "punch-in" *p*H is also determined by inserting *p*H electrodes directly into the sediment at ambient temperature prior to squeezing. The *p*H electrodes for both methods are plugged into an Orion digital millivolt meter. These readings are converted to *p*H using the following formula:

$$pH = 7.41 + \frac{\text{EMF 7.41 buffer - EMF sample}}{\text{slope}}$$

$$\text{Slope} = \frac{\triangle \text{EMF}}{\triangle pH} = \frac{\text{EMF4.01buffer-EMF7.41buffer}}{pH^{1}\ 7.41\ \text{buffer - } pH^{1}\ 4.01\ \text{buffer}}$$

2) Alkalinity: Alkalinity is measured by a colorimetric titration of a 1-ml aliquot of interstitial water with 0.1 *N* HCl using a methyl red/blue indicator.

$$\text{Alkalinity (meq/kg)} = (\text{ml HCl titrated}) \cdot (97.752)$$

3) Salinity: Salinity is calculated from the fluid's refractive index as measured by a Goldberg optical refractometer, using the ratio:

$$\text{Salinity } (^{\circ}/_{\circ\circ}) = (0.55) \cdot \triangle N,$$

where $\triangle N$ = refractive index difference × 10^4. Local surface seawater is regularly examined by each of the above methods for reference.

Sedimentologic Analyses

1) Carbon-carbonate: The carbon-carbonate data were determined by a Leco induction furnace combined

[1]Temperature corrected value.

with a Leco acid-base semiautomatic carbon determinator. Step-by-step procedures are in Volume 4 of the Initial Reports of the Deep Sea Drilling Project and a discussion of the method, calibration, and precision are in Volume 9.

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

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

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

2) Grain size: Grain-size distribution was determined by standard sieving and pipette analysis. The sediment sample was dried, 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 62.5μ sieve with the fines being processed by standard pipette analysis following Stokes settling velocity equation (Krumbein and Pettijohn, 1938, p. 95-96), which is discussed in detail in Volume 9 of the Initial Reports of the Deep Sea Drilling Project. Step-by-step procedures are in Volume 5. 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 9.

3) X-ray: Semiquantitative determinations of the mineral composition in bulk samples, 2 to 20μm, and <2μm fractions were performed according to the methods described in Volume 28, Initial Reports of the Deep Sea Drilling Project. The mineral analyses of the 2 to 20μm and <2μm fractions were performed on $CaCO_3$-free residues.

Treatment of the raw samples was: washing to remove seawater salts, grinding to less than 10μ 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 Part V, Appendix I (this volume).

Columns 1 and 2 contain the core numbers and the depths of the cored intervals (in meters below the mudline). The third column gives the depths of the composited, sample intervals or the depths of single samples. Column 4 contains the percentage of the diffuse scattered X-rays to the Bragg angle and diffuse scattered X-rays. The amorphous scattering percentage in column 5 is derived from the data of column 4 by a simple conversion based on the ratio of Bragg angle and diffuse scattering in pure quartz. It is a measure of the proportion of crystalline and amorphous materials in the sample. The remaining columns contain crystalline mineral percentages computed by the method of mutual standards using peak heights.

Several unidentified minerals were detected in Leg 31 samples. These were reported on a ranked, semiqualitative scale using a hypothetical mineral concentration factor of 3.0 and other semiquantitative criteria as outlined below:

Trace	(<5%); diffraction pattern is weak and identification was made on the basis of two major diagnostic peaks.
Present	(5%-25%); a number of peaks of the mineral are visible in the diffraction pattern.
Abundant	(25%-65%); diffraction peaks of the mineral are prominent in the total diffraction pattern, but the peaks of other minerals are of an equivalent intensity.
Major	(>65%); the diffraction peaks of the mineral dominate the diffraction pattern.

Although a certain quantity of the unidentified minerals is implied, their concentration is not included in the concentrations of the identified minerals which are summed to 100%. The terms "Trace," "Present," etc. are also used in discussing identified minerals in the text of this report and imply the concentration ranges as indicated above.

Lithologic Nomenclature, Classification, and Symbols

Stratigraphic Terminology

Many different lithologies were encountered on Leg 31. Although no formal rock stratigraphic units are proposed in this volume, the sediments are informally divided into units and subunits. For each site, these unit designations are outlined in a table in the Lithology section and also in the Hole Summary Diagram. Boundaries between units and subunits in cored intervals were both sharp and gradational. If a boundary occurred between cores, it was placed in the middle of the drilled interval.

Sediment Classification

The naming and classification of sediments follows the system of Weser (1973). Certain minor modifications to the basically descriptive approach embodied in this system have since been made and are incorporated in the revision outlined in this chapter.

Lithologic Symbols

Accompanying the introduction of the sediment classification to the DSDP volumes is the employment of a set of lithologic symbols. These symbols and their method of employment has continued, with only minor modification, through all volumes subsequent to Volume 18 (i.e., Volumes 18 to 31). The basic sediment symbols thus employed are shown in Figure 4.

These symbols have been put on all core and site summary forms. Where complex lithologies occur, instead of superimposing symbols, each constituent is represented by a vertical bar. The width of each bar corresponds to the percentage value of the constituent it represents in the manner shown on Figure 5. It will be noted that the class limits of the vertical bars correspond to those of the sediment classification. With this system of graphical representation, all major and the rich portion of the minor constituents can be shown. The bearing (2%-10%) part of the minor constituents is shown by the overprinting of an appropriate letter or symbol.

It will be noted that these symbols encompass both compositional and textural aspects of the sediments. To represent both of these aspects simultaneously in a lithologic column is difficult. Consequently, the convention on Leg 31 has been that when a sediment is of clastic origin, a textural symbol is used and when of nonclastic origin a compositional symbol is used. There were a few instances where it was not obvious as to whether a sediment was of clastic origin or not. In such cases the sediment was represented by a compositional symbol.

Classification and Nomenclature Rules

I. Rules for class limits and sequential listing of constituents in a sediment name
   A. Major constituents
      1. Sediment assumes name of those constituents present in major amounts (major defined as >25%). See example in rule IA3.
      2. Where more than one major constituent is present, the one in greatest abundance is listed farthest to the right. In order of decreasing abundance, the remaining major constituents are listed progressively farther to the left.
      3. Class limits when two or more major constituents are present in a sediment are based on 25% intervals, thusly— 0-25, 25-50, 50-75, 75-100.
      Example illustrating rules IA and IB and the resulting sediment names:

%Clay	%Nannos	
0-25	75-100	= Nanno ooze
25-50	50-75	= Clayey nanno ooze
50-75	25-50	= Nanno clay
75-100	0-25	= Clay

   B. Minor constituents
      At the discretion of the geologist, constituents present in amounts of 10-25% may be prefixed to the sediment name by the term rich.
      Example: 50% nannofossils, 30% radiolarians, 20% zeolites would be called a zeolite-rich rad nanno ooze.
      At the discretion of the geologist, constituents present in amounts of 2-10% may be prefixed to the sediment name by the term bearing.
      Example: 50% nannofossils, 40% radiolarians, 10% zeolites would be called a zeolite-bearing rad nanno ooze.
   C. Trace constituents. Constituents present in amounts of <2% may follow the sediment name with addition of the word trace. This again is at the discretion of the geologist.

II. Specific rules for calcareous and siliceous tests
   A. Nannofossil is applied only to the calcareous tests of coccolithophorids, discoasters, etc.
   B. The term calcareous or siliceous, depending on skeletal composition is applied where no attempt is made to distinguish fossils as to major subgroup. Thus, if no percent estimate is made, a mixture of radiolarians, diatoms, and silicoflagellates would be called siliceous ooze. Where this distinction is made, the appropriate fossil name is used.
   C. Fossil tests are not qualified by a textural term unless very obviously redeposited.
   D. Abbreviations, as nanno for nannofossil, rad for radiolarian, etc., may be used in the sediment name.
   E. The term ooze follows a microfossil taxonomic group whenever it is the dominant sediment constituent.
   F. Usage of the terms marl and chalk to designate amounts of microfossils, 30-60% and >60% respectively, as used by Olausson (1960) and others, is dropped. The term chalk is retained to designate a compacted calcareous ooze.

III. Clastic sediments
   A. Clastic constituents, whether detrital,[2] volcanic, biogenous, or authigenic, are given a textural designation. When detrital[2] grains are the sole clastic constituents of a sediment, a simple textural term suffices for its name. The appropriate term is derived from Shepard's triangle diagram (Shepard, 1954). The textural term can be preceded by a mineralogical term when this seems warranted. Such mineralogical terms are applied as per rules IA and B.
   B. When the tests of a fossil biocoenosis or authigenic and detrital grains occur together, the fossil or authigenic material is not given a textural designation (as per rule IIC). However, the detrital material is classified texturally by recalculating its size components to 100%. With the presence of other constituents in the sediment, the detrital fraction now requires a compositional term.
   C. Clastic volcanics
      Redeposited pyroclastics also become a clastic component. They are again recognized by the term volcanic and receive a textural term such as gravel, sand, silt, etc. It is particularly difficult at times to differentiate between volcanic sand (i.e., transported by tractive mechanisms) and crystal ash (i.e. direct outfall resulting from explosion of a volcano).
   D. Clastic authigenic constituents
      Where authigenic minerals are recognized as being a redeposited constituent, they are given a textural designation in addition to their mineral names.

IV. Volcanic and authigenic constituents
   A. Volcanic constituents
      Pyroclastics are given textural designations already established in the literature. Thus, volcanic breccia = >32 mm, volcanic lapilli = <32 mm to >4 mm, and volcanic ash = <4 mm. It is at times useful to further refine the textural designations by using such modifiers as coarse or fine. An ash wholly, or almost wholly, of glass shards is termed vitric ash.
   B. Authigenic constituents
      1. Authigenic minerals enter the sediment name in a fashion similar to that outlined under rules IA and B. Normally, as will a fossil biocoenosis, the authigenic minerals are not given a textural designation and texture.
      2. The terms ooze and chalk are applied to carbonate minerals of all types using the same rules that apply to biogenous constituents.

V. Color
   A. Color is not formally part of the sediment name. However, its employment for sediment description is important particularly as it provides one of the criteria used to distinguish pelagic and terrigenous sediments.
   B. Common usage dictates that it is no longer expedient to employ the term red for sediments (*usually* pelagic) which are various shades of red, yellow, and brown. The proper color designation should be used.

[2]Detrital = all clastic grains derived from the erosion of preexisting rocks except for those of biogenous, authigenic, or volcanic origin.

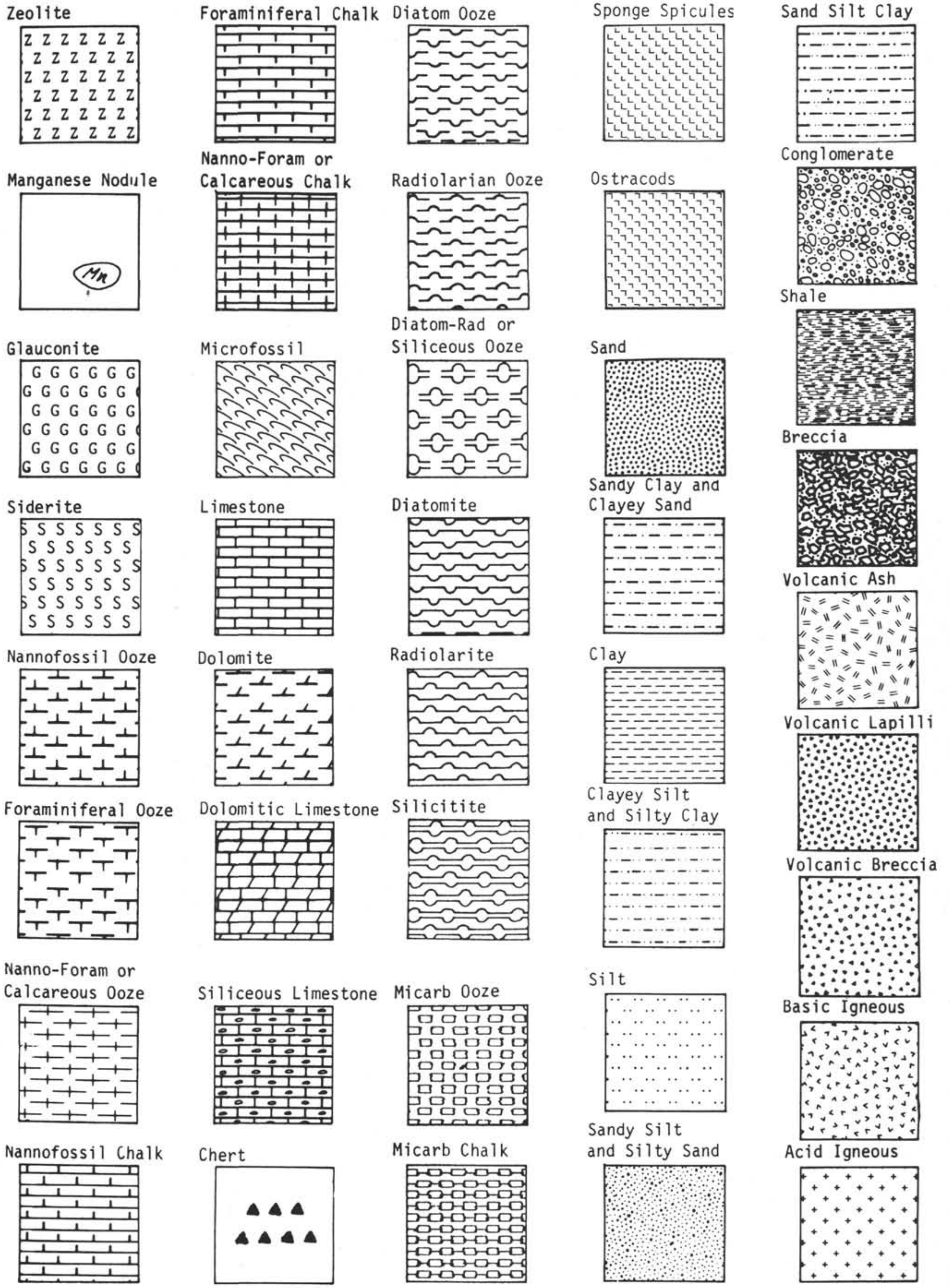

Figure 4. *Lithologic symbols.*

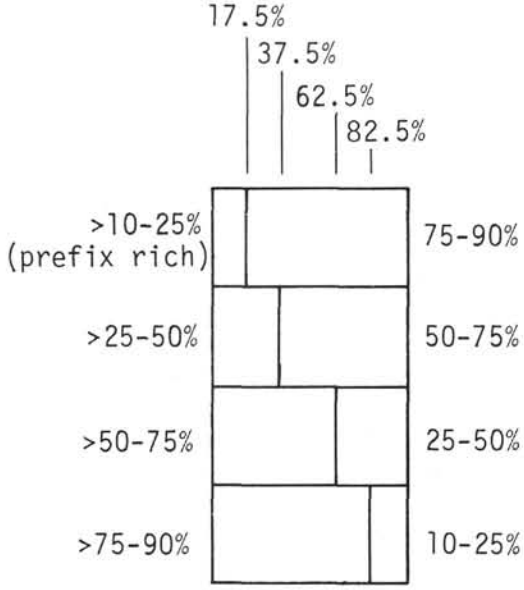

Figure 5. *Vertical bar width representation of class limits.*

Core Forms (Figure 6)

Lithologies shown in the lithologic column are based on percentage composition values determined by shipboard smear-slide examinations. Where these values differed from the results of shore-based laboratory studies of grain-size, carbonate, or X-ray mineralogy data, the appropriate correction was made. Entries in the column headed "Litho, Sample" indicate where control on lithologies exists. At times, compositional differences appeared to coincide with color changes, in these instances the lithologic changes were made to coincide with color boundaries.

Several items are entered in the column headed "Lithologic Description": (a) Numerical color designations and names follow the Munsell system as employed by GSA. The colors recorded in the core barrel summaries were determined during shipboard examination immediately after splitting the sections. Experience with carbonate sediments shows that many of the colors will fade or disappear with time after opening and storage. Colors particularly susceptible to rapid fading are purple, light and medium tints of blue, light bluish, gray, dark greenish-black, light tints of green, and pale tints of orange. These colors change to white, yellowish-white, or light tan; (b) Written descriptions tell the name of the dominant lithology, followed by pertinent remarks concerning various aspects of the sediments. Smear-slide descriptions of the dominant lithology are given, followed by similar descriptions of important minor lithologies. The reader should be aware that smear-slides are not point-counted, and therefore percentage values initially so derived are usually not too precise. In this sense, the numerical values serve more as an approximation of relative constituent amounts rather than as an accurate quantitative guide. To improve the quantitative aspects of the smear-slide data, they were updated by the shore-based laboratory data. Consequently, many of these values, particularly those reflecting texture, are precise. Numerous compositional estimates when later compared with shore-based laboratory studies were found to be closely comparable. The largest error in visual estimation normally occurred where one of the sediment components consisted of carbonate grains; however, this error was eliminated by using the shore-based carbon carbonate data which has a high degree of precision; (c) The remaining portion of the Lithologic Description column contains the results of shore-based laboratory studies on grain-size, X-ray, and carbon carbonate, which were carried out at Scripps and Riverside for the X-ray data, only the results from bulk analyses are shown; (d) In the "Fossil Character" columns of the core forms, letters are used to designate the abundance and preservation of the respective fossils. Their position indicates the sample location. The capital letter designates abundance and the small letter shows preservation (i.e., A_e). The letters used to indicate fossil abundance are as follows:

A = Abundant (flood, many species and specimens);
C = Common (many species, easy to make age assignment);
R = Rare (enough for age assignment); and
T = Trace (few species and specimens, not enough for age assignment).

Letters to designate fossil preservation include these four:

e = excellent (no dissolution or abrasion);
g = good (very little dissolution or abrasion);
f = fair (dissolution and/or abrasion and/or recrystallization very noticeable); and
p = poor (substantial or very strong evidence of dissolution and/or abrasion, and/or recrystallization).

In the "Zone" column, foraminifera, nannoplankton, and Radiolaria zones are written, with the foraminifera zone nearest the left margin of the core form, the nannoplankton zone in the center, and the Radiolaria or Diatom zone nearest the right; (e) In the deformation column, four degrees of drilling deformation were recognized as follows:

Slightly deformed---	Highly deformed ////
Moderately deformed——	Soupy ~~~~~~

Biostratigraphy and Basis for Age Determination

Abundance and preservation of both calcareous and siliceous microfossils vary significantly at Leg 31 sites as a function of the wide spectrum of water depths encountered and latitudinal breadth of the drilling sites spanning 17° to 40°N in the marginal western Pacific (Figure 1; Table 1). Leg 31 had major biostratigraphic goals including recovery of reference sections deposited beneath equatorial, transitional, and subarctic waters. Continuous coring at Sites 292 and 296 in the Philippine Sea area (Figure 1) recovered two superb mid to late Tertiary calcareous sequences containing abundant and well-preserved calcareous nannofossils and planktonic foraminifera, with radiolarians present in all but the youngest portions of these sediments. The Site 292 section is composed almost entirely of calcareous pelagic

Site Hole Core Cored Interval: Meters below sea floor

AGE	ZONE	FOSSIL CHARACTER				SECTION	METERS	LITHOLOGY	DEFORMATION	LITHO. SAMPLE	LITHOLOGIC DESCRIPTION
	Foraminifera Zones Nannofossil Zones Radiolarian and/or Diatom Zones		See Notes* (lower portion of this sample form)			1 2 3 4 5 6	0.5 1.0	See Explanatory Notes	Slight Deformation — — — Moderate Deformation ———— Intense Deformation ~~~~~ Drilling Breccia OOO	Smear Slide depth in centimeters in a section.	(see below)
							Core Catcher				

Area of General Description: general lithology, colors, deformation, and specific characteristics.

Smear Slide Descriptions

(Note: "Clay mineral" in composition column may designate unresolvable, fine clay-size material)

Lithology. (Major and Minor included)
Smear: by section and depth (cm)
Texture in % Composition in %

(Specific characteristics of smear slides may follow the basic listing)

X-ray, Carbon-carbonate, Grain Size Analyses.

X-ray 6 - 107 (bulk fraction)

Sec. cm
Composition in %: components have abbreviated names.

Carbon-carbonate 6 - 107 (Total C, Org. C, $CaCO_3$)

Sec. cm

Grain Size 6 - 107 (Sand %, Silt %, Clay %)

Sec. cm

---

*Notes

1. Fossil character = fossil name (Nannos, Forams, Rads, Diatoms, Silicoflagellates, etc.).
   a. Small marks (-) in column under FOSSIL CHARACTER show the location of the sample.
   b. First letter near the small mark designates "Abundance" in capital letters.
      A = Abundant (flood; many species and specimens)
      C = Common (many species; easy to make age determinations)
      R = Rare (enough for age assignment)
      T = Trace (few species and specimens)
   c. The second letter designates "Preservation" and is written in small letters to distinguish from "Abundance" designation.
      e = excellent (no dissolution or abrasion)
      g = good (very little dissolution or abrasion)
      f = fair (dissolution and/or abrasion and/or recrystallization very noticeable)
      p = poor (substantial or very strong evidence of dissolution and/or abrasion and/or recrystallization)
   d. In "ZONE" column, imagine three vertical columns in the space provided. Foram zone closest to the left, the Nannoplankton zone in the middle, and the Rad. zone on the right.

   Example(s): Ae
   Cg

Explanatory notes in chapter 1

Figure 6. *Sample core form and legend.*

ooze and chalk and most certainly represents a potential biostratigraphic reference section for the western equatorial Pacific. The section encompassed late Pleistocene through latest Eocene time and rested on a basalt dated radiometrically as 37 to 38 m.y. Calcareous zonations indicate that the Oligocene portion of the Site 292 column is unbroken, thus representing one of the most complete low-latitude records of this controversial epoch available and destined for repeated paleontologic scrutiny. Site 296 offers a mid-latitude counterpart to the Site 292 section, and again offers a closely cored sequence representing an almost unbroken record of Pleistocene through late Oligocene planktonic evolution and productivity within the Kuroshio Current. Other sites in the Philippine Sea offer only adequate to poor paleontologic control.

Good to excellent Pliocene and Pleistocene siliceous sequences were recovered at Sites 299, 301, and 302 in the Sea of Japan (Figure 2). Marginal to good calcareous assemblages were found only in Pleistocene portions of these columns. Nannofossil floras and planktonic foraminiferal biofacies exhibited severely reduced diversity due to the subarctic and cool temperate late Neogene conditions prevailing in this area. Variations in both diatom and planktonic foraminiferal biofacies record significant oscillations of surface-water temperature during the Plio-Pleistocene period. In fact, the siliceous biota, in general, reflects the relatively cool surface temperatures of the entire Pliocene and Pleistocene period. This time span is represented at these sites with radiolarians, diatoms, and silicoflagellates, all correlative in part with other high-latitude late Neogene sequences recovered on DSDP Legs 18 and 19 in the marginal North Pacific.

Zonations of the low- to mid-latitude faunas and floras of the Philippine Sea sites follow zonations established by Blow (1969), Riedel and Sanfilippo (1971), Burkle (1972), and Bukry (1973a, 1973b) with only minor modifications (Figure 7). However, it is apparent that study of the excellent Oligocene sequences at Sites 292 and 296 will result in a better understanding of the evolution of key low-latitude zonal taxa within this period in all likelihood producing changes in zone boundaries and definitions. Not surprisingly, there are discrepancies in placement of the Miocene-Oligocene, late-early Oligocene, and Oligocene-Eocene boundaries among the various fossil groups studied at these key sites. Detailed studies should resolve these discrepancies, inasmuch as the sediment-time record for this epoch is complete with controversy centered on arbitrary definitions rather than on missing intervals.

Philippine Sea Area: Sites 290 to 298

Age, epoch, and subepoch boundaries presented on core summary logs are based almost exclusively on calcareous nannoplankton zonation for ease of definition (Figure 7, Table 2). It should be noted that there are discrepancies in placement of some of these boundaries between various fossil groups as specifically noted in the paleontologic summaries in each site summary chapter. Faunas recovered at these sites range in age from Pleistocene to late Eocene, with apparently reworked specimens of Paleocene and Cretaceous planktonic foraminifera at Sites 290, 293, 295, and 298. Several specimens of displaced larger foraminifera were recovered in bathyal sediments at Site 296.

Sea of Japan Area: Sites 299 to 302

Unexpected early termination of drilling at all sites in the Sea of Japan prevented penetration and recovery of biostratigraphically significant Miocene sediments; however, good Pleistocene and Pliocene siliceous sequences were recovered at Sites 299, 301, and 302. Diatom zonation provides the sole basis for ages presented on core summary logs at Sites 299 through 302 for ease of definition following a zonation developed by Koizumi, (1973a, 1973b). Some modification of the latter zonation (Figure 8) has been made involving upward adjustment of zonal and epoch boundaries due to revised correlations with the radiometric and paleomagnetic time scales as discussed by Koizumi (this volume). For example, the earliest Pliocene zones of this scheme encompass formations and faunas formerly included within the late Miocene as traditionally viewed by Japanese paleontologists working on Neogene sequences exposed in northern Honshu (Burkle, 1971; Ikebe et al., 1972; Koizumi, 1973a, this volume). Thus, there is a discrepancy in the placement of the Miocene-Pliocene boundary between diatom, radiolarian, and silicoflagellate zonations at these sites (Koizumi, this volume; Ling, this volume). The oldest faunas and floras are assigned to the earliest Pliocene on the basis of diatom zonation and to the latest Miocene of the basis of radiolarian and silicoflagellate zonations (Figure 8, Tables 2 and 3).

Low diversity calcareous nannofossil floras and planktonic foraminifera are essentially restricted to Quaternary horizons at Sites 299 through 302 due in large measure to the unusual bottom conditions created by climatic extremes in the Sea of Japan (Ingle, Chapter 36, this volume).

TABLE 2
Calcareous Nannofossil Datum Levels, Epoch Boundaries, and Subdivisions, Philippine Sea[a]

Epoch Boundary or Subdivision	Calcareous Nannofossil Datum
Pleistocene/Pliocene	top *Discoaster brouweri*
Late Pliocene/early Pliocene	top *Reticulofenestra pseudoumbilica* and *Sphenolithus abies*
Early Pliocene/late Miocene	top *Triquetrorhabdulus rugosus* and base *Ceratolithus acutus*
Late Miocene/mid Miocene	top *Discoaster hamatus*
Mid Miocene/early Miocene	top *Helicopontosphaera ampliaperta*
Early Miocene/late Oligocene	top *Cyclicargolithus abisectus*
Late Oligocene/early Oligocene	base *Sphenolithus distentus*
Early Oligocene/late Eocene	top *Discoaster barbadiensis* and *D. saipanensis*
Late Eocene/mid Eocene	top *Chiasmolithus grandis*

[a]Also used in Sea of Japan area where calcareous material is present. Boundaries follow Bukry (1973a).

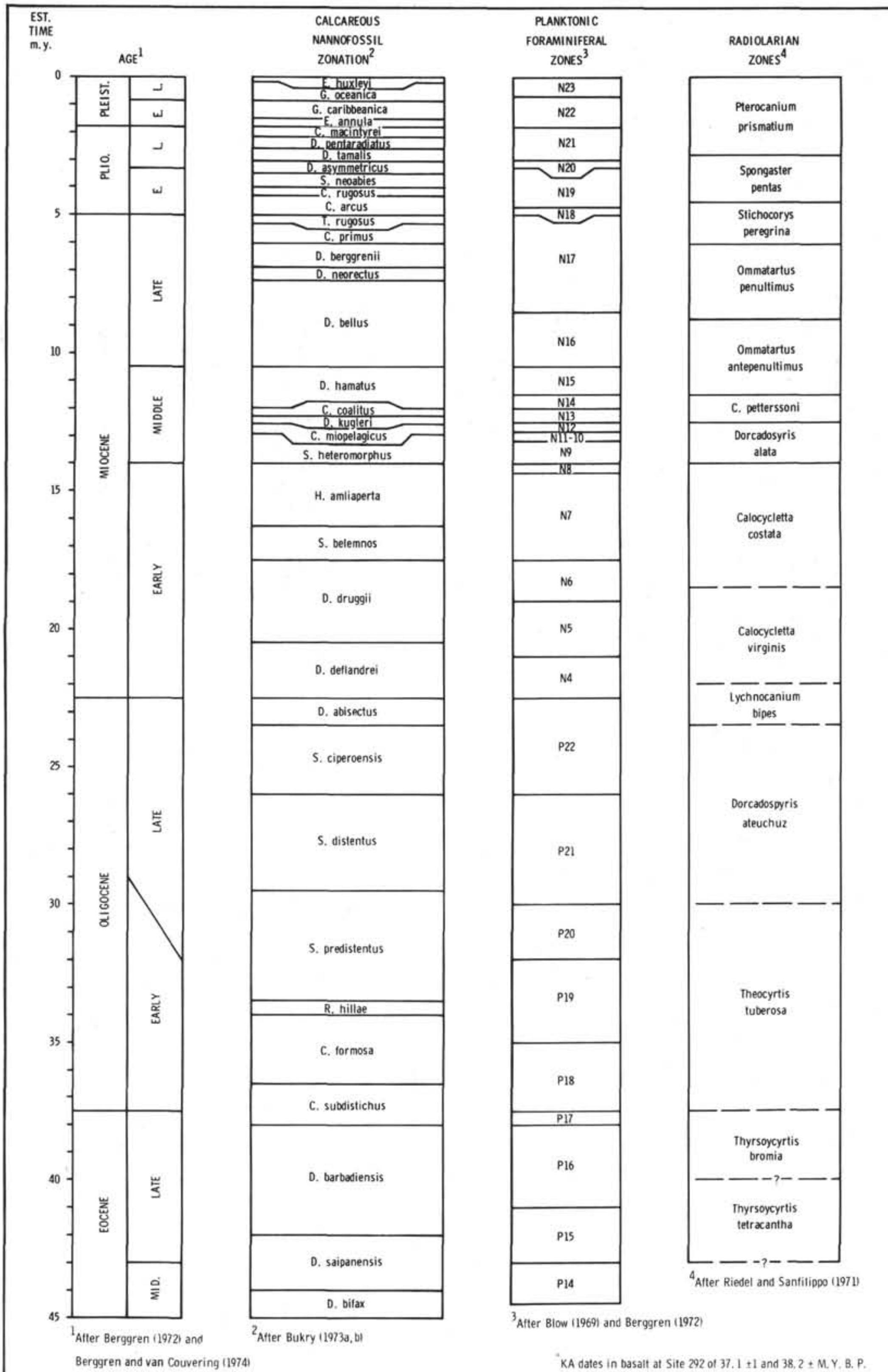

Figure 7. *Calcareous nannofossil, planktonic foraminiferal, and radiolarian zonations used at Sites 290 through 298 in the tropical-subtropical Philippine Sea area. Boundaries and definitions by Blow (1969), Riedel and Sanfilippo (1971), Berggren (1972), and Bukry (1973a, 1973b) with only minor modifications as detailed in reports in this volume by Ellis, Ling, and Ujiié. Zonation of Quaternary diatoms at Sites 296, 297, and 298 follows Burkle (1972). Alignment of the radiometric time scale, epoch boundaries, and various zones follows Berggren (1972) and Berggren and Van Couvering (1974). However, the latest information at press time (Theyer and Hammond, 1974) indicates that the boundary between the late and middle Miocene should be placed at 15 m.y.B.P. rather than at 14 m.y.B.P. as shown on this figure causing downward adjustment of middle Miocene zone boundaries relative to the radiometric time scale.*

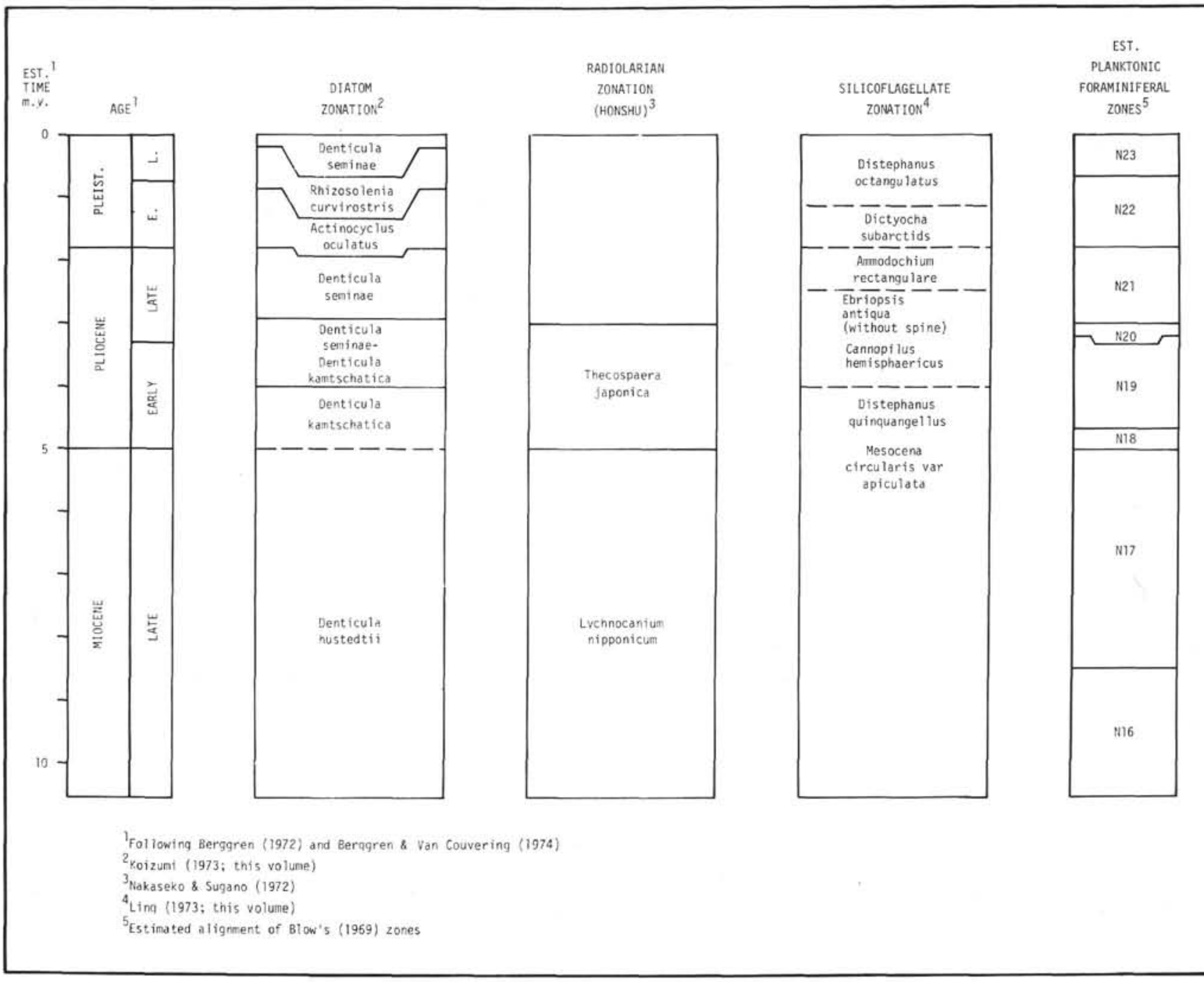

Figure 8. *Diatom and silicoflagellate zones utilized at Sites 299, 300, 301, and 302 in the Sea of Japan. Calcareous nannoplankton zones used at these sites are the same as given on Figure 7. Correlation of silicoflagellate zones with diatom zones is tentative and subject to revision. Radiolarian zones established in late Neogene strata of Honhsu by Nakaseko and Sugano (1972) are presented for reference and were only partially recognized at Leg 31 sites in the Sea of Japan. Absence of low-latitude species of planktonic foraminifera at Sea of Japan sites precluded recognition of zones established by Blow (1969); an estimated alignment of these zones is based on correlations with diatom zones by Koizumi (1973a, this volume) and correlations of high-latitude planktonic foraminifera by Ikebe et al; 1972 and Ingle (1973; Chapter 36, this volume).*

Notes on Saipan Radiolarian Assemblages

Eocene radiolarian assemblages from Saipan described by Riedel (1957) and also an undescribed occurrence of middle Tertiary radiolarians in a sample provided by the U.S. Geological Survey from Map Island in the Yap Group were reexamined. As a result of advances in our knowledge of radiolarian stratigraphy during the past few years, it is now possible to assign these sparse assemblages to zones with rather well-understood age relations.

The localities of the Eocene samples from Saipan are described by Cloud et al. (1956), and the radiolarians present in each sample are as follows:

S26, Densinyama Formation: *Periphaena decora* Ehrenberg [*Heliodiscus humboldti* (Ehrenberg) of Riedel, 1957]; *Calocyclas turris* Ehrenberg; *Thyrsocyrtis bromia* Ehrenberg; *Thyrsocyrtis rhizodon* Ehrenberg (*Podocyrtis* sp. aff. *P. argus* Ehrenberg of Riedel, 1957); *Thyrsocyrtis tetracantha* (Ehrenberg) and the *Theocampe armadillo* (Ehrenberg) group of Riedel and Sanfilippo, 1971. The assemblage belongs in the *Thyrsocyrtis bromia* Zone (late Eocene).

S346, Hagman Formation: *Lithocyclia aristotelis* (Ehrenberg) group of Riedel and Sanfilippo, 1970; *Calocyclas turris* Ehrenberg; *Thyrsocyrtis bromia* Ehrenberg; *Thyrsocyrtis rhizodon* Ehrenberg and *Theocampe mongolfieri* (Ehrenberg). The assemblage belongs in the *Thyrsocyrtis bromia* Zone (late Eocene).

S353 and S354, Hagman Formation: *Lithocyclia aristotelis* (Ehrenberg) group of Riedel and Sanfilippo,

TABLE 3
Diatom Datum Levels, Epoch Boundaries, and Subdivisions, Sea of Japan[a]

Epoch Boundary or Subdivision	Diatom Datum
Pleistocene/Pliocene	top *Thalassiosira antiqua*
Late/early Pliocene	top *Denticula kamtschatica*
Pliocene/Miocene	base *Denticula seminae*
Late/mid Miocene	top *Denticula lauta*

[a]Boundaries based on Koizumi (1973a, 1973b).

1970 (*Trigonactura* sp. of Riedel, 1957); *Calocyclas hispida* (Ehrenberg); *Calocyclas turris* Ehrenberg; *Lychnocanoma bellum* (Clark and Campbell) (*Lychnocanium* sp. of Riedel, 1957); *Thyrsocyrtis rhizodon* Ehrenberg (*Podocyrtis* sp. aff. *P. argus* Ehrenberg of Riedel, 1957); and *Theocampe mongolfieri* (Ehrenberg). The assemblage belongs in the *Thyrsocyrtis bromia* Zone (late Eocene).

S463 was not readily available for reexamination.

We have examined also USGS samples YM-22, YM-24, and YT-76 from the Map Formation, Yap Group, and identifiable radiolarians were found only in YM-24. Forms recognized are *Calocycletta costata* (Riedel) and *Stichocorys delmontensis* (Campbell and Clark), and thus the assemblage appears to represent the *Calocycletta costata* Zone or the *Dorcadospyris alata* Zone (early to middle Miocene). Details of the locality of this sample are given on the geologic map in Johnson et al. (1960).

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