1. INTRODUCTION AND EXPLANATORY NOTES, LEG 38, DEEP SEA DRILLING PROJECT

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SCIENTIFIC GOALS AND RESULTS

Because of its position between the North Atlantic and the Arctic oceans, its young age, small size, and diversity of geological structures, the Norwegian-Greenland Sea provided a unique target for deep drilling on Leg 38 of the *Glomar Challenger* (Figure 1). From studies of the sediments and basement rocks it was expected to gain insight particularly as to the following:

1) The tectonic framework and evolution of this area with special emphasis on the continental margins and on questions concerned with shifts of spreading axis and existence of foundered continental areas.

2) The youngest times of existence of land bridges between Eurasia and North America and the effect these land bridges had on water circulation and paleoclimates.

3) The date of the initiation of glaciation and dates of glacial advances and retreats.

4) Description of the Tertiary marine microfauna and microflora of the Norwegian-Greenland Sea, which are essentially unknown at present, and investigation of their similarity with microfauna and microflora from other areas.

Results from Specific Provinces

The Vøring Plateau

The Vøring Plateau is a prominent feature of the Norwegian continental margin. It has a nearly flat surface at a depth of about 1200 meters, and is divided by the Vøring Plateau Escarpment into an inner and an outer part (Figure 1). The outer part is underlain by a prominent shallow acoustic reflector and possesses linear magnetic anomalies. The inner part is apparently underlain by a succession of sediments several kilometers thick and lies in a magnetic "quiet zone." Talwani and Eldholm (1972) have suggested that (1) the shallow reflector under the Outer Vøring Plateau represents igneous oceanic basement formed immediately after the opening of the Norwegian Sea, (2) the Vøring Plateau Escarpment forms the "ocean-continent" boundary, and (3) the thick sedimentary column of the Inner Vøring Plateau includes Mesozoic or earlier sedimentary accumulations.

The objective at the Vøring Plateau sites was to test these hypotheses and to collect samples of the prominent acoustic reflector, which could represent igneous rocks formed just after the opening of the Norwegian Sea. The latter would be of general interest, since in most oceans the basement created shortly after opening is buried under a thick sediment cover and is unreachable by drilling. In addition, these holes in relatively shallow water represented the best chance to obtain calcareous fossils, and in the holes landward of the escarpment, possibly to obtain Mesozoic samples.

Three sites were drilled seaward of the Vøring Plateau Escarpment. Sites 338 and 342 were drilled on the Outer Vøring Plateau and Site 343 was drilled at the foot of the Vøring Plateau in the Lofoten Basin (Figure 1, Table 1). Basalt, in general quite altered, was recovered at all three sites. Preliminary analysis suggests that the basalt is alkalic at Sites 342 and 338 (See Kharin, this volume). K/Ar dates for the basalts at both holes ranged from 44 to 46 m.y. (middle Eocene). The most nearly complete sedimentary section (early Eocene to Holocene) was obtained at Site 338. The section contains terrigenous Eocene sediments, dominantly pelagic Oligocene and Miocene sediments, and Plio-Pleistocene terrigenous sediments.

Three sites were drilled on the Inner Vøring Plateau; Sites 339 and 340 were on diapiric structures, and the cores confirmed earlier findings that the diapiric material consisted of Eocene diatomaceous oozes. Site 341 was drilled in an area of flat-lying beds, and the objective was to obtain a Tertiary biostratigraphy of the Norwegian continental margin. The hole was drilled through a "glacial" section (Pleistocene and possibly Pliocene age), nearly five times as thick as that present at Site 338. This section consisted largely of shallow-water sediments that were apparently ponded by the Vøring Plateau Escarpment. Below the "glacial" section lie middle Miocene diatomaceous oozes and diatomites, the total thickness of which is unknown. The middle Miocene section is several times thicker than the corresponding section seaward of the escarpment.

Sediments on the landward side of the Vøring Plateau Escarpment are remarkable for another reason. At Site 341, small pockets of gas formed in virtually every core recovered below a depth of 50 meters. All but one sample contained methane, and nearly all gas samples from the Miocene contained traces of ethane. The methane content increased rapidly below 183 meters in the Pleistocene, and decreased below 343 meters in the Miocene. Miocene sediments near the bottom of the hole had a strong petroliferous odor and produced a bright yellow fluorescence. Morris, (this volume) discusses the results of analyses of the soluble

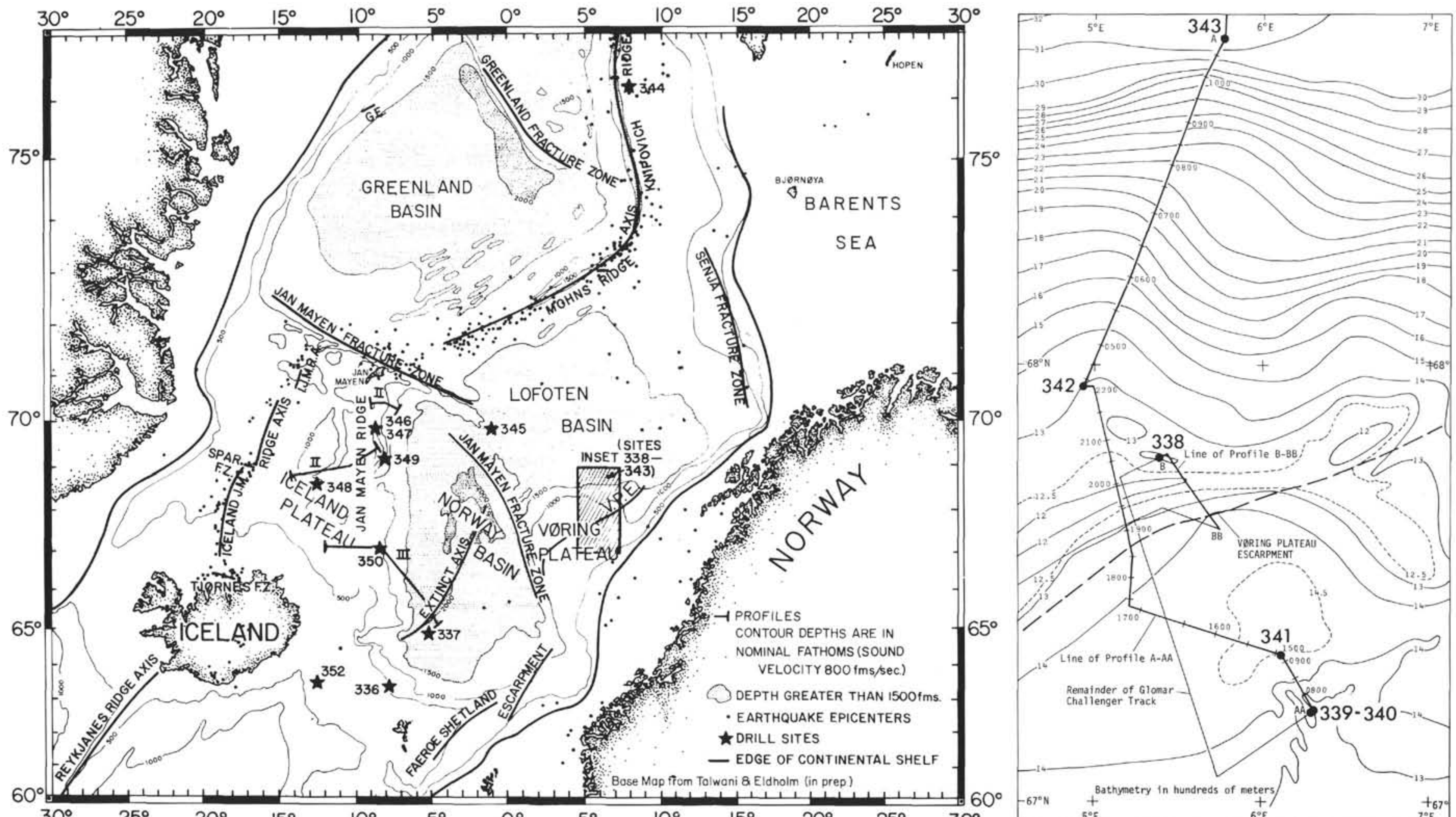


Figure 1. *Location of Leg 38 drilling sites, and bathymetry and structure of the Norwegian-Greenland Sea. (Note: Site 351 was occupied but was not drilled. Its location has not been shown on this map. See Table 1 for details.) The inset map shows the track of* Glomar Challenger *between Sites 338 and 343 on the Vøring Plateau Escarpment, and corrected bathymetry of the area, in hundreds of meters, constructed principally from records taken by* R.V. Vema *of Lamont-Doherty Geological Observatory, supplemented by* Glomar Challenger *data.*

hydrocarbons, and their origin. Coring at Site 341 was suspended at 456 meters, and the hole was cemented.

Norway Basin

Sea-floor spreading at Mohns Ridge and at Reykjanes Ridge appears to have taken place in more or less steady fashion with development of typical symmetrical ridges. However, the sea floor has developed quite differently in the area between the Jan Mayen Fracture Zone and the Faeroe-Iceland Ridge. It is clear that sea-floor spreading is now going on at the Iceland-Jan Mayen Ridge, which lies asymmetrically close to Greenland. It is also generally accepted that spreading occurred in the past in the Norway Basin. Part of the drilling program was designed to find when spreading stopped in the Norway Basin, and in what steps the spreading axis shifted to the Iceland-Jan Mayen Ridge.

Geophysical surveys had located a structural valley in the Norway Basin that coincides with the symmetry axis of a well-developed linear magnetic anomaly pattern and was judged to be the old spreading axis (Talwani and Eldholm, 1972). To avoid drilling into a very large sediment thickness, Site 337 was drilled on top of the rift mountains east of the valley (Figure 1). From a total of 113 meters of sediment recovered, 47 meters of Pliocene and Pleistocene is of "glacial" origin and the remainder is older (early or middle Oligocene). The latter sediments are almost entirely pelagic muds and clays. Basalt was recovered from 113 to 132.5 meters and yielded K/Ar dates of 18-24 m.y. (late Oligocene to early Miocene). Allowing for the fact that the site lies some distance east of the axis, a tentative date of middle Oligocene is obtained for the cessation of sea-floor spreading in the Norway Basin.

Jan Mayen Ridge

Because of the absence of magnetic anomalies and the presence of dipping sedimentary layers, it has been suggested that the Jan Mayen Ridge was once attached to Greenland, but has been separated from it by a second stage of spreading. Relatively flat-lying beds are at the top, especially on the west side of the ridge; they lie over what are apparently truncated eastward dipping older beds. Sediments with a velocity about 2 km/sec (refraction data) immediately underlie the unconformity. A much deeper layer, with a velocity greater than 5 km/sec, probably represents igneous basement. Because of the steep eastward dips, it was hoped that igneous basement might be reached by coring as close to the western ridge as possible.

Three sites (346, 347, and 349) reached an unconformity at the base of the horizontal layers at 101, 121, and 91 meters, respectively. The oldest beds below the unconformity were late Eocene or Oligocene. At one site (349), a basalt conglomerate layer was present above the unconformity.

There are indications that of the three sites, the easternmost (349) may have the youngest sediments immediately below the unconformity (as beds dipping to the east would require). It was quite difficult to penetrate the sediments below the unconformity, which were predominantly massive sandy mudstones. Igneous basement was not reached in any of the holes, and it was concluded that even at the edge of the ridge it was out of reach. Apparently the west flank of the ridge is, at least at the top, not igneous basement but a massive sandy mudstone. Cores from this rock yielded a velocity of slightly higher than 2 km/sec, which agrees with the refraction results.

Below the Eocene sediments that were cored, seismic refraction data show a large thickness of sediments with high velocities normally associated with sediments of predrift age. Although basement was not reached, it is believed that, because of the presence of these sediments, this ridge is continental rather than oceanic.

The nature of sediments and the unconformity at the Jan Mayen Ridge sites are of great interest: the sediments below the unconformity are almost completely terrigenous in origin, containing appreciable amounts of coarse sands. Only arenaceous foraminifera appear to have been preserved in the sediments. Above the unconformity the biogenic component increases markedly in the sediments and the Miocene sediments from Sites 346 and 347 contain large amounts of sponge spicules. As the beds immediately above the unconformity appear to postdate the cessation of spreading in the Norway Basin (middle Oligocene), it seems reasonable to suggest that earlier the Jan Mayen Ridge was attached to Greenland and perhaps formed its continental shelf and slope, and thus received terrigenous sediments directly from Greenland. The unconformity probably marks the time of separation of the Jan Mayen Ridge from Greenland and the consequent change in the sedimentary regime.

Icelandic Plateau

Site 348 is in a part of the Icelandic Plateau that lies between the Iceland-Jan Mayen Ridge (where the spreading pattern has been established on the basis of magnetic anomalies) and the Jan Mayen Ridge with its associated magnetic quiet zone (Figure 1, Table 1). Magnetic measurements show well-developed linear magnetic anomalies. Preliminary interpretation suggests that they are symmetrical about an axis, and might range in age from between the age of anomaly 6 and 5 to the age of anomaly 7 (i.e., about 15-28 m.y.).

The basement at Site 348 consists of tholeiitic basalt (See Kharin, this volume) with K/Ar dates of 18-19 m.y. (early Miocene).Although the ages are different, the sedimentation pattern at this site resembles that on the Jan Mayen Ridge. The basal sediments are dominantly terrigenous, being almost pebbly at some horizons. The age at the base of the cored section is Oligocene (which is within the range tentatively indicated by the magnetic anomalies for the range of basement age). It is interesting that three related events yield ages within a narrow range around middle to late Oligocene. These events are (1) cessation of spreading in the Norway Basin, (2) deposition of the oldest beds underlying the unconformity on the Jan Mayen Ridge, and (3) initiation of spreading west of the Jan Mayen Ridge.

At Site 348, the sediments change upwards from a distinct boundary to sediments with a larger biogenic component (dominantly siliceous oozes) of middle and late Miocene age similar to sediments from Sites 346,

TABLE 1
Leg 38 Coring Summary

Hole	Dates (1974)	Latitude	Longitude	Water Depth[a]	Penetration	No. of Cores	Cored (m)	Recovered (m)	Recovery (%)
336	6-9 Aug.	63°21.06'N	07°47.27'W	811.0	515.0	44	396.5	220.9	55.7
337	10-12 Aug.	64°52.30'N	05°20.51'W	2631.0	132.5	15	132.5	99.5	75.0
338	13-16 Aug.	67°47.11'N	05°23.26'E	1297.0	437.0	45	427.5	208.7	48.8
339	16-17 Aug.	67°12.65'N	06°17.05'E	1262.0	108.0	12	108.0	50.5	46.7
340	17-18 Aug.	67°12.47'N	06°18.38'E	1217.0	104.5	11	104.5	67.2	64.3
341	18-20 Aug.	67°20.10'N	06°06.64'E	1439.0	456.0	34	313.5	213.0	67.9
342	20-22 Aug.	67°57.04'N	04°56.02'E	1303.0	170.5	8	75.5	48.0	63.6
343	22-24 Aug.	68°42.91'N	05°45.73'E	3131.0	284.0	16	132.0	59.3	44.9
344	26-30 Aug.	76°08.98'N	07°52.52'E	2156.0	414.0	37	338.0	140.7	41.0
345	1-5 Sept.	69°50.23'N	01°14.26'W	3195.0	802.0	36	336.5	189.5	56.3
346	6-7 Sept.	69°53.35'N	08°41.14'W	732.0	187.0	20	187.0	120.4	64.4
347	7-8 Sept.	69°52.31'N	08°41.80'W	745.0	190.0	4	24.0	12.15	50.6
348	9-12 Sept.	68°30.18'N	12°27.72'W	1763.0	544.0	34	316.0	215.1	68.0
349	13-14 Sept.	69°12.41'N	08°05.80'W	915.0	319.5	13	120.0	81.2	67.7
350	15-16 Sept.	67°03.34'N	08°17.68'W	1275.0	388.0	16	150.5	49.5	32.9
351	17 Sept.	67°47.34'N	11°18.26'W	← Not Drilled →					
352	19 Sept.	63°38.97'N	12°28.26'W	990.0	103.5	6	46.0	27.6	60.0
352A	20 Sept.	63°38.97'N	12°28.26'W	990.0	122.5	3	28.5	5.1	17.2
Totals					5278.0	354	3236.5	1808.4	55.9

[a]PDR depth in meters.

347, and 349. This suggests that the dominantly terrigenous Oligocene sediments were obtained from the coast of Greenland. A shift of ridge axis near the middle Miocene resulted in creation of the new Iceland-Jan Mayen Ridge to the west of the older spreading ridge on the Icelandic Plateau. This changed the sedimentary regime, and terrigenous sediments were no longer dominant.

In summary, the ages of the oldest sediments recovered, and the change in the nature of sediments recovered at the various holes, support a shift of the ridge axis from the Norway Basin in two stages. The first, in middle to late Oligocene, separated the Jan Mayen Ridge from Greenland; and the second, in middle to late Miocene, shifted the spreading axis from the Icelandic Plateau to the presently active Iceland-Jan Mayen Ridge.

Iceland-Faeroe Ridge

Sites 336 and 352 are on the northern and southern flanks of the Iceland-Faeroe Ridge (Figure 1). By studying and comparing the sediments from these holes, it was expected to learn the time of submergence of this ridge.

At Site 336, about 159 meters of Plio-Pleistocene "glacial" sediments have been deposited on top of Tertiary sediments (late Oligocene to middle or late Eocene), which in turn lie on basaltic basement. The basaltic basement is covered by rubble probably derived from the basalt by subaerial erosion. K/Ar dates of 40-43 m.y. (late Eocene) were obtained from the basalt. The microfauna from the overlying marine Eocene sediments suggests a history of submergence at this site and by extrapolation, for the entire Iceland-Faeroe Ridge.

Before submergence of the Iceland-Faeroe Ridge, the northern flank of the ridge had no direct connection with the North Atlantic. This is substantiated by the findings at Site 352 on the southern flank of the ridge. Here, "glacial" sediments directly overlie middle Oligocene sediments, but—unlike north of the ridge—the microfauna and the microflora are rich and typically North Atlantic. Also, the nature of the sediments is quite different, supporting the conclusion that the northern flank of the ridge had no connection with the North Atlantic up to this time. Just when a permanent connection was established will emerge from detailed studies.

LEG 38 OPERATIONAL SUMMARY

Leg 38 of the Deep Sea Drilling Project started on 29 July, 1974 at Dublin, Ireland, and ended 58 days later at Amsterdam, The Netherlands, on 26 September 1974. *Glomar Challenger* traveled 4285.8 nmi and drilled a total of 17 holes at 17 sites in the Norwegian-Greenland Sea (Figure 1, Table 1). Water depths averaged 1541 meters and varied between 732 and 3131 meters. For the 17 holes drilled, two were abandoned earlier than anticipated: one due to increasing shows of hydrocarbons (Site 341) and two due to deteriorating hole conditions and weather (Holes 352, 352A). Site 351 was abandoned before drilling was attempted.

The distribution of the 58 days total leg time was 54.5% site time, 38.4% cruise time, and 7.1% port time. Total site time of 31.9 days was divided into 21.7% coring, 5.4% drilling, 17.7% trip, and 55.2% other. A total of 5278 meters of sediments and rocks was penetrated, of which 61.3% was cored. Usable recovery was obtained on 99.4% of the 354 cores attempted, and total recovery was 56% (Table 1).

The weather was generally favorable for the operations during the majority of the leg, however, there were occasions when conditions adversely affected operations. In particular, virtually continuous storm conditions seriously curtailed activities at the last two sites (Sites 351 and 352). Also, while underway to

Site 344, a storm forced a temporary course change. Good, meaningful, and accurate meteorological information was available from a number of different sources and generally adequate forecasting was received with good onboard interpretation and local prediction.

Locating and locking onto the beacon in the automatic position-keeping mode was usually proficiently achieved and affected only by the prevailing weather conditions. These conditions at Site 352 accounted for 5-3/4 hr before finally locking onto the beacon. Confused and strong current, swell, and wind absorbed almost the total positioning power available.

Overall station keeping was vigilantly maintained and was excellent. This was true in particular when adverse weather demanded corrective power approaching the maximum available. Only three off-hole excursions developed where string rotation was prohibited. Once, it became necessary to start withdrawing the string towards sea bed. In most instances, the off-hole translation criteria curtailing operations was enforced because of the relatively shallow water conditions, in particular, at Sites 336, 346, 347, 349, and 352.

A part of the operations program was a field evaluation of the Lynes Retrievable Formation Tester (RFT) for downhole durability, and in both operating modes as a safety tool and formation tester. Five specific evaluation tests, absorbing one-half day direct operating time, were conducted.

Two passive tests, at Sites 338 and 341, were made to provide data on the abrasion resistance and wear rate of the packer element when reciprocated and rotated in both sedimentary and basaltic formations. Two active evaluation tests, Sites 342 and 348, provided operating data and experience of the formation testing function and confirmed the satisfactory performance, potential value and acceptability of the tool in this role. An active test in the safety tool mode at Site 345 was frustrated by an inadequate packer seat and the risk of massive hydraulic fracturing and stuck pipe. The secondary function of the circulation valve system proved to be completely dependable and satisfactory.

Site 351 Operations Summary

Site 351, located at 67°47.34'N lat, 11°18.26'W long was occupied for 5.5 hr on 17 September 1974. However, continuing and deteriorating weather conditions prevented the hole from being drilled. The PDR depth of the beacon was 1844 meters. Following, is the operations summary for Site 351.

Site 351 was approached from the southeast on course 313° at normal speed (10 knots, 210 rpm) on 17 September 1974 after steaming 83 n mi including surveying, in 10 hr, 25 min, at an average speed of 7.9 knots from Site 350. At 0338Z, 17 September, the course was corrected to 324° and at 0630Z to 314°. At 0712Z, the speed was reduced to 9 knots (185 rpm). Position was fixed in conjunction with profile selection and the beacon dropped at 1022 hr. Weather deteriorated during the journey, and the fringe effects of a storm developed a strong swell which was forecast to continue. The ship continued on the same course and speed until she maneuvered to return to the site of the beacon drop.

A long compact bit was made up to exploit the additional BHA weight available. A delay of 3 1/2 hr occurred after commencing to run the BHA due to failure of the stabber system. From 1500 hr, a delay of 5 hr, 35 min accumulated waiting on weather which continued to deteriorate. At 2035 hr it was decided to abandon the site and steam to Site 352.

EXPLANATORY NOTES

Responsibilities for Authorship

The authorship of site report chapters is collectively the shipboard party, with ultimate responsibility lying with the two chief scientists. Chapters 2 through 9 present data and discussions on the holes drilled. However, the presentation of the Site Reports does not necessarily follow the format established in previous DSDP volumes. Three site report chapters consider a number of sites associated with a specific physiographic province. These chapters are: Chapter 2 (Sites 336 and 352, 352A, Iceland-Faeroe Ridge); Chapter 4 (Sites 338 to 343, Vøring Plateau); and Chapter 7 (Sites 346, 347, and 349, Jan Mayen Ridge). The remaining sites (337, 344, 345, 348, and 350) are discussed in individual chapters. All site report chapters, however, follow the same general outline (below) with the authorship listed in parentheses.

Site Data
Background and Objectives (Talwani and Udintsev)
  Geological Setting
  Objectives
Operations (Talwani and Udintsev)
  Presite Surveys
  Drilling Operations
  Postsite Surveys
Lithology (Nilsen, Warnke, White, Caston)
  Lithologic Units (descriptions of)
  Igneous Petrography (where applicable) (Kharin)
Basalt Geochemistry (Raschka and Eckhardt)
Physical Properties (Faas)
  Density, Water Content
  Sonic Velocity
  Shear Strength (where applicable)
Inorganic Geochemistry
Organic Geochemistry (Morris)
Biostratigraphy (Müller, van Hinte, Bjørklund, Schrader, and Manum)
  Biostratigraphic Summary
  Foraminifera
  Calcareous Nannofossils
  Diatoms
  Radiolaria
  Silicoflagellates
  Palynology
  Sedimentation Rates (where applicable)
Summary and Interpretations (Talwani and Udintsev)
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 10-32) and the Synthesis chapters (Part IV, Chapters 33-34) is cited in the text.

Special note is mentioned for two groups of chapters in Part III (shore-based studies). Chapters 10 through 14 deal with the petrography and geochemistry of the igneous rocks by various authors. Chapter 15, which follows this chapter group attempts to provide a comprehensive overview of the results. A second group of chapters are Chapters 18 through 24 which present studies of organic geochemistry by members of the JOIDES Organic Geochemistry Panel. Chapter 18, preceding this group, also provides an overview and summary of the results.

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.

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 parameters of bit weight and rpms are recorded on the drilling recorder and influence the rate of penetration.

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: cutting, retrieval (with accompanying changes in pressure and temperature), and 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 352) was given the number of the site (for example, Hole 352), a second hole drilled by withdrawing from the first hole and redrilling was labeled "A" hole (Hole 352A).

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 2). 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 38. The label "38-336 3-2, 25 cm" thus refers to Leg 38, Hole 336, Core 3, Section 2, sampled 25 cm from the top of that section. The label "38-336-3, 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.

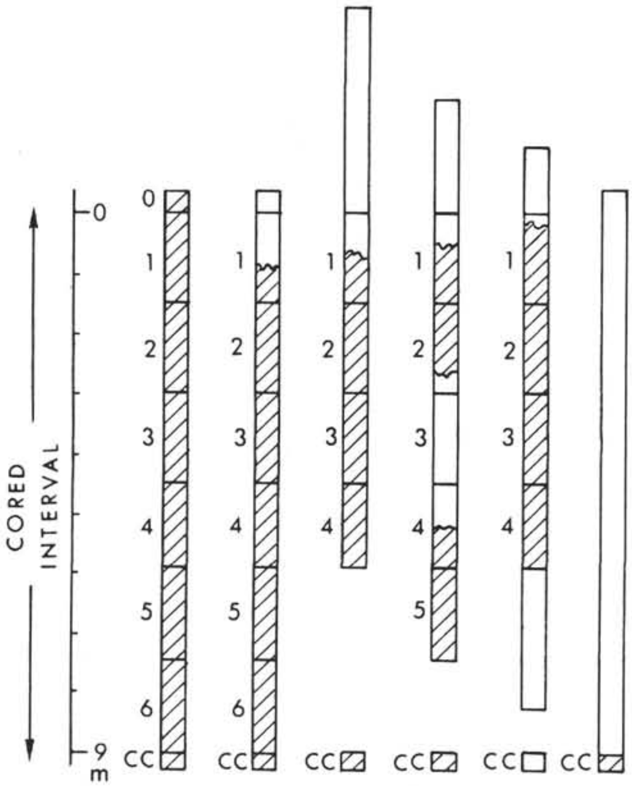


Figure 2. *Method of labeling sections of cores when recovery is complete, incomplete, and divided. The cores have been lined up so that the top of Section 1 is always coincident with the top of the cored interval, according to the method of calculating downhole depth of samples. Core-catcher samples are always considered to have come from the bottom of the cored interval regardless of the depth assigned to the adjacent section above.*

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.

Core Handling

The first assessment of the core material was made on samples from the core catcher. An age by paleontology enabled 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, and the core split into halves by a wire cutter, if the sediment was a soft ooze. If compacted or partially lithified sediments were included, the core was 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 carbon, organic carbon, and 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 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, 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 East Coast Repository at Lamont-Doherty Geological Observatory and are available to investigators.

Procedures Used in the Measurement of Physical-Chemical Properties 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); and (c) by continuous measurement along the length of the core section with the GRAPE using as standards, water (1.024 g/cc) and aluminum (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 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. The accuracy is about ±2%. The values (km/sec) are plotted on forms 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 at 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 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 for each core section.

6) Heat flow: Heat-flow measurements were made in situ in the sediment section at Sites 338 and 341. The upward heat-flow measurements were computed from the temperature of the sediment 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.

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 lithologic 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. Discussions of vane shear studies will be found in the Site Report chapters.

Geochemical Measurements

Aboard ship, analyses for pH, alkalinity, and salinity are conducted routinely.

1) pH: pH is determined by two different methods. One is a flow-through electrode method, the other is a punch-in electrode method. pH 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" pH is also determined by inserting pH electrodes directly into the sediment at ambient temperature prior to squeezing. The pH electrodes for both methods are plugged into an Orion digital millivolt meter.

2) Alkalinity: Alkalinity is measured by a colorimetric titration of a 1-ml aliquot of interstitial water with 0.1N 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 refractive index as measured by a Goldberg optical refractometer, using the ratio:

$$\text{Salinity } (^0/_{00}) = (0.55) \cdot \triangle N$$

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

Sedimentologic Analyses

1) Carbon-carbonate: The (DSDP) carbon-carbonate data were determined by a LECO induction furnace combined 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 DSDP Volume 9.

Also included on the core forms for Leg 38 are carbon-carbonate data received from Phillips Petroleum Company. For these samples the weight percent of organic carbon and carbonate carbon are presented.

2) Grain size: Grain-size distribution was determined by standard sieving and pipette analysis. Step-by-step procedures are in DSDP 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 DSDP Volume 9.

3) X-ray: Semiquantitative determinations of the mineral composition are tabulated on the core forms (this volume) as reported by laboratories of Phillips and British Petroleum companies.

Lithologic Nomenclature, Classification, and Symbols

Stratigraphic Terminology

Many different lithologies were encountered on Leg 38. 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 or in an accompanying figure. 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 sediment classification used was devised by the JOIDES Panel on Sedimentary Petrology and Physical Properties and adopted for use by the JOIDES Planning Committee in March 1974 (Figures 3 and 4).

Accompanying the introduction of the sediment classification to the DSDP volumes is the employment of a set of lithologic symbols. The basic sediment symbols employed are shown in Figure 3.

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. It will be noted that these symbols encompass both compositional and textural aspects of the sediments. Other symbols are employed to designate sedimentary structures (Figure 5).

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 derived are usually not too precise. In this sense, the numerical values serve more as an approximation of relative consitutent 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 have a high degree of precision; (c) The remaining portion of the column contains the results of shore-based laboratory studies on grain-size, X-ray, and carbon carbonate; (d) In the "Fossil Character" columns of the core forms, letters are used to designate

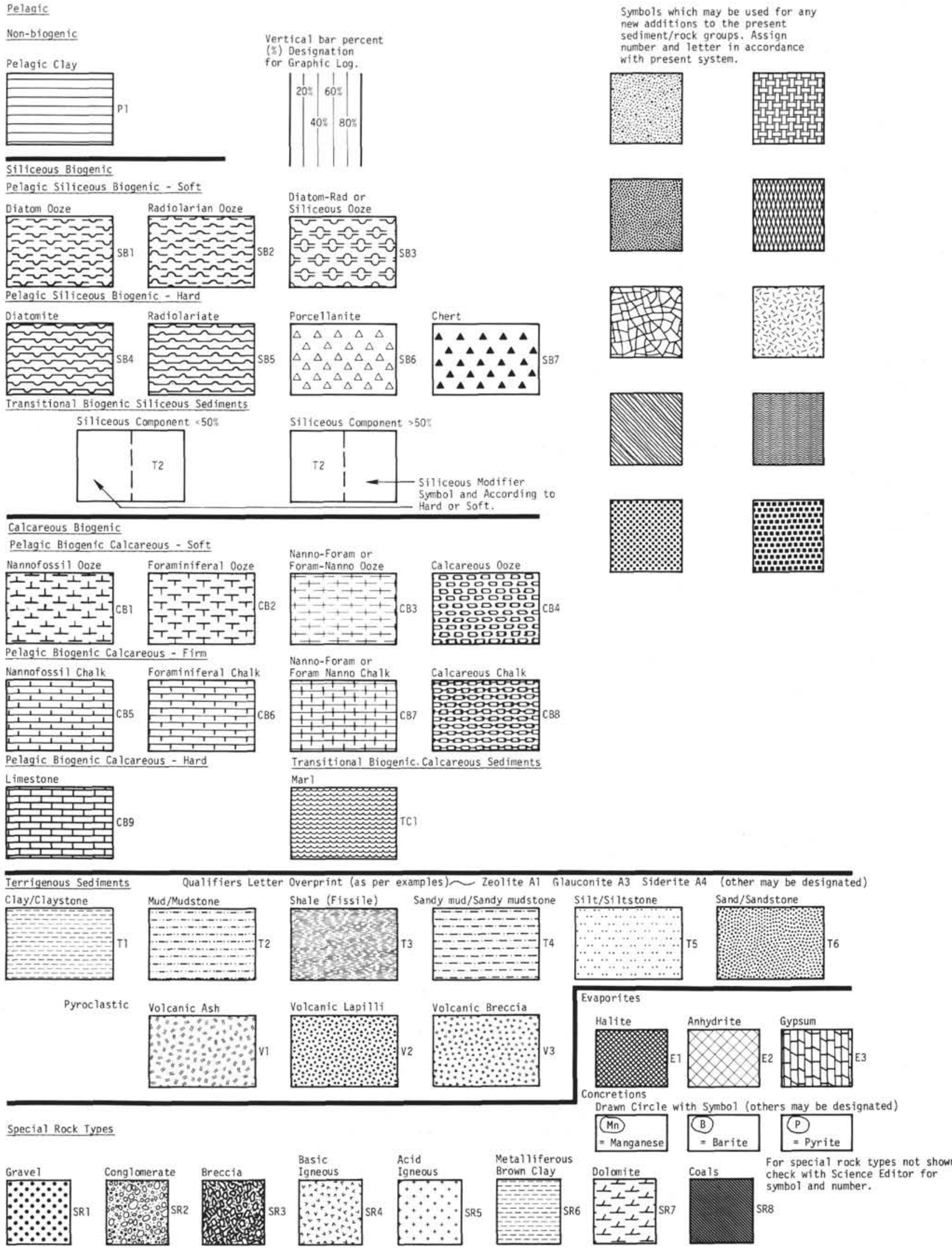


Figure 3. *Graphic symbols to accompany the lithologic classification scheme.*

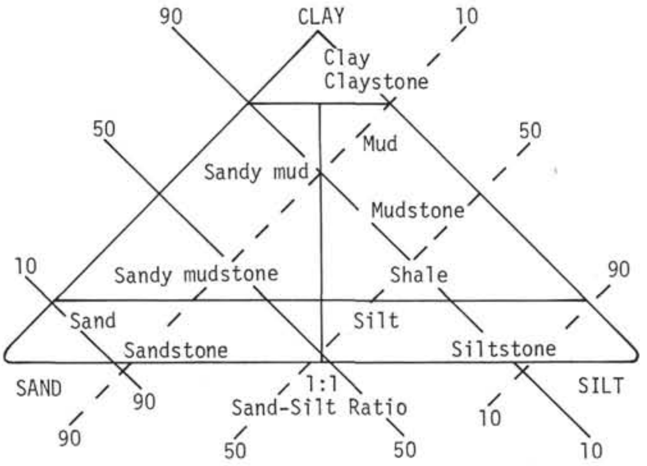


Figure 4. *Textural groups – terrigenous sediments.*

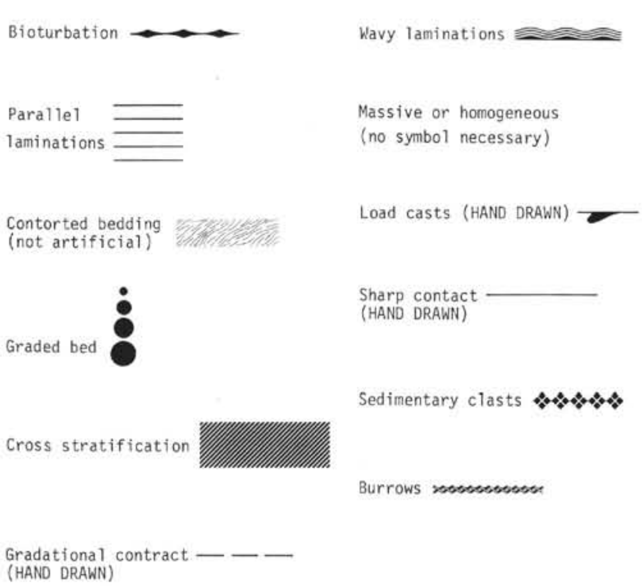


Figure 5. *Sedimentary structure symbols.*

the abundance and preservation of the respective fossils. Their position indicates the sample location. Letters used to indicate fossil abundance are as follows:

A = Abundant (flood, many species and specimens);
B = Barren
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 or e = excellent (no dissolution or abrasion);
G or g = good (very little dissolution or abrasion);
F or f = fair (dissolution and/or abrasion and/or recrystallization very noticeable); and
P or p = poor (substantial or very strong evidence of dissolution and/or abrasion, and/or recrystallization).

In the "Zone" column, foraminifera, nannoplankton, silicoflagellate and diatom or radiolarian zones are written; (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 38 sites as a function of the wide spectrum of water depths encountered and latitudinal breadth of the drilling sites spanning 63° to 76°N in the Norwegian-Greenland Sea (Figure 1; Table 1). Leg 38 had major biostratigraphic goals, including recovery of reference sections deposited beneath sub-Arctic waters.

The time scale of Berggren (1972a) and Berggren and van Couvering (1974, p. 170) was used as a basis for age determination. However, apart from the calcareous nannofossils and the silicoflagellates, "standard" zonal schemes could not be applied in this high-latitude region and empirical local zonations were established for the different groups of fossils. The zonal scheme is given in Table 2 and discussed below.

Radiolarians (K.B.)

During Leg 38 the Norwegian Sea Cenozoic sediments were cored from the Arctic region for the first time in history. As similar material never has been available, it was now possible to do a detailed study on Cenozoic radiolarian stratigraphy and paleoecology. Due to time limitations, the major emphasis was to establish a northern high-latitude radiolarian biostratigraphy.

The radiolarian assemblages recovered during this leg have very few species in common with holes drilled further south in the Atlantic Ocean. As no key fossils could be found in sufficient numbers upon which the lower latitude Atlantic and Pacific oceans are based, it was necessary to develop a local Arctic radiolarian stratigraphy. No absolute or good age determination of the sediment was possible by using radiolarians. Therefore, the radiolarian stratigraphy obtained had to be correlated to a time scale by correlation through the diatoms (Recent-middle Miocene) and silicoflagellates (late Miocene-Eocene),as reported elsewhere in this volume by Schrader and Martini and Müller, respectively. Further discussion of the radiolarian zonation will be found in Bjørklund (Chapter 31, this volume).

Site 338 turned out to be the most important for the establishment of the radiolarian stratigraphy, as this site yielded radiolarian-bearing sediments ranging from late Miocene to late (?) Eocene. From this site 10 radiolarian zones were recognized.

Calocyclas talwanii Zone (29, CC to 27-3, 76-78 cm), late Eocene.

Lophocorys norvegiensis Zone (27-3, 76-78 cm to 25, CC), late Eocene

Phorticium sp. A Zone (24-3, 62-64 cm to 21, CC), Oligocene

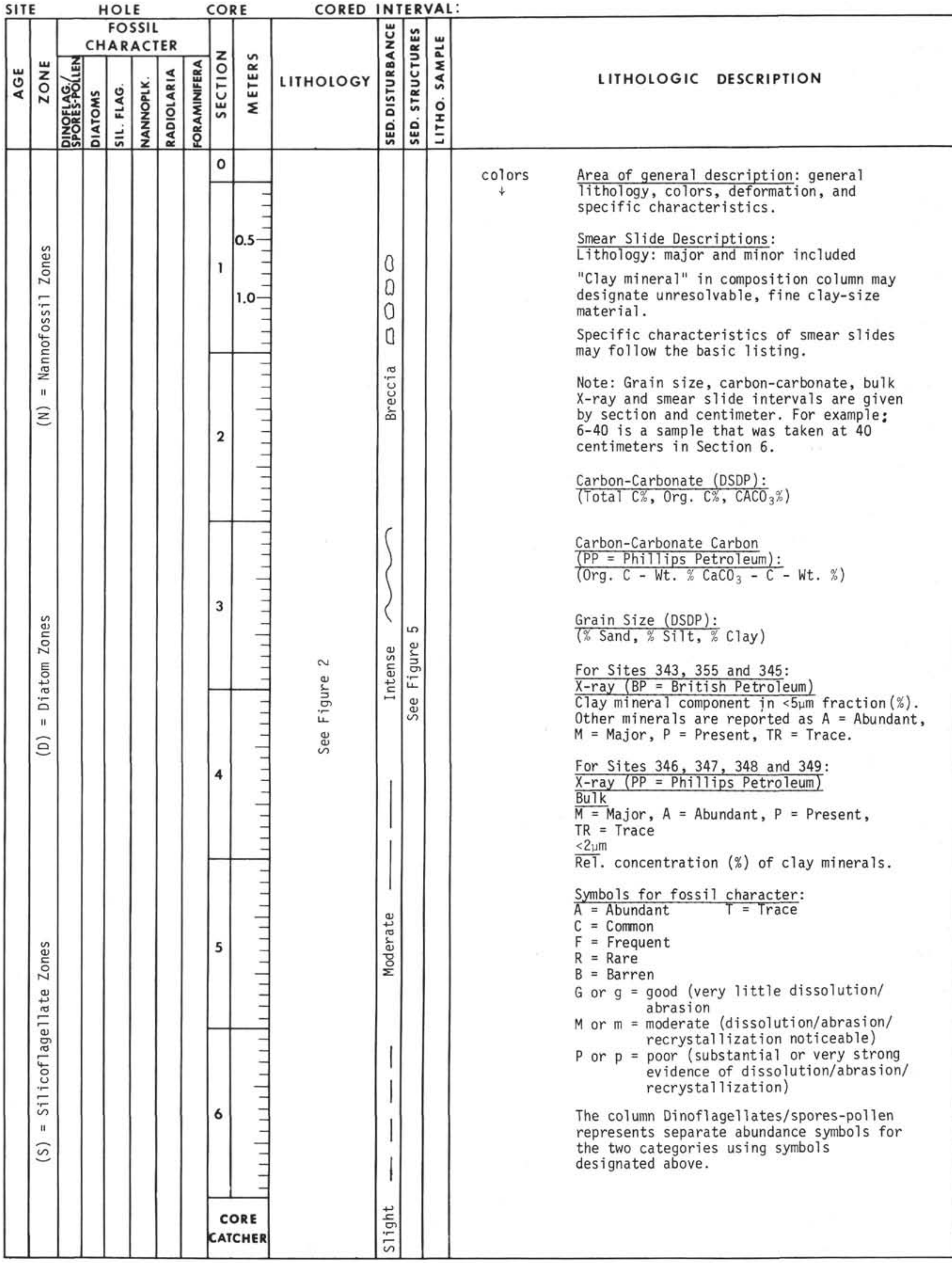


Figure 6. *Sample core form and legends.*

Velicucullus oddgurneri Zone (19-3, 80-82 cm to 18, CC), Oligocene

Gondwanaria japonica Zone (18, CC to 13, CC), early Miocene

Ceratocyrtis robustus Zone (21, CC to 19-3, 80-82 cm), Oligocene

Cyrtocapsella eldholmi Zone (13, CC to 12, CC), early Miocene

Stichocorys bioconica Zone (12, CC to 11-2, 115-117 cm), early Miocene

Actinomma holtedahli Zone (11-2, 115-117 cm to 10-2, 146-148 cm), E-M Miocene

Lithomelissa stigi Zone (10-2, 146-148 cm to 8-2, 53-55 cm), middle Miocene

A radiolarian assemblage from Site 339 of a middle (?) Eocene age was recovered. As this site was near the top of a diapir, it is questionable how valuable this site will be for stratigraphic purposes. However, one radiolarian zone was suggested based on the faunal assemblage recovered.

Artostrobus (?) *quadriporus* Zone. (12, CC to 9, CC), middle Eocene

The oldest radiolarian assemblage recovered was obtained from Site 343. Here, a radiolarian composition quite different from that at Site 339 was recovered. The silicoflagellates suggest an age of early Eocene, and a radiolarian zone is suggested even if the base and top are not defined.

Archnocalpis tumulosa Zone. (6, CC to 5, CC), early Eocene

Late Miocene, Pliocene, and Pleistocene sediment was recovered from Sites 341 and 348. It was not without difficulties that this upper zonation was pieced together. At Site 338, Sample 7, CC there was a high concentration of *Hexalonche* sp. B. This species was hardly observed in Sample 8-2, 53-55 cm, the latter believed to be close to the middle-late Miocene boundary. The high occurrence of *Hexalonche* sp. B is therefore believed to be close to the base of late Miocene. This species was also found in high numbers at Site 341, Sample 15-2, 30-32 cm and Site 348, Sample 31-5, 17-19 cm. Also at those sites *Hexalonche* sp. B had a very short time range of these mass abundancies, and most likely this species had a "bloom" all over the Norwegian Sea in early late Eocene, and may therefore serve as a good time marker. Above this *Hexalonche* sp. B peak at Site 348, a complete sediment column was suggested based on the obtained diatom and silicoflagellate zonations. For Site 348, a radiolarian zonation from late Miocene to Recent could be defined.

Antarctissa whitei Zone, late Miocene-Pliocene

Cycladophora davisiana Zone, Quaternary

Foraminifera (J.E.v.H.)

The standard planktonic foraminiferal zonation used for most other DSDP legs cannot be directly applied in the Norwegian-Greenland Sea. The, mainly tropical, species on which the standard is based never lived in this high-latitude area. Even zonal schemes recently established for the North Atlantic (Berggren, 1972b; Poore and Berggren 1975) do not apply except for the youngest part of the section. After a more detailed (SEM) study of the rare plankton, it may be justified to construct a high-latitude zonation, which will consist of a few broad zones only.

The difficulty in using planktonic foraminifera not only stems from poverty of the original populations, but also because most sections cored were deposited below or near the carbonate compensation surface (CCS, Berger and Winterer, 1974) which, probably throughout the Tertiary, was exceptionally shallow in the area. Most tests of the plankton, of a low diversity to start with, are dissolved and have not been preserved. Apart from extremely rare *Globorotalia* in the Pleistocene of the Vøring Plateau, not one keeled planktonic test was found.

Table 2 gives the preliminary combined planktonic, calcareous benthonic, and arenaceous benthonic foraminiferal zonal scheme. It obviously has a low resolution. However, the scheme is applicable over the entire area and allows for a broad age determination of most of the cores. The age of the zones is based on direct comparison with northwestern Europe, and where it was possible to check with other fossil groups, it proved to be reliable in time stratigraphic correlation.

The zones marked with a 1 are local range zones defined by the range of their nominal species. The zones marked with a 2 are partial range zones defined as follows. The *Neogloboquadrina pachyderma* Zone is defined by the dominant occurrence of left-coiling *N. pachyderma*. The *N. atlantica* S Zone (Sinistral) is defined by the dominance of left-coiling *N. atlantic* in the planktonic fauna. *N. atlantica* D (dextral) has a substantial number of dextrally coiling specimens, however, a systematic count has not been made as yet, and the boundary is not necessarily at 50%. The *Spirosigmoilinella* sp. Zone is defined by the presence of *Spirosigmoilinella* sp. without *Martinotiella communis*, and without *Spiroplectammina spectabilis*.

The base of the *N. pachyderma* Zone is considered to be about 2.8 m.y. old. Unlike other participants of Leg 38, I am of the opinion that this coincides with the Plio-Pleistocene boundary, that is with the base of the Calabrian stage as defined by Gignoux. The "age of the Plio-Pleistocene boundary" was discussed extensively in a report distributed among Leg 38 participants. It is available from the author, upon request.

Nannoplankton Zonation (C.M.)

Due to scarcity and low species diversity of the nannoplankton assemblages in the Norwegian-Greenland Sea, it is not possible to use one of the existing zonations. As far as possible, previously defined zones are used (*Emiliania huxleyi* Zone, *Gephyrocapsa oceanica* Zone, *Sphenolithus ciperoensis* Zone, *Sphenolithus distentus* Zone, and *Reticulofenestra umbilica* Zone). Otherwise only stratigraphic intervals are given, which are characterized by the presence of a species (interval with *Pseudoemiliania lacunosa*, interval with *Reticulofenestra pseudoumbilica*, interval with *Helicosphaera ampliaperta*, interval with *Isthmolithus recurvus*, and interval with *Imperiaster obscurus*).

For definitions of the zones and intervals used in this report, and the list of species utilized, see Müller (Chapter 26, this volume).

TABLE 2
Paleontological Zonations, DSDP, Leg 38

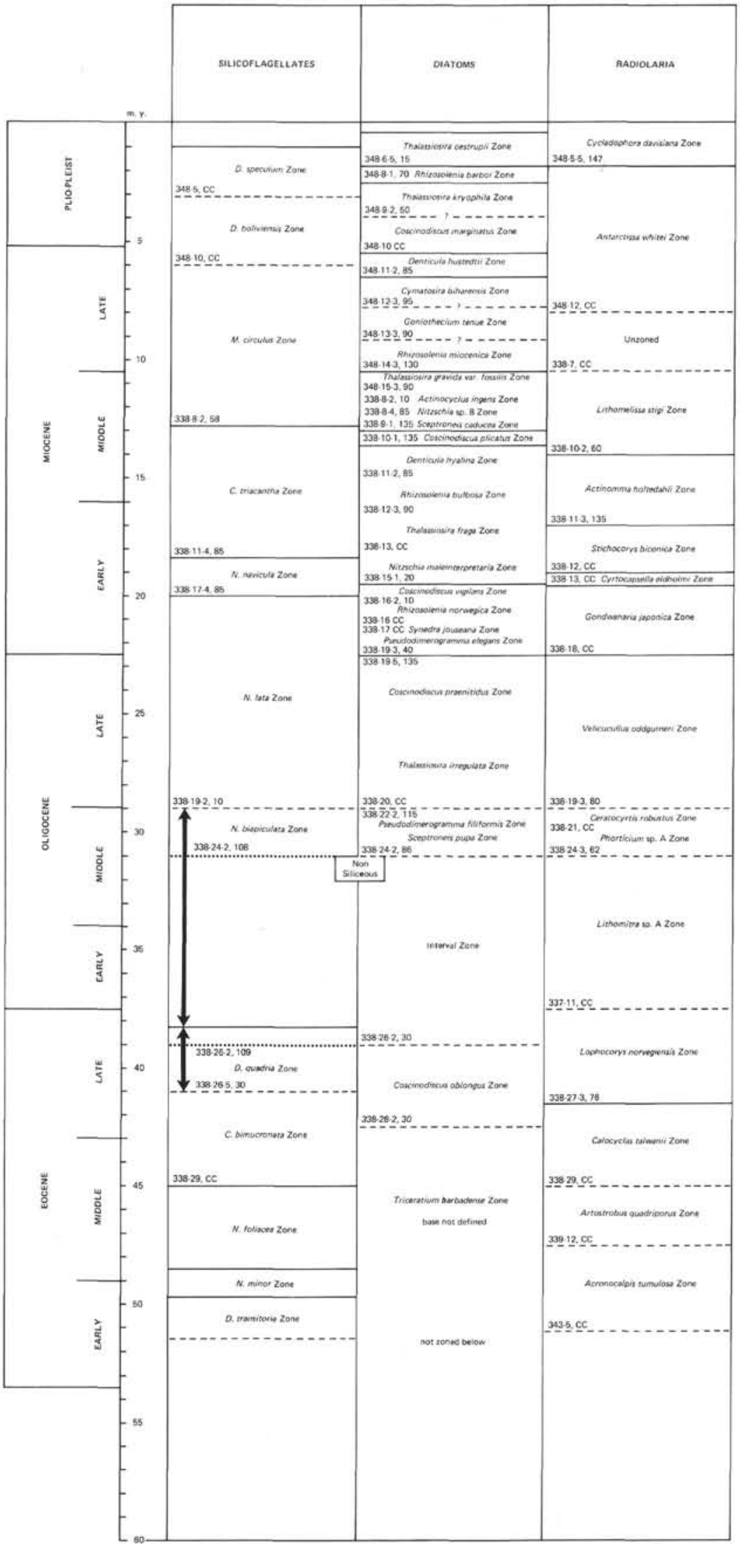
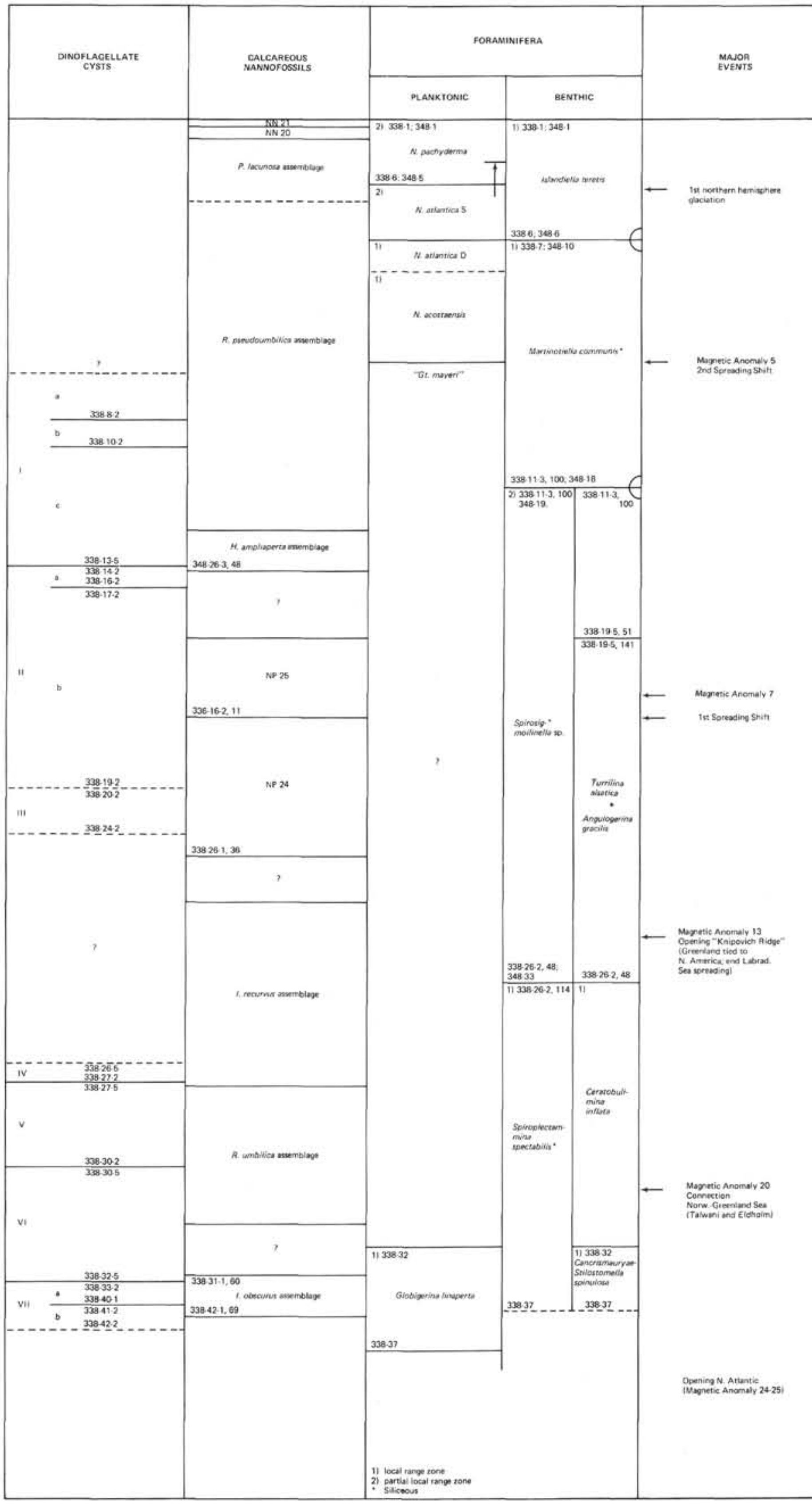


TABLE 2 – *Continued*



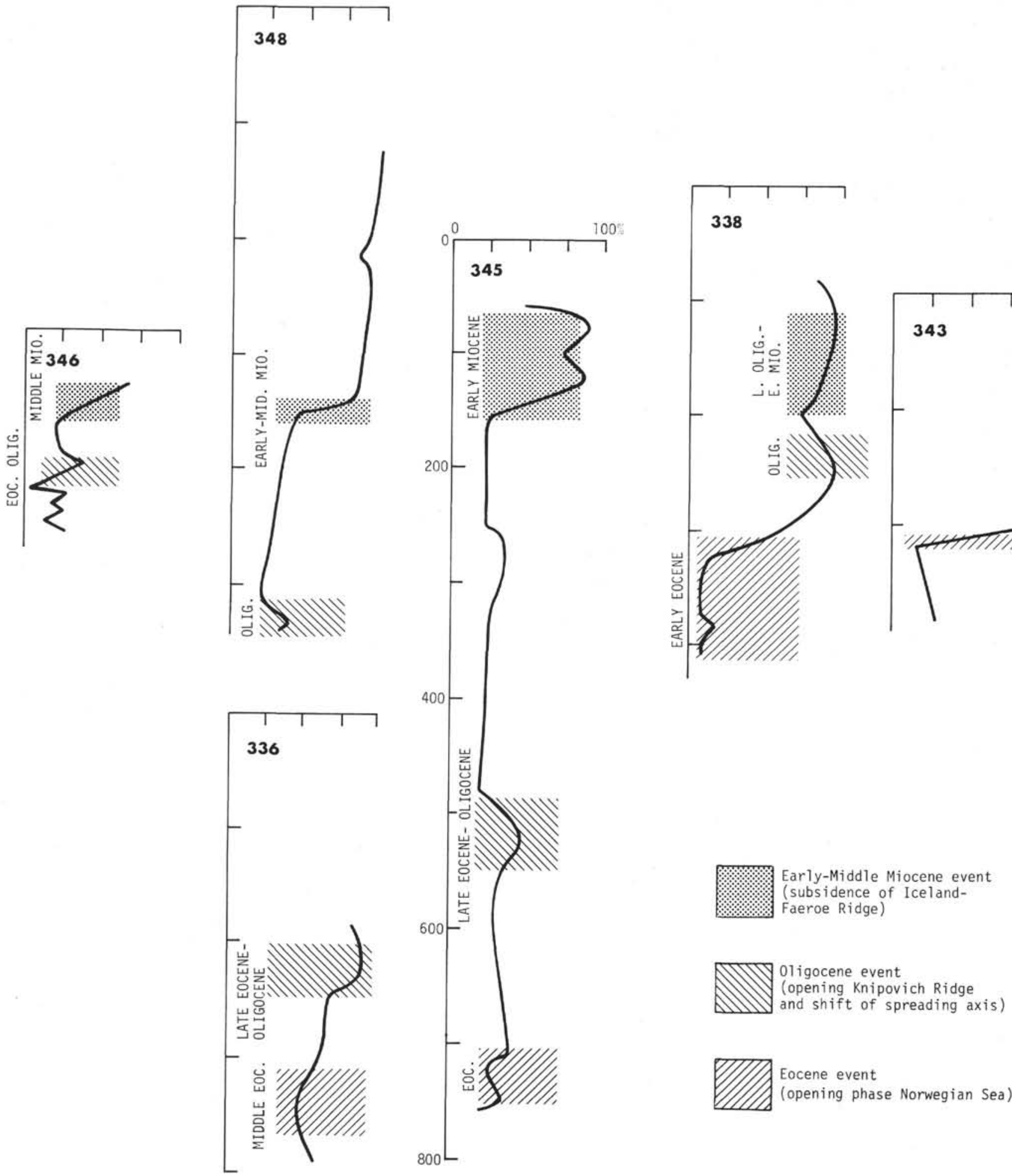


Figure 7. *Suggested correlation of "palyno-events" as indicated by cyst ratios for Sites 336, 338, 345, 346, and 348 (curves redrawn and slightly smoother than similar diagrams presented in the site Report Chapters).*

Silicoflagellate Zonation (C.M. and E.M.)

The silicoflagellate zonation used in this report for the early Eocene to middle Miocene interval is virtually the same as outlined in Martini (1971, 1972, 1974), with a necessary correction in the upper Eocene. For the late Miocene to Quaternary interval, a combination of zones suggested by Ling (1973) and Bukry (1973) for North Pacific sediments is used. The Quaternary zonation is obscured by heavy reworking of older taxa during "glacial" times, and the *Distephanus speculum* Zone is the only one recognizable.

Diatoms (H.-J. S.)

Abundance and preservation of siliceous phytoplankton skeletons were generally good at Leg 38 sites and enabled us to establish a composed (Sites 338 and 348) section ranging from the early Eocene to the Recent. Since the larger amount of the occurring species seems to be endemic to the Greenland-Norwegian Sea, a local diatom zonation was established for this area. On the other hand, a smaller number of species, being good marker species in the North Pacific, the Equatorial Pacific, and the Antarctic, were used for correlation of this local zonation to the Pacific and Antarctic including both low- and high-latitude diatom zonations. Epoch and age assignments as being established in the Equatorial Pacific on paleomagnetically controlled piston and drill cores were used exclusively for the Miocene through Recent interval and data being presented in Berggren and van Couvering (1974) for the lower part of the section and Berggren (1972) for the Eocene-Oligocene interval.

Dinoflagellate Cysts (S.B.M.)

No applicable standard dinocyst zonation is available. Based on fairly detailed range studies at Site 338 (early Eocene to middle Miocene), a provisional local zonal scheme was made, which, when applied to other sites (Figure 7), gave reasonably good correlations compared with results obtained with other fossil groups. However, it remains to work out ranges at other sites in greater detail to see what members of the zone assemblages are most diagnostic, before zones can be properly defined.

ACKNOWLEDGMENTS

The scientific party aboard *Glomar Challenger* during Leg 38 gratefully acknowledges the assistance of numerous workers who made the expedition possible. The efforts and enthusiasm of Captain Loyd Dill, the ship's crew, and the drilling crew, in sea conditions that at times made operations very difficult, are especially appreciated. The liaison between the scientists and drilling crew was effectively undertaken by Mr. Michael Pennock, an outstanding professional Cruise Operations Manager, on loan from British Petroleum Co. Ltd.

We also sincerely appreciate the technical assistance and cooperation of Mr. Ted Gustafson, Laboratory Officer, and of the technical group who performed numerous tasks necessary for the success of the scientific studies. Ms. Mary Young, the yoeman, performed her tasks above and beyond the call of duty. At Amsterdam, all shipboard reports for the 17 sites were ready for publication.

We also acknowledge the considerable assistance by members of the JOIDES Atlantic Advisory Panel and its chairman in the overall planning of the cruise.

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