

DEEP-SEA SEDIMENTATION
ON THE NORTHWEST AFRICAN
CONTINENTAL MARGIN

by

ROBERT ALEXANDER YOUNG
B.S., Brooklyn College
(1969)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

January, 1972

Signature of Author.....

Department of Earth and Planetary
Sciences, January 21, 1972

V U

Certified by...*L*

.....
Thesis Supervisor

Accepted by.....*S*

Chairman, Departmental Committee on
Graduate Students

Lindgren
WITHDRAWN
M.S. TECH.
FEFROM3
MIT LIBRARIES

ABSTRACT

TITLE OF THESIS: Deep-Sea Sedimentation on the Northwest African Continental Margin

AUTHOR: Robert Alexander Young

Submitted to the Department of Earth and Planetary Sciences on January 21, 1972, in partial fulfillment of the requirements for the degree of Master of Science.

A detailed examination of four cores from the northwest African continental rise has demonstrated that no change occurred in the provenance of the clay mineral or inorganic silt fractions during the late Pleistocene and Holocene. This contrasts with reported changes in sediments of the North American continental rise. Regional sedimentation processes have also remained constant during this time.

Composition of the non-carbonate fraction of the African continental rise sediments indicates a volcanic provenance whereas North American continental rise sediments reflect a terrigenous source.

The African continental shelf is much narrower than its North American counterpart; the continental rise is wider by 30%, several hundred meters deeper, and more gently sloping. Abyssal plains lie seaward of the continental rise on both sides of the North Atlantic, but the abyssal plain off northwest Africa is narrow and poorly developed. A chain of volcanic islands and seamounts occurs on the northwest African continental rise for which there is no analogue on the continental rise of North America.

Bottom currents are not presently active on the African continental rise although seismic profiles indicate they may have been important during the Pleistocene. Core lithology indicates pelagic sedimentation and turbidity current deposition are the dominant sedimentation processes.

Microfaunal analysis of the cores shows changes in dinoflagellate abundance which are possibly related to the glacio-eustatic lowering of sea level which occurred during the last 35,000 years.

Thesis Supervisor: Dr. Charles D. Hollister

Title: Assistant Scientist, Woods Hole Oceanographic Institution

TABLE OF CONTENTS

| | <u>PAGE NO.</u> |
|---|-----------------|
| ABSTRACT | 2 |
| ACKNOWLEDGEMENTS | 5 |
| INTRODUCTION | 6 |
| Clay Mineral Provenance and Climatic Changes | 6 |
| The Eastern and Western North Atlantic Continental Margins | 7 |
| Purpose of this Study | 8 |
| PREVIOUS WORK | 9 |
| Pleistocene History of Northwest Africa and Its Relation to Deep-Sea Sedimentation | 9 |
| Recent Geological and Geophysical Studies of the Northwest African Continental Rise | 10 |
| METHODS | 12 |
| RESULTS | 15 |
| Foraminiferal Studies | 15 |
| Dinoflagellate Analysis | 16 |
| Mineralogy of the Sediments: | 18 |
| Clay Mineralogy | 18 |
| Mineralogy of the Silt Fraction | 21 |
| Carbonate Abundance | 21 |
| Age Dating of the Sediments | 22 |
| DISCUSSION AND SYNTHESIS OF THE RESULTS | 23 |

| | <u>PAGE NO.</u> |
|--|-----------------|
| CONCLUSIONS | 29 |
| REFERENCES | 32 |
| TABLES | 41 |
| FIGURES | 45 |
| APPENDIX 1 - Laboratory Techniques | 60 |
| APPENDIX 2 - X-ray Diffraction Data | 66 |
| APPENDIX 3 - Silt Mineralogy; grain counts | 71 |
| APPENDIX 4 - Carbonate Abundance | 73 |
| APPENDIX 5 - Dinoflagellate Species List and Summarized Tabulation of Specimen Counts | 77 |

ACKNOWLEDGEMENTS

Appreciation is due my thesis advisor, Dr. Charles Hollister, for suggesting the study of African continental margin sedimentation as well as for continuing guidance and helpful critical discussions.

Mr. David B. Ericson (LDGO) kindly furnished unpublished core data, and Dr. James D. Hays (LDGO) provided access to the Lamont core collection supported by ONR N00014-67-A-0108-0004 and NSF GA 19690. Mr. John Hathaway (USGS) provided much helpful advice as well as the facilities for the clay mineral analysis. Drs. John Milliman, David Ross and Tj. van Andel (OSU) furnished advice and stimulating discussions during the course of the work. Dr. David Wall and Mr. Barrie Dale supervised the dinoflagellate analysis and entered into many useful discussions during the final stages of the study. Miss Anne Boersma assisted with the foraminiferal identification and Mr. Roger Flood and Mrs. Rosemary Young assisted in the laboratory.

Radiocarbon dating and fellowship support were provided by the MIT-WHOI Joint Program in Oceanography. Shipboard data acquisition (CHAIN Cruise 96) and certain laboratory analyses were supported by the Office of Naval Research (ONR N00014-66-C-0241; NR083-004).

INTRODUCTION

Clay Mineral Provenance and Climatic Changes - The Pleistocene glaciations have had large-scale effects on sedimentation patterns in the North Atlantic Basin and the resulting changes in provenance of the coarse-grained fraction have been investigated by numerous workers (Murray and Renard, 1891; Bramlette and Bradley, 1940; Ericson et al, 1961; Heezen and Hollister, 1971, especially Chap. 9).

Recent results of the Deep Sea Drilling Project and other independent investigations suggest that changes in clay mineral provenance occurred in the earliest and latest Pleistocene sediments of the western North Atlantic (Lancelot, et al, in press; Zimmerman, in press; Hathaway, in press) as well as in the late Pleistocene-Holocene sediments of the Oregon continental rise (Duncan et al, 1970). The general distribution of clay minerals in marine surface sediments has been documented for the Atlantic Ocean by Heezen et al (1960), Biscaye (1965), and for the World Ocean by Griffin et al (1968).

The clay mineral changes are not assignable to a single cause. Along the Atlantic coast redistribution of fine-grained sediments by southerly flowing contour currents along the continental rise is thought to have been the main cause of the late Pleistocene changes, whereas a complex series of glacial advances and retreats which intermittently blocked the geographical connection between source and depositional environment is probably responsible for the changes observed in west coast sediments. Thus, continental rise sediments apparently contain a clay mineral succession attrib-

utable to changes in provenance which can be correlated with glacial events.

Sediments of the northwest African continental rise were chosen for this study to test whether the previously cited conclusions regarding provenance of clay minerals in sediments of the western North Atlantic could be applied to another continental rise which was thought to be affected by climatic changes in the late Pleistocene.

The Eastern and Western North Atlantic Continental Margins -
Several important differences can be seen in the bathymetry of the continental margins bordering the eastern and western North Atlantic. The shelf and slope of northwest Africa are well developed as is its North American counterpart (figures 1 and 2), but the African shelf is very narrow (25-60 km) compared to the American shelf (about 100 km). The shelf break is at 90-150 m shoaling gradually from Gibraltar to Spanish Sahara (McMaster and LaChance, 1968; Summerhayes et al, 1971). The continental slope gradient ranges from 1:15 to 1:40 (Heezen et al, 1959) and is less steep than the American slope. Outcrops of Tertiary rocks occur on both African and North American slopes but are restricted to the upper slope off Africa.

The African continental rise is wider by 30%, more gently sloping, and deeper than the rise off North America (Heezen et al, 1959). Relief on the rise is generally less than 20 m and gradients range from 1:400 to 1:1000. A perched, flat floored basin enclosed by the 3500 m contour occurs south and adjacent

to the Canary Islands between the North and South Banks seamounts and the continental slope. A 4000 m deep, flat-floored channel separates the Madeira Islands on the lower African rise from the Selvage Island-Conception/Dacia Banks on the upper continental rise. By contrast, the North American continental rise is fairly uniform and smooth, broken only by the lower continental rise hills with relief of up to 350 m in the Hatteras-Hudson Canyon region and the few isolated seamounts of the New England Seamount Chain (Heezen et al, 1959; Ballard, 1966; Rona, 1969). Abyssal plains terminate the seaward side of the continental rise provinces on both sides of the Atlantic but the plain off Africa is very narrow and poorly developed.

Processes affecting continental margin sedimentation also differ. The vigorous deep and bottom currents which have helped shape the continental rise and built the Blake-Bahama Outer Ridge along the western margin are not present in the eastern basin (Heezen et al, 1966; Markl et al, 1970). Apparently only gravitational displacement due to slumps, slides, or turbidity current activity affected lateral transport of sediments in the deep basin off Africa.

Purpose of This Study - The primary goal of this study is the investigation of compositional changes in the clay mineral fraction of sediments within the upper 10 meters of the northwest African continental rise. Therefore, sediments from four representative

cores were sampled in detail and examined by X-ray diffraction analysis and under the petrographic microscope.

It was also necessary to determine glacial/interglacial climatic zones in the sediments. Accordingly, a study of the foraminiferal and dinoflagellate fauna was undertaken. The general geologic setting was also investigated through description of lithofacies and sedimentary structures seen in cores and in subbottom profiling records.

An important aspect of deep sea sedimentation is the accumulation of pelagic carbonates. Wiseman (1965) and Hays (1971) have reported good correlation between faunally defined warm and cool zones and absolute carbonate content in sediments from nearby regions. However, Broecker (1971; personal comm.) has reported that no simple relationship exists between climate and percent carbonate in deep sea sediments. Therefore, detailed total percent carbonate analyses were accomplished in an attempt to shed more light on this problem.

PREVIOUS WORK

Pleistocene History of Northwest Africa and Its Relation to Deep Sea Sedimentation - Pleistocene climatic fluctuations on the continent are interpreted from observation of cold climate phenomena including local alpine glaciation in the Rif and Atlas ranges of Morocco (figure 1; Fairbridge, 1971) and orientation of fossil dune fields (Fairbridge, 1964). Increase of precipitation and lower temperatures are thought to have formed fossil soil solifluction

layers found at elevations from 700 to 1100 m lower than at present in the Atlas and Rif ranges (Raynal, 1956, 1960)(not seen). Intermittent precipitation of large water volumes at lower elevations apparently prevailed in northwest Africa during the glacials, depositing thin beds of reddish silts in flash floods over many now dry flood plains (Choubert, 1948). This intermittency created a series of soil forming-soil redistributing cycles in river valleys of the otherwise arid region probably causing marked changes in discharge of silt and finer grained detritus from rivers along the Moroccan coast. Vigorous discharge of Moroccan rivers during the Pleistocene is indicated by the several now abandoned canyons incised into the slope and shelf break (figure 1) and from evidence of extensive erosion of shelf sediments during the Pleistocene on the presently quiescent shelf (McMaster and LaChance, 1968, 1969; Summerhayes et al, 1971).

Recent Geological and Geophysical Studies of the Northwest African Continental Rise - Seismic reflection profiles and well log data show that the shelf and slope of northwest Africa are covered by prograding sediments of Mesozoic to Quarternary age (McMaster and LaChance, 1968; Robb, 1971; Summerhayes et al, 1971). Post-Oligocene sedimentation has been mainly on the slope and upper rise while extensive erosion of the Moroccan shelf occurred during the Pleistocene.

Volcanism and tectonism have also been instrumental in

shaping the continental margin. The Canary Islands were probably formed during the Oligocene and have been active throughout the late Quaternary (Fuster et al, 1968a, b, c, d). The Madeira Islands are probably of similar age but their most recent volcanic activity can be only roughly dated as Pleistocene (Fuster et al, 1968a). The Cenozoic orogenies of North Africa produced folding, faulting, and downwarping in the Rif and Atlas mountains (de Sitter, 1956; Sougy, 1962; Querol, 1966). Some of these tectogenic structures can be traced seaward under the post-Eocene sediments to the shelf break and beyond (Lavrov and Syrskiy, 1968; McMaster and LaChance, 1968; Robb, 1971).

Geophysical studies of the rise and abyssal plains deal mainly with deep-seated structures influencing the regional magnetic and gravity fields (Jones et al, 1966; Dash and Bosshard, 1969; Rona et al, 1970). Examination of seismic reflection profiles (Collette et al, 1969; Lowrie and Eskowitz, 1969; Luyendyk et al, in preparation) show the rise sediments to consist of a series of sharp, conformable reflectors within the upper one second of acoustic penetration, gradually becoming smooth and level above a rough acoustic basement. Collete et al have assumed that the parallel reflectors probably represent turbidites except in areas near seamounts where lava flows may have occurred.

Preliminary results from Deep Sea Drilling Project sites 135 and 136 from within the study area indicate that the upper 300 m of continental rise sediments are pelagic carbonates of mid-Tertiary

to Holocene age (Hayes et al, 1971). This section unconformably overlies terrigenous silty clays, silicified siltstones and hard mudstones of early Eocene to early Cretaceous age at site 135, and upper Cretaceous silty clays with ash layers to middle Cretaceous marl oozes at site 136.

Since the days of the CHALLENGER Expedition (1872-73) at least 50 gravity and piston cores have been taken in the area, but knowledge of the effects of the late Pleistocene climatic changes on sediment provenance is restricted to superficial mineralogical descriptions of seven cores included in paleontologic investigations of Schott (1935), Phleger et al (1953), Ericson et al (1961), and the core descriptions of Olausson (1961).

METHODS

Core Selection and Sampling - The general criteria for core selection included location, nature of disturbances in the core, regional sedimentation rate, and previously published climatic information on the core.

A preliminary inspection of over 30 cores from the study area showed that sediments are primarily light tan to dark brown foraminiferal silty-lutites, interlayered with sand and silt layers composed of pelagic carbonates with less than 10% detrital minerals.

Cores from the northern and southern part of the region were sampled to examine regional differences in sediments. Clay mineral fractions from turbidite and pelagic carbonate intervals were sampled to determine differences resulting from mode of deposition

or transportation.

The published sedimentation rates and faunal-climatic curves for cores A180-37, A180-39, R5-54, and SP8-4 (Ericson et al, 1961) and from unpublished data on cores A180-36 and -38, all from the study area (figure 2), indicate a sedimentation rate on the order of 1.5 cm/1000 yr. Thus, closely spaced sample intervals are required to be certain that no climatic cycles are overlooked. Cores A180-39 and SP8-4 from Lamont and CH96 G1 and G10 from WHOI were selected for detailed study. At the time of selection bathymetric information showed all cores to be removed from steep slopes. Recently acquired information (Egloff, in preparation) shows A180-39 to be near the base of a seamount (figures 1 and 2).

Laboratory Techniques - Detailed description of techniques used in the study is given in Appendix 1 but a general outline is presented here for reference.

Oriented aggregates of clay minerals for X-ray analysis were deposited from suspension on silver (Millipore) filters under vacuum. Carbonate was removed by spraying the prepared filters with dilute acetic acid while still under vacuum. After being run untreated each filter was placed on a thin film of ethylene glycol to expand the montmorillonite minerals. After the glycolated filters were run they were oven heated to 550°C for 30 min. and rerun. For the purposes of this study each clay mineral was identified by the

presence of one characteristic X-ray diffraction peak: ethylene glycol treated montmorillonites, 17 Å; untreated illites, 10 Å; untreated kaolinite + chlorite, 7 Å. X-ray conditions were kept the same for all runs and the determination of absolute amounts of each clay mineral identified was done by the method of Biscaye (1965). Limitations of this method are discussed in Appendix 1. Quantitative clay mineral data is presented as weighted peak-area percent.

As a qualitative measure of relative abundance the 4.36 Å quartz peak was compared to the clay mineral peak areas and the results presented as a ratio. X-ray data is tabulated in Appendix 2.

Grain mounts of the 20-64 μ carbonate free fraction were studied under the petrographic microscope and grain counts tabulated in Appendix 3.

Percent carbonate was determined by the method of Hülsemann (1966) and by the standard acid leaching (weight loss) in dilute acetic acid. Sample data is given in Appendix 4.

Dinoflagellate samples were prepared from HCl and warm HF treated sediment samples. Species counts and sample information is given in Appendix 5.

The mineralogical and faunal studies were supplemented by examination and description of all cores from the study area in the WHOI and Lamont collections (see Table 1 for core locations, depths, and lengths). Seismic reflection and PDR records from CHAIN 96 (E. Bunce, personal comm.; C.D. Hollister, personal comm.) and KANE 9 (Lowrie and Eskowitz, 1969) were also examined

to aid in interpretation of regional sedimentation patterns.

RESULTS

Foraminiferal Studies - Studies of the planktonic foraminifera in cores by Schott (1935), Cushman and Henbest (1940), Phleger et al (1953), Eriqson et al (1961) and others have shown the existence of periodic variations in relative abundance of temperature-sensitive species. It has been established by other means, mainly radioactive isotope analysis, that cool or warm faunas in cores generally coincide with known continental glacial time intervals.

Since no previous faunal analyses of CH96 G1 and G10 had been done a study of the foraminiferal fauna was attempted. Specimens in most samples showed evidence of breakage. In fact, so many samples were broken that no statistically meaningful climatic analysis could be attempted. To determine if post-coring handling of the samples was responsible for the damage, splits of several raw samples from the same core interval noted as heavily broken in the initial analysis were prepared by several workers. In most cases the splits had similarly broken assemblages. On this evidence, the appearance of the tests, the abundance in most heavily broken samples of less broken specimens of more resistant species (as defined by Berger, 1968, and Ruddiman and Heezen, 1967), and depth of deposition the cause of breakage is assigned for the most part to dissolution effects except where the sediments are obviously associated with turbidite layers.

Dinoflagellate Studies - Since the foraminiferans were unsuitable for climatic analysis, the dinoflagellate fauna was examined. Dinoflagellates experience a bimodal life cycle. In the active (thecate) stage the cell wall is enclosed by cellulosic plates arranged in a regular manner. To begin the resting (cyst) stage, the organism forms a highly resistant cyst inside the theca and leaves the theca through an opening called the archaeopyle. The theca then decomposes. The cyst often has distinctive, regular, septal ridges, spines, and other ornamentation which reflects in some complex way the arrangement of thecal plates. The identification of the dinoflagellates is based on the location and shape of the archaeopyle, pattern of ornamentation, and size range.

The realization that the resting cysts of some extant dinoflagellates were homologous with fossil dinoflagellates, as well as with a group of microfossils known as hystrichospheres whose affinities were previously unknown (Wall, 1965; Evitt and Wall, 1968), and that like foraminifera and other microfauna, dinoflagellates may have environmental preferences (Wall, 1970; Williams, 1970a), gave impetus to the study of dinoflagellates in marine sediments.

In the past, dinoflagellates have been considered as exclusively shallow-water organisms since the termination of the resting stage seemed to depend on being on a shallow sea floor affected by

significant, possibly seasonal, fluctuations in temperature, salinity, and light intensity. However, the repeated presence of groups of living dinoflagellate genera in the Slope Water and sediments of the outer shelf/upper slope which are not affected at depth by fluctuations in the above-mentioned environmental factors demonstrates that at least some dinoflagellate groups may not require a resting cycle in bottom sediments (Wall and Warren, 1969; D. Wall, personal comm.).

The number of dinoflagellates per gram of dry sediment found in cores CH96 G1 and G10 is shown in figures 3 and 4 (species counts are tabulated in Appendix 5). Pollen spores were also counted but are not presented graphically since they add nothing to the discussion (Appendix 5).

In both cores examined the abundance of dinoflagellates drops to zero below the upper 75 cm. The complete absence of the organisms in the lower section is anomalous in light of previous studies and its implications will be discussed in a following section.

Dinoflagellate abundance apparently does not depend on percent carbonate or lithofacies (figures 3 and 4). For example in CH96 G1, 200-650 cm interval, dinoflagellate abundance remains at zero despite changes of up to 70% in carbonate abundance (figure 3). Dinoflagellates are also absent in the series of sand and silt layers from 160 to 805 cm in CH96 G10 (figure 4).

The abundance of the genera Leptodinium and Hemicystodinium are inversely proportional to the abundance of Spiniferites in

core CH96 G1 (figure 3) but the groups are directly proportional in core CH96 G10 (figure 4).

Mineralogy of the Sediments - Cores studied for their mineralogy included A180-39, SP8-4, CH96 G1 and CH96 G10. Core locations, depths, and lengths are given in Table 1. Sample data is summarized in Appendix 2 (clays) and Appendix 3 (silts).

Clay mineralogy: the composition and abundance of the clay mineral fraction was determined from over 350 X-ray diffraction analyses of 96 samples from the four cores. Data is presented as absolute abundance and quartz/clay mineral peak-area ratio curves. Graphic core logs and faunal stratigraphies are included for comparison with mineralogy. For convenience cores will be discussed as pairs from 26° and 33° N.

26° N Cores: Absolute Abundance of the clay mineral groups in core A180-39 is fairly uniform and unchanging down the core, averaging 45% montmorillonite, 40% illite, and 15% kaolinite + chlorite (figure 5).

A probable increase in quartz denoted by the maximum in the three peak-area ratio curves occurs at 120-200 cm in the w faunal zone. See Appendix 1 for explanation of the criteria used to distinguish significant peaks.

The abundance of montmorillonite in CH96 G1 drops from 60% to 45% near the core top and remains fairly constant down to 250 cm, while the amount of illite decreases from 30% to 20%, and kaolinite + chlorite increases from 10% to 25% in the same interval (figure 6). Between 250 and 400 cm the abundance curves undergo several

significant fluctuations. Illite decreases to a minimum of 15% at 380 cm while montmorillonite has two maxima of 65% at 280 cm and 340 cm, and kaolinite + chlorite has a maximum of 35% at 300 cm and a minimum of 10% at 340 cm. Between 400 and 475 cm abundances are similar to those of the 0-250 cm interval. Below 500 cm to the core bottom the abundance curves show variations of a similar magnitude but of longer wavelength than those of the 250-400 cm interval. Abundance of montmorillonite in turbidite layers does not appear to differ significantly from that of the pelagic intervals. In fact, the largest changes in montmorillonite abundance occur between 200 and 600 cm, an interval in which no recognizable turbidites are found.

Only the peak centered at 200 cm in all three peak-area curves is considered a measure of an increase in quartz abundance.

33° N Cores: only one climatic cycle is penetrated by core SP8-4 (figure 7). Montmorillonite abundance increases slightly in this core across the x-y faunal boundary from 35% to 50%, illite decreases from 45% to 35%, and kaolinite + chlorite decreases from 20% to 10%. Unfortunately, the upper 20 cm of the core is used up so that changes, if any, across the y-z boundary are not known.

The peak-area ratios show a series of maxima in zone y, possibly due to changes in the amount of quartz present. The

maxima near the bottom of zone y in the Q/I and Q/M curves are probably not significant.

The clay minerals in core CH96 G10 have significant peaks in the abundance curves in the 350-500 cm interval (figure 8). From the core top to 175 cm the abundances remain at 35% montmorillonite, 45% illite, and 20% kaolinite + chlorite. At 175 cm montmorillonite increases to about 50% and illite decreases to 30%. Between 350 and 410 cm montmorillonite decreases from 35% to less than 10%, illite increases from 30% to over 60%, and kaolinite + chlorite decreases from nearly 30% to about 20%. At 470 cm montmorillonite increases to 80%, illite decreases to 15%, and kaolinite + chlorite to under 10%. At 500 cm the abundances have returned to the values found above 350 cm and are generally uniform except for two small illite/montmorillonite peaks at 570-600 cm and 670-720 cm.

There is no significant difference in abundance of montmorillonite between the sand/silt layers and normal pelagic carbonate layers except for the decrease from 77% to 40% associated with the turbidite at 453-483 cm. By 405 cm in the overlying pelagic layer montmorillonite abundance has decreased to 5-10%. Kaolinite + chlorite remains constant in the interval causing the illite abundance to increase greatly in the low montmorillonite zone.

All peak-area ratios show a well defined peak in the 30-90 cm interval due to an increase in quartz. Below this zone

only the Q/K+C peaks at 570-670 cm and 700-750 cm, and the Q/I peak at 700-750 cm are considered due to an increase in quartz abundance.

Mineralogy of the Silt Fraction: No vertical variations in composition or abundance are found in any of the cores which can be correlated with any of the other variables investigated, but similarities of mineral distribution for cores from the same latitude are found (Table 2). The 33° N pair can be characterized as having a pyroxene-hornblende-quartz assemblage, while the 26° N pair have a quartz-feldspar-mica assemblage.

Quartz, plagioclase, pyroxene, hornblende, volcanic glass, and biotite were the most common minerals present. Other minerals present included opaques (magnetite), zeolite (sanadine?), sphene, and olivine. Siliceous microfossils were seen in the residues of CH96 G1. Iron staining was seen on silt-sized quartz particles but no preference was seen in the staining on the basis of size, angularity, or roundness of the quartz grains. In general, volcanic glass and opaque minerals constituted the largest proportion of the Other group listed in Table 2.

Carbonate Abundance: The percent total carbonate of the four cores examined in this study plus core ALB 217 reported by Olausson (1961) and their associated faunal-climatic zones as reported by Ericson et al (1961), Phleger et al (1953)(for ALB 217), and in this study, are shown in figure 9. The climatic

zones for ALB 217 reported by Phleger et al are probably not strictly comparable to those of Ericson et al because of differences in quantitative paleontologic techniques; however, it can be seen by inspection that there is at least a rough similarity in their faunal interpretations.

Analysis of over 200 sediments samples (Appendix 4) did not produce clear relationships between climatic zone and carbonate abundance as has been previously reported for other cores from nearby regions. Most cores used in this study were not analysed for carbonate but their core-tops were considered as low in carbonate if they consisted of medium to dark brown, silty lutite. This lithofacies appeared in the upper 30 cm of many cores in the study area and appears to be distributed randomly without regard for carbonate compensation depth (figure 10). Thus, depth is apparently not the single most critical factor controlling carbonate accumulation for the most recent surface sediments of this region.

Age Dating of the Sediments - Absolute abundance of dinoflagellates in the upper 75 cm of cores CH96 G10 and G1 agrees well with data from surface samples from this area (Williams, 1970a; D. Wall, personal comm.). Below this level abundance in both cores drops to zero. In a previous study of the deep-sea occurrence of dinoflagellates in the Red Sea, variations of abundance have been shown to follow a time scale closely related to late Pleistocene glacial chronology (Wall and Warren, 1970). If maximum dinoflagellate abundance is directly

related to a warm climate both cores have a warm (postglacial ?) zone from 0 to 75 cm underlain by over 700 cm of cool zone sediments. In particular, if a sharp increase in abundance at 75 cm is used as a criteria for defining the Holocene boundary the resulting sedimentation rates for the Holocene are found to be a factor of 4 X greater than rates published for nearby cores (Ericson et al, 1961). To resolve this question radiocarbon dating of the carbonate fraction in the 70-74 cm interval of core CH96 G1 was performed resulting in a date of $27,420 \pm 900$ ybp (see figure 3). This date implies that the rapid increase in dinoflagellate abundance occurs near the beginning of the (Wurm) Upper Pleniglacial (van der Hammen et al, 1967) rather than being related to the Pleistocene-Holocene boundary. If the core top is presumed intact an average sedimentation rate of 2.9 cm/1000 yr can be calculated. Since funding and time was available for only one radiocarbon date no speculation will be made at this time on the relation of the dated dinoflagellate curve to the undated curve of CH96 G10 although their striking similarity is noted.

DISCUSSION AND SYNTHESIS OF RESULTS

Demonstration of the apparent homogeneity of the clay mineral fraction in late Pleistocene and Holocene pelagic sediments of the northwest African continental rise is one important result of this study. Compositional homogeneity is clearly seen in cores SP8-4 and A180-39 in which no turbidites are present (figures 5 and 7).

The uniformity of clay deposition may also be seen by comparing the range of absolute abundance values for cores examined in this study with clay abundances from nearby core tops at approximately the same latitude examined by Biscaye (1964a)(figure 11). Although absolute values of clay mineral abundances obtained in this and Biscaye's study differ, the range of values in both studies is very similar, except for the case of montmorillonite. Local variations of this mineral are probably due to volcanic activity. The systematic displacement of the two sets of data (figure 11) perhaps serves to illustrate how procedural differences can affect the "absolute" values obtained, often making comparison of data from different studies unreliable.

Some preliminary data on eolian dusts collected off northwest Africa show they are composed primarily of quartz and have characteristically low (< 10%) montmorillonite abundance in the clay mineral fraction (Chester and Johnson, 1971). Surface water samples collected in the study area also show low montmorillonite concentrations (Folger, 1970). Montmorillonite is strongly associated with volcanic activity mainly as an alteration product of ash and volcanic glass (Griffin and Goldberg, 1963; Weaver, 1967). Thus, the moderately high percentage of montmorillonite in the sediments is probably indicative of a volcanic source.

A good example of montmorillonite variability in a turbidite

sequence is the 350-500 cm interval of CH96 G10 (figure 8). The percent montmorillonite in this layer decreases from 77% at 460 cm in the lower part of the sequence to 33% at 433 cm in the overlying pelagic sequence. Conversely, the silt laminae at 405-408 cm have very low montmorillonite content (<10%) which suggests a high degree of mixing with non-volcanic materials. The appearance of the quartz/clay mineral peak-area ratio curves suggests that periods of quartz abundance have occurred relative to the clay minerals. The pattern of quartz abundance is apparently randomly distributed with regard to climate and lithofacies. Quartz is a major mineral constituent of the African-derived dists collected in the study area (Chester and Johnson, 1971). It is suggested that periods of severe meteorological conditions (albeit shorter in time-scale than glacial cycles and probably not directly related to glacial conditions) may have created heavy eolian dust loads which resulted in a higher rate of fine-grained quartz sedimentation.

A survey of sediment type and sedimentary structures in 49 cores taken in the region shows that graded and bedded sand and silt facies are common but normally constitute less than 20% of the total cored interval (figure 12). No systematic regional differences are observed in frequency or thickness of these coarser layers. Based on inspection of precision echo sounding records taken on CHAIN 96 and the bathymetric charts and figures 5, 6, and 13 from Heezen and Johnson (1969), absence of silt and sand layers in cores V23-89 and 90 in the Canary-Madeira abyssal

plain, in core V27-163 taken 120 km south of Madeira, and in core RC9-205 from the Gibraltar Fan is thought to be due to their position on local topographic highs making them inaccessible to turbidity current deposition. Possibility of fine grained lutite turbidites occurring in the cores is difficult to assess not only because of lack of detailed textural analysis but because of the highly bioturbated appearance of the sediment. But, the presence of numerous burrows and mottles in the pelagic sediments is evidence in itself of slow accumulation rate of the fine grained sediments and hence an argument against lutite turbidite deposition.

Cores on and near the North and South Banks 300 km SW of the Canary Islands are also remarkably free of sand and silt layers despite their proximity to steep-walled seamounts. Detailed topographic control is lacking in this region but the cores' location on local topographic highs or in protected areas may also be the reason for the apparent lack of turbidites. Cores ALB 215, V23-95, -96, and K9-39, taken nearer the Canary Islands all contain 15% or more graded or bedded sand or silt layers that were probably deposited by turbidity currents.

Mineralogical data discussed in previous sections show that the silt fraction of all cores studied contains minerals probably derived from volcanic sources. Source of sand and silt layers is

therefore assumed to be the pelagic carbonate and volcanic sedimentary blanket on the slopes of the seamounts and volcanic islands in the region.

Examination of 3.5 KHz records from the study region show the presence of several near-surface subbottom reflectors in sediments of the continental rise and abyssal plains. It is not certain if the acoustic reflectors represent turbidites or dense pelagic carbonate layers commonly found in the cores, since each sediment type, if interbedded in material of contrasting physical properties, can act as a good acoustic reflector.

In contrast to the western boundary of the North Atlantic, bottom currents are probably not presently important in the shaping of the northwest African continental margin. Dynamic computations made to determine volume transport and relative velocity between a series of deep hydrographic stations taken along 36° N, 32° N, and $18^{\circ}30'$ W (Young and Nichols, unpublished) indicate little or no motion takes place below the 2000 m reference level. Deep bottom photographs taken in the study area (Lowrie et al, 1970; Heezen and Hollister, 1971, fig. 13.37) and during CHAIN 96 (C.D. Hollister, personal comm.) show no evidence of presently active bottom currents. This evidence, coupled with the bioturbated condition of the pelagic sediments, suggests that the surficial material

is undisturbed by bottom current reworking processes. Buried, crenulated reflectors seen in seismic reflection profiles taken along the African continental rise may be the result of paleo-bottom currents driven by general intensification of oceanic circulation during the Pleistocene glaciations (Egloff, 1971).

The apparently random distribution of carbonate-rich core-top sediments is difficult to explain. It is apparently not a simple function of depth and local differences of 500 m or more in the present day carbonate compensation depth are extremely unlikely. More likely, the factors influencing the rate of carbonate accumulation depend upon poorly understood interactions among such factors as detrital sedimentation rate, surface productivity, pH, temperature, pressure, and total CO₂ concentration (Broecker, 1971).

Only two systematic studies of dinoflagellate occurrence in deep marine sediments have been published (Wall, 1967; Wall and Warren, 1969). The most basic knowledge of factors controlling the vertical and horizontal distribution of dinoflagellate groups is still lacking, although the work begun by Williams (1970a,b) and Wall promises to shed more light on this relatively new stratigraphic tool. Accordingly, an unambiguous interpretation of the meaning of the increase in dinoflagellates at about 27,000 ybp is not warranted, but speculation on the factors known to influence groups can be attempted. According to the curve presented by

Milliman and Emery (1968), at 27,000 ybp sea level was slowly lowering from near its present height, the rate rapidly increasing until about 14,000 ybp when it probably stood about 130 m lower than at present. As previously discussed, much nearshore material was evidently eroded at this time and presumably transported seaward. The light, silt-sized, low-density cysts are hydraulically equivalent to a much smaller sized particle and hence more easily kept in suspension than a similar sized mineral grain. Increase in dinoflagellate abundance in deep sea sediments during this period of low sea level stand might then be due to their higher rate of seaward transport. It is also possible that lowered sea levels and hence reduced areal extent of continental shelf and island reefal areas favored the dominance of dinoflagellate groups presently thought to inhabit the outer shelf and slope. The dominance of one such group, the genus Leptodinium in samples from northwest Africa is a possible consequence of this glacio-eustatic event.

CONCLUSIONS

The following conclusions can be made concerning sedimentation on the northwest African continental margin:

1. Provenance of clay minerals in sediments of the northwest African continental rise has not changed during the late Pleistocene and Holocene in contrast to previously reported changes in provenance of fine grained sediments from the North American

continental rise. Montmorillonites from the African margin are probably volcanic in origin.

2. Sediments of the eastern basin margin are predominantly pelagic carbonates with interbedded turbidite layers. Composition of the inorganic silt and sand fraction from turbidite and non-turbidite intervals in cores from the eastern and western margins reflects predominantly volcanic and terrigenous sources, respectively. Low concentration of terrigenous material in continental rise sediments off northwest Africa contrasts strongly with the high concentrations of terrigenous material in continental rise sediments along the North American continental rise.

3. The major difference in sedimentation processes active on the opposite margins of the North Atlantic is the virtual absence of competent bottom currents in the eastern basin. The primary mode of lateral sediment transport is turbidity current activity.

4. Carbonate abundance, although thought by some workers to be an accurate measure of climatic change in the recent sediments, did not correlate with foraminiferal climatic stratigraphy of the eastern margin cores studied in this work.

5. This study offers the opportunity for comparing foraminiferal and dinoflagellate stratigraphies in modern marine sediments. Unlike other shell or test-producing micro-organisms, the highly resistant nature of the dinoflagellate cysts makes them ideal as fossilizable organisms. Recognition of the association of living

and fossil dinoflagellate groups and investigation species autecology has only taken place during the past decade. However, on the basis of this and the other cited studies it is suggested that dinoflagellates may prove a useful stratigraphic tool for the study of modern marine sediments.

REFERENCES

- Ballard, J.A., 1966, Structure of the lower continental rise hills of the western North Atlantic, *Geophysics*, 31, 506-523
- Berger, W., 1968, Planktonic foraminifera: selective solution and paleoclimatic interpretation, *Deep Sea Res.*, 15, 31-43
- Biscaye, P.E., 1964a, Mineralogy and sedimentation of the deep-sea sediment fine fraction in the Atlantic Ocean and adjacent seas and oceans, *Geochemistry Tech. Rept. 8*, Dept. of Geology, Yale, 86 p.
- _____, 1964b, Distinction between kaolinite and chlorite in Recent sediments by X-ray diffraction, *Am. Mineralogist*, 49, 1281-1289
- _____, 1965, Mineralogy and sedimentation of recent deep sea clay in the Atlantic Ocean and adjacent seas and oceans, *Bul. Geo. Soc. Amer.*, 76, 803-832
- Bramlette, M.N., and Bradley, W.H., 1940, Geology and biology of North Atlantic deep sea cores, Part I, Lithology and geologic interpretations, USGS Prof. Paper 196-A, 1-35
- Broecker, W.S., 1971, Calcite accumulation rates and glacial to interglacial changes in oceanic mixing in Turekian, K.K. (ed.), *Late Cenozoic Glacial Ages*, 1971, Yale Press, New Haven, p. 239-265

- Chester, R., and Johnson, L.R., 1971, Atmospheric dusts collected off the Atlantic coasts of North Africa and the Iberian Peninsula, *Marine Geo.*, 11, 251-260
- Choubert, G., 1948, Sur l'age des limons rouges superficiels du Maroc, *C.R. Acad. Sci.*, 227, 558-560
- Collette, B.J., Ewing, J.I., Lagaay, R.A., and Truchen, M., 1969, Sediment distribution in the oceans; the Atlantic between 10° and 19° north, *Marine Geo.*, 2, 279-345
- Cushman, J.A., and Henbest, L.G., 1940, Geology and biology of North Atlantic deep sea cores, Part II, foraminifera, USGS Prof. Paper 196-A, 35-50
- Dash, B.P., and Bosshard, E., 1969, Seismic and gravity investigations around the western Canary Islands, *Earth and Plan. Sci. Ltr.*, 7, 169-177
- Duncan, J.R., Kulm, L.D., and Griggs, G.B., 1970, Clay mineral composition of late Pleistocene and Holocene sediments of Cascadia Basin, northeastern Pacific Ocean, *Jour. Geo.*, 78, 213 -221
- Egloff, J., 1971, Morphology of the ocean basin seaward of northwest Africa: the Canary Islands to Monrovia, Liberia, in preparation
- Ericson, D.B., Ewing, M., Wollin, G., and Heezen, B.C., 1961, Atlantic deep sea sediment cores, *Bul. Geo. Soc. Amer.*, 72, 193-286
- Evitt, W.R., and Wall, D., 1968, Dinoflagellate studies: IV.

- Thecae and cysts of Recent Peridinium limbatum (Stokes)
 Lemmermann, Stanford Univ. Pub. Geo. Science, 12, 1-15
- Fairbridge, R.W., 1964, African ice age aridity in Nairn, A.E.M.
 (ed.), Problems in Paleoclimatology, 1964, Interscience,
 New York, p.356-360
- _____, 1971, Quaternary sedimentation in the Mediterranean
 controlled by tectonics, paleoclimates, and sea level,
 Programs with Abs. VIII Inter. Sedimentological Cong.
 1971, Heidelberg, p. 29
- Folger, D.W., 1970, Wind transport of land-derived mineral,
 biogenic, and industrial matter over the North Atlantic,
 Deep Sea Res., 17, 337-352
- Fuster, J.M., Hernandez-Pacheco, A., Munoz, M., Badiola, E. Rodri-
 guez, and Cacho, L. Garcia, 1968a, Geology and Volcanology
 of the Canary Islands, Tenerife, Inst. "Lucas Mallada"
 Consejo Superior de Invest. Cientif., Madrid
- _____, Arana, V., Brandle, J.L., Navarro, U. Alonso, and Aparicio,
 A., 1968b, Geology and volcanology of the Canary Islands,
 Gran Canaria, Inst. "Lucas Mallada" Consejo Superior de
 Invest. Cientif., Madrid
- _____, Santin, S. Fernandez, and Sagredo, J., 1968c, Geology and
 Volcanology of the Canary Islands, Lanzarote, Inst.
 "Lucas Mallada" Consejo Superior de Invest. Cientif.,
 Madrid
- _____, Andrero, A., Gastesi, P, Ibarrola, E., and Ruiz, J. Lopez,

- 1968, Geology and volcanology of the Canary Islands, Fuerteventura, Inst. "Lucas Mallada" Consejo Superior de Invest. Cientif., Madrid
- Griffin, J.J., and Goldberg, E.D., 1963, Clay mineral distributions in the Pacific Ocean in Hill, M.N. (ed.), The sea, V. 3, 1963, Interscience, New York, 728-741
- Griffin, J.J., Windom, H., and Goldberg, E.D., 1968, The distribution of clay minerals in the World Ocean, Deep Sea Res., 15, 433-459
- Hathaway, J.C., in press, Regional clay mineral facies in the estuaries and continental margin of the United States east coast in Nelson, B.W., (ed.), Environmental framework of coastal plain estuaries, Geo. Soc. Amer. Memoir 133
- Hays, J.D., and Peruzza, A., 1971, Late Pleistocene climates inferred from calcium carbonate content of equatorial Atlantic deep sea cores, Abs. with Programs, Geo. Soc. Amer. Nat. Meeting 1971, 3, p. 595
- Hayes, D.E., Pimm, A.C., Benson, W.E., Berger, W.J., von Rad, U., and Supko, P.R., 1971, Deep Sea Drilling Project Leg 14, Geotimes, Feb., 1971, 14-18
- Heezen, B.C., Nesteroff, W.D., and Sabatier, G., 1960, Repartition des mineraux argileus dans les sediments profonds de l'Atlantique nord et equatorial, Comptes Rendus Acad.

Sci. Paris, 250, 410-412

_____, Hollister, C.D., and Ruddiman, W.R., 1966, Shaping of
the continental rise by deep geostrophic contour currents,
Science, 152, 502-508

_____, and Johnson, G.L., 1969, Mediterranean undercurrent and
microphysiography west of Gibraltar, Bul. de'l Inst.
Oceanographique (Monaco), 67, 1-95

_____, and Hollister, C.D., 1971, The Face of the Deep, Oxford,
New York, 659 p.

Hülsemann, J., 1966, On the routine analysis of carbonates in
unconsolidated sediments, Jour. Sed. Petr., 36, 622-625

Jones, E.J.W., Laughton, A.S., Hill, M.N., and Davies, D., 1966,
A geophysical study of part of the western boundary
of the Madeira-Cape Verde Abyssal Plain, Deep Sea Res.,
13, 889-907

Lancelot, Y., Hathaway, J.C., and Hollister, C.D., in press,
Lithology of sediments from the western North Atlantic -
Leg XI Deep Sea Drilling Project, in Ewing, J., et al,
Initial Reports of the Deep Sea Drilling Project,
Vol. XI, Washington (U.S. Govt. Printing Office)

Lavrov, V.M., and Syrskiy, V.N., 1968, Extensions of the west African
structural elements into the oceanic floor, (English
Translation) Doklady Akad. Nauk. SSSR, 177, 92-94

- Lowrie, A. and Escowitz, E. (eds.), 1969, Global Ocean Floor Analysis and Research Data Series: Vol. 1, KANE 9, U.S. Govt. Printing Office, 976 p.
- Lowrie, A., Jahn, W., and Egloff, J., 1970, Bottom current activity in the Cape Verde and Canaries Basin, eastern Atlantic, Abs. Trans. Amer. Geophysical Union, 51, p. 336
- McMaster, R.L., and LaChance, T.P., 1968, Seismic reflectivity studies on northwestern African continental shelf: Straits of Gibraltar to Mauritania, Bul. AAPG, 52, 2387-2395
- _____, and _____, 1969, Northwest African continental shelf sediments, Marine Geo., 7, 57-67
- Markl, R.G., Bryan, G.B., and Ewing, J.I., 1970, Structure of the Blake-Bahama Outer Ridge, Jour. Geop. Res., 75, 4539-4555
- Mehra, O. P., and Jackson, M.L., 1960, Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate, in Swineford, A. (ed.), Proc. 7th Natl. Conf. Clays and Clay Minerals, Permagon, London, 317-327
- Milliman, J.D., and Emery, K.O., 1968, Sea levels during the past 35,000 years, Science, 162, 1121-1123
- Murray, F., and Renard, A.F., 1891, Report on deep sea deposits based on specimens collected during the voyage of HMS CHALLENGER in the years 1872 to 1876, CHALLENGER Reports,

London, Govt. Printer, 525 p.

- Olausson, E., 1961, Description of sediment cores from the North Atlantic, Rept. Swedish Deep Sea Exped., 7, Fasc. 6, 227-286
- Pierce, J.W., and Siegel, F.R., 1969, Quantification in clay mineral studies of sediments and sedimentary rocks, Jour. Sed. Petr., 39, 187-193
- Phleger, F.B., Parker, F.L., and Peirson, J.F., 1953, North Atlantic foraminifera, Rept. Swedish Deep Sea Exped., 7, Fasc. 1, 122 p.
- Querol, R., 1966, Regional geology of the Spanish Sahara in Reyre, D. (ed.), Sedimentary Basins of the African Coast - Symposium Assoc. African Geo. Surveys, New Delhi - 1964, Paris, 27-39
- Raynal, D., 1956 and 1960, cited in Butzer, K.W., 1964, Environment and Archaeology, Aldine Pub., Chicago, p 265-334
- Reyre, D. (ed.), 1966, Sedimentary Basins of the African Coast, Part I, Atlantic Coast, Assoc. African Geo. Surveys, Paris, 187 p.
- Robb, J.M., 1971, Structure of continental margin between Cape Rhir and Cape Sim, Morocco, northwest Africa, Bul. AAPG, 55, 643-650
- Rona, P.A., 1969, Linear "lower continental rise hills" off Cape Hatteras, Jour. Sed. Petr., 39, 1132-1141

- _____, Brakl, J., and Heirtzler, J.R., 1970, Magnetic anomalies in the northeast Atlantic between the Canary and Cape Verde Islands, Jour. Geop. Res., 75, 7412-7420
- Ruddiman, W.F., and Heezen, B.C., 1967, Differential solution of planktonic foraminifera, Deep Sea Res., 14, 801-808
- Schott, W., 1935, Die foraminiferen in dem aequatorialen teil des Atlantischen Ozeans, Wiss. Erg. Deut. Atl. Exp. a.d. Forsh-u. Vermess. METEOR, B. III, Teil 3, p. 43-134, Berlin u. Leipzig
- Sitter, L.U. de, 1956, Structural Geology, McGraw-Hill, New York, 552 p.
- Sougy, J., 1962, West African fold belt, Bul. Geo. Soc. Amer., 73, 871-876
- Summerhayes, C. P., Nutter, A.H., and Tooms, J.S., 1971, Geological structure and development of the continental margin of northwest Africa, Marine Geo., 11, 1-25
- van der Haamen, T., Maarleveld, G.C., Vogel, J.C., and Zagwijn, W.H., 1967, Stratigraphy, climatic succession and radio-carbon dating of the Last Glacial in the Netherlands, Geol. en Mijnb., 46, 79-95
- Wall, D., 1965, Modern hystrichospheres and dinoflagellate cysts from the Woods Hole region, Grana Palynol., 6, 297-314
- _____, 1967, Fossil microplankton in deep sea cores from the Caribbean sea, Palaeontology, 10, pt. 1, 95-123

- _____, 1970, The lateral and vertical distribution of dinoflagellates in Quaternary sediments, in Proceedings Symp. Micropal. Bottom Sed., Cambridge, England, 1967, p. 399-405
- _____, and Warren, J.S., 1969, Dinoflagellates in Red Sea piston cores, in Degens, E.T., and Ross, D.A. (eds.), Hot Brines and Recent Heavy Metal Deposits in the Red Sea, Springer Verlag, New York, 317-328
- Weaver, C.E., 1967, The significance of clay minerals in sediments, in Nagy, B. (ed.), Fundamental Aspects of Petroleum Geochemistry, Elsevier, Amsterdam, 37-75
- Williams, D.B., 1970a, The occurrence of dinoflagellates in marine sediments, in Proceedings Symp. Micropal. Bottom Sed., Cambridge, England, 1967, p. 231-243
- Williams, D.B., 1970b, The distribution of marine dinoflagellates in relation to physical and chemical conditions, in Proceedings Symp. Micropal. Bottom Sed., Cambridge, England, 1967, p. 91-95
- Wiseman, J.D.H., 1965, The changing rate of calcium carbonate sedimentation on the equatorial Atlantic floor and its relation to continental late Quaternary stratigraphy, Rept. Swedish Deep Sea Exped., 7, Fasc. 7, 289-354
- Young, R.A., and Nichols, J.A., 1971, Movement of water masses off the northwest coast of Africa, unpublished manuscript
- Zimmerman, H., in press, Sediments of the New England continental rise, Bul. Geo. Soc. Amer.

TABLE 1 - Position, depth and length of all cores sampled or described for this study.

| Core No. | Latitude (°N) | Longitude (°W) | Depth (corr m) | Length (cm) |
|----------|------------------|-------------------|-------------------|----------------|
| ALB 215 | 29°55' N | 17°32' | 4310 | 539 |
| ALB 217 | 27°27' | 19°43' | 4360 | 795 |
| A180-36 | 28°04' | 23°36' | 5114 | 368 |
| A180-37 | 27°21' | 22°03' | 5173 | 471 |
| A180-38 | 26°42' | 20°47' | 4650 | 440 |
| A180-39 | 26°50' | 19°18' | 3566 | 368 |
| A180-42 | 24°39' | 17°05' | 2158 | 415 |
| CH96 G1 | 27°21' | 21°59' | 4878 | 749 |
| CH96 G10 | 32°36' | 21°26' | 5120 | 838 |
| K9-39 | 27°31' | 16°27' | 3533 | 794 |
| K9-40 | 25°37' | 19°20' | 3795 | 800 |
| K9-41 | 25°38' | 19°26' | 3665 | 1083 |
| R5-54 | 25°52' | 19°03' | 3387 | 388 |
| RC9-205 | 35°49' | 8°29' | 2312 | 480 |
| SP8-4 | 32°49' | 18°31' | 3462 | 183 |
| V4-15 | 35°11' | 15°20' | 2439 | 245 |
| V4-32 | 35°03' | 11°37' | 2296 | 445 |

Note: Abbreviations for ships are: ALB = ALBATROSS, A = ATLANTIS, CH = CHAIN, K = KANE, R = REHOBETH, RC = ROBERT CONRAD, SP = SAN PABLO, V = VEMA

| Core No. | Latitude (°N) | Longitude (°W) | Depth (corr m) | Length (cm) |
|----------|------------------|-------------------|-------------------|----------------|
| V4-33 | 34°35' | 8°41' | 3766 | 290 |
| V4-34 | 37°40' | 11°08' | 1540 | 245 |
| V10-80 | 31°23' | 11°37' | 2550 | 831 |
| V10-82 | 26°14' | 18°04' | 3775 | 1042 |
| V10-83 | 25°13' | 21°23' | 4530 | 625 |
| V10-84 | 24°24' | 24°04' | 5255 | 1167 |
| V23-87 | 34°05' | 19°42' | 5127 | 998 |
| V23-88 | 31°06' | 21°58' | 5031 | 900 |
| V23-89 | 29°52' | 24°06' | 5334 | 832 |
| V23-90 | 29°51' | 25°03' | 5395 | 1050 |
| V23-93 | 30°27' | 23°24' | 5310 | 625 |
| V23-94 | 30°37' | 20°09' | 5380 | 69 |
| V23-95 | 30°24' | 18°23' | 4598 | 938 |
| V23-96 | 29°48' | 15°05' | 3471 | 984 |
| V27-148 | 35°46' | 13°27' | 4867 | 837 |
| V27-149 | 35°20' | 14°02' | 4433 | 203 |
| V27-150 | 35°27' | 12°59' | 4861 | 598 |
| V27-151 | 35°53' | 12°23' | 4868 | 559 |
| V27-152 | 35°32' | 12°04' | 4861 | 597 |
| V27-153 | 35°51' | 11°38' | 4861 | 334 |
| V27-154 | 35°37' | 10°51' | 4872 | 805 |
| V27-155 | 36°03' | 10°34' | 4852 | 430 |
| V27-156 | 36°08' | 10°13' | 4850 | 879 |

| Core No. | Latitude | Longitude | Depth (corr m) | Length (cm) |
|----------|----------|-----------|-------------------|----------------|
| V27-157 | 34°15' | 10°40' | 4405 | 520 |
| V27-158 | 34°17' | 11°46' | 4464 | 221 |
| V27-159 | 35°59' | 13°20' | 4444 | 482 |
| V27-160 | 33°26' | 12°53' | 4380 | 380 |
| V27-161 | 33°35' | 13°58' | 4446 | 551 |
| V27-162 | 34°12' | 16°52' | 4281 | 440 |
| V27-163 | 31°30' | 17°22' | 4530 | 490 |
| V27-164 | 29°29' | 19°37' | 4623 | 369 |
| V27-166 | 25°51' | 22°43' | 4945 | 441 |

Table 2 - Average composition of the 20-64 μ fraction determined by grain counts on the petrographic microscope. Values represent average percent of grains counted.

| | | <u>Quartz</u> | <u>Fspar</u> | <u>Mica</u> | <u>Horneblende + Pyroxene</u> | <u>Weathered Fragments</u> | <u>Other</u> |
|-------|----------|---------------|--------------|-------------|-------------------------------|----------------------------|--------------|
| 33° N | SP8-4 | 47 | 5 | 3 | 24 | 15 | 7 |
| | CH96 G10 | 49 | 4 | 3 | 9 | 9 | 26 |
| 26° N | A180-39 | 67 | 8 | 4 | 2 | 6 | 13 |
| | CH96 G1 | 51 | 4 | 4 | 7 | 15 | 19 |

LIST OF FIGURES

- Figure 1: Bathymetry of the northwest African continental margin. Depths in corrected meters. Dashed contours are 100 m intervals, solid contours are 500 m intervals.
- Figure 2: Core locations in the study area. Deep Sea Drilling Project sites shown for reference. Provence limits approximated on the basis of bathymetry. See Table 1 for exact locations, depths, and lengths of cores. Ship abbreviations: A = Atlantis; ALB = Albatross; CH = Chain; K = Kane; R = Rehobeth; SP = San Pablo; V = Vema.
- Figure 3: Abundance of total dinoflagellate fauna and selected genera from core CH96 G1. Abundance measured in number of specimens per gram dry sediment. Dashed Holocene-Pleistocene boundary extrapolated from radiocarbon date of 70-74 cm layer.
- Figure 4: Abundance of total dinoflagellate fauna and selected genera from core CH96 G10. Abundance measured in number of specimens per gram dry sediment.
- Figure 5: Clay mineral abundance curves and ratios of quartz and clay mineral peak areas for core A180-39. Faunal zones from Ericson et al (1961).
- Figure 6: Clay mineral abundance curves and ratios of quartz and clay mineral peak areas for core CH96 G1. Dinoflagellate

Figure 6: abundance curve and radiocarbon age date determined (continued)

for this study. Dashed Holocene-Pleistocene boundary extrapolated from radiocarbon determined sedimentation rate.

Figure 7: Clay mineral abundance curves and ratios of quartz and clay mineral peak areas for core SP8-4. Faunal zones from Ericson et al (1961).

Figure 8: Clay mineral abundance curves and ratios of quartz and clay mineral peak areas for core CH96 G10. Absolute abundances from 340-433 cm approximate. Dinoflagellate abundance curve shown for comparison.

Figure 9: Percent carbonate curves and faunally determined climatic zones for a group of cores from the northwest African continental rise. General core lithology also shown.

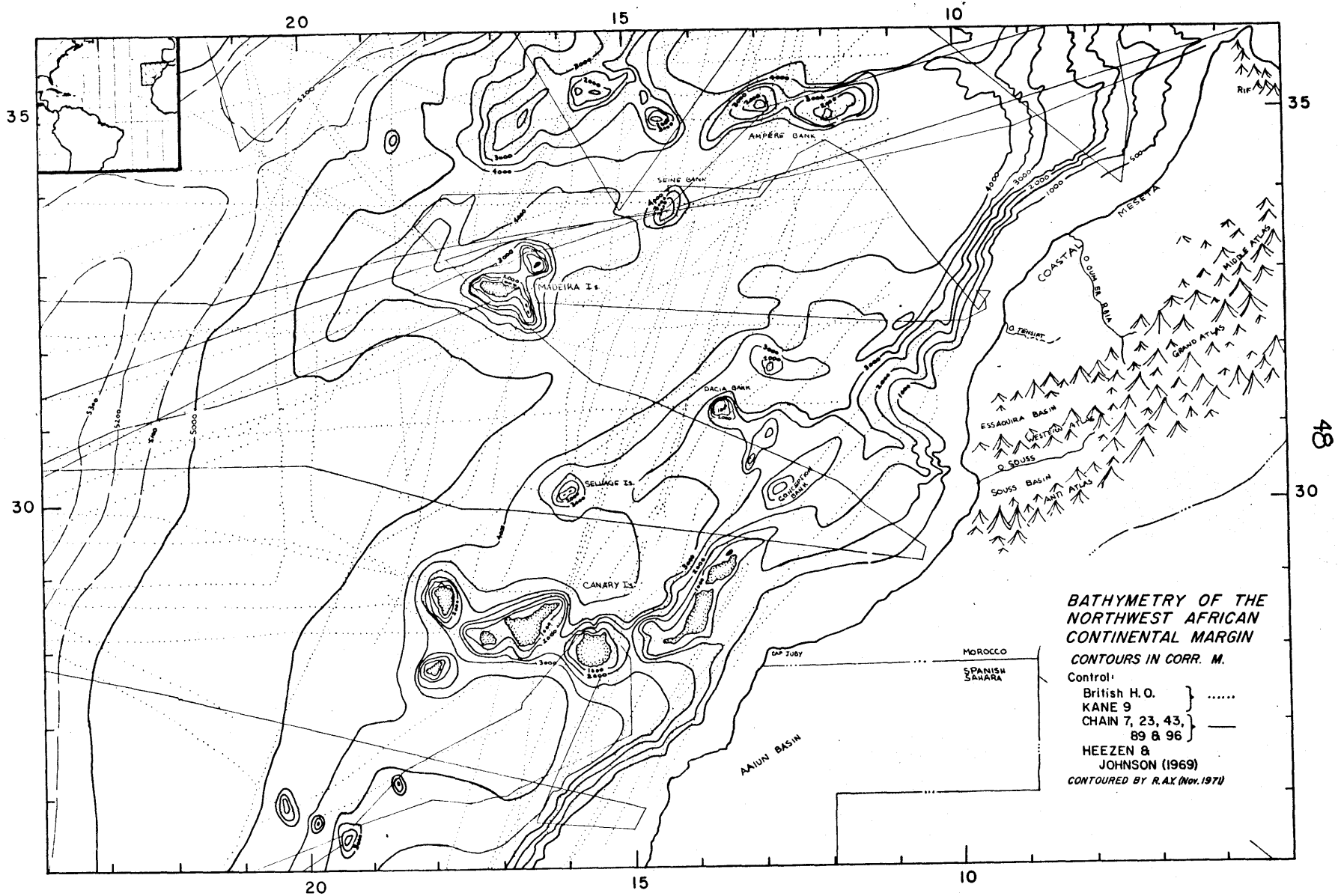
Figure 10: Cores from the northwest African continental margin containing brown to dark brown, low-carbonate, silty lutites in the upper 30 cm.

Figure 11: The abundance range of clay minerals from sediments in cores A180-39, SP8-4, CH96 G1 and CH96 G10 (each enclosed by a broken line) compared to clay mineral abundance found in nearby core top sediments. Data from nearby cores taken from Biscaye (1964a). Apeces

Figure 11: of triangles are points of 100% abundance for each (continued)

labeled mineral. M = montmorillonite; I = illite; K + C = kaolinite + chlorite. Although abundance ranges enclosed by the broken line and illustrated by the values from Biscaye are similar, the two data sets are systematically displaced, possibly due to differences in analytic procedures. Aperiodic volcanic activity is thought to be responsible for the wide range of montmorillonite abundance.

Figure 12: Core lithofacies diagram showing sand and silt layers in cores from the study area. Top of core is approximate location. Refer to figure 2 for core identification.



**BATHYMETRY OF THE
NORTHWEST AFRICAN
CONTINENTAL MARGIN**

CONTOURS IN CORR. M.

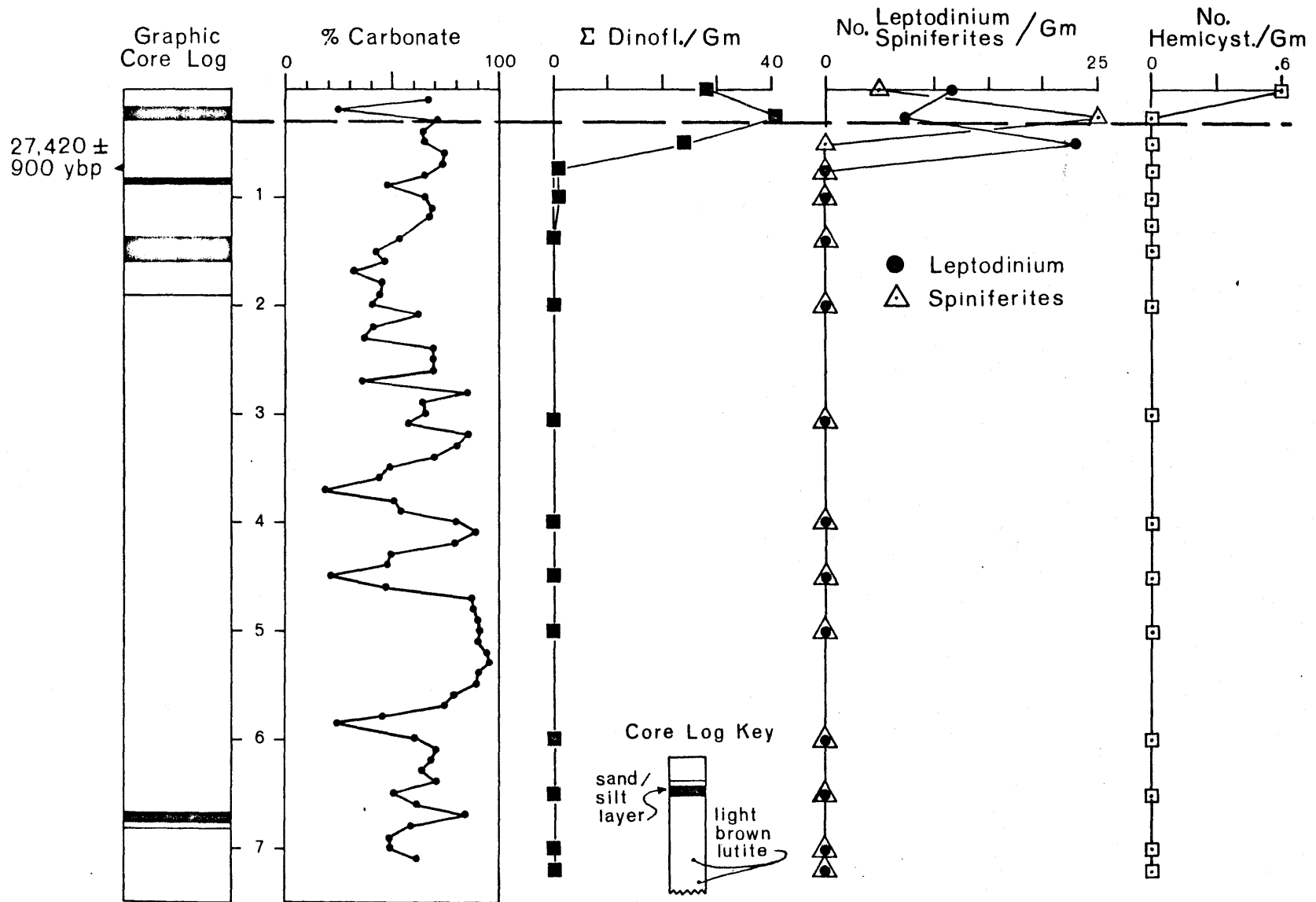
Control:

- British H. O. }
- KANE 9 }
- CHAIN 7, 23, 43, }
- 89 & 96 }

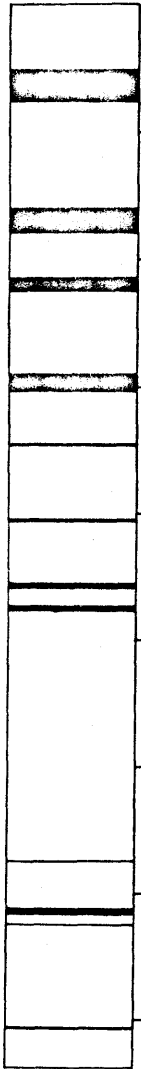
HEEZEN &
JOHNSON (1969)

CONTOURED BY R.A.X. (Nov. 1971)

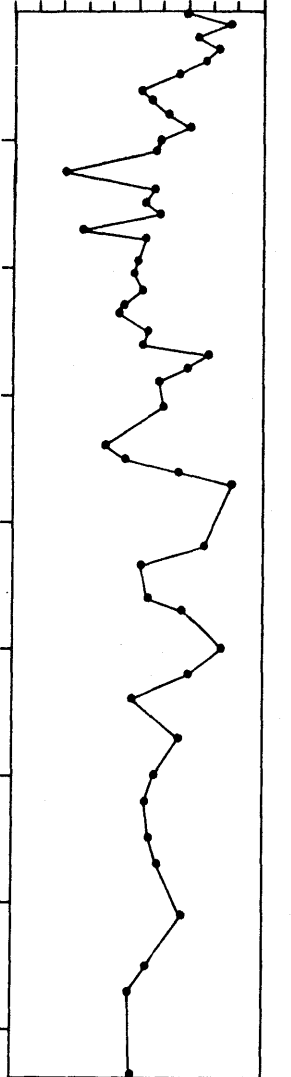
CH96 G1



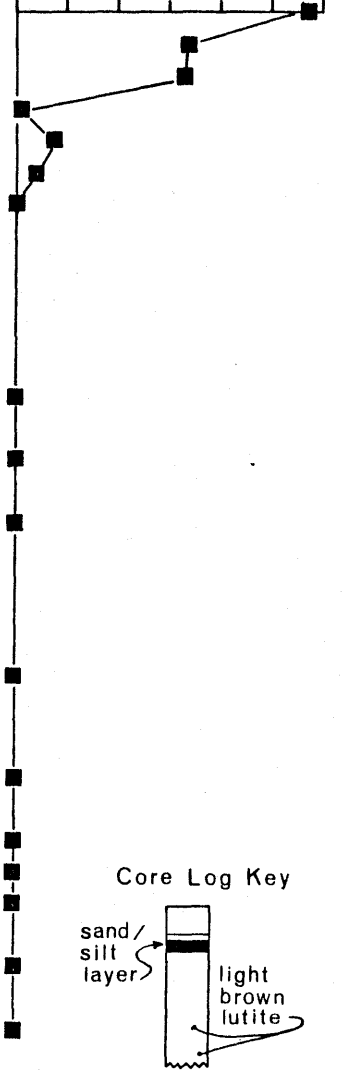
Graphic Core Log



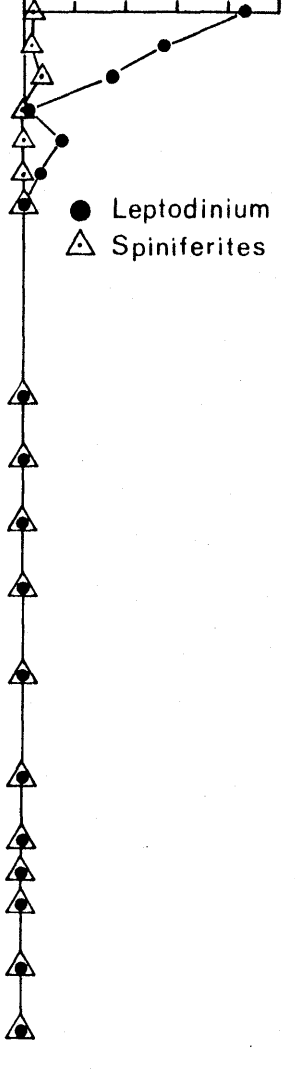
% Carbonate



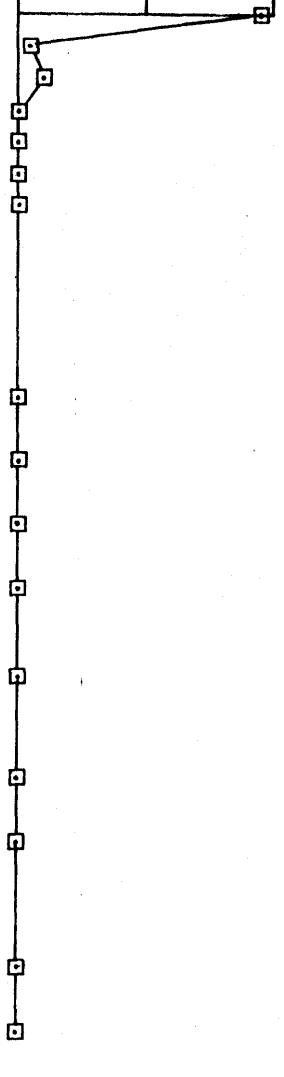
Σ Dinoflagellates/Gm



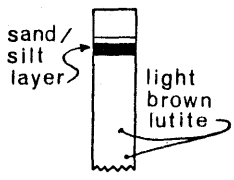
No. Leptodinium Spiniferites /Gm



No. Hemicyst./Gm



Core Log Key

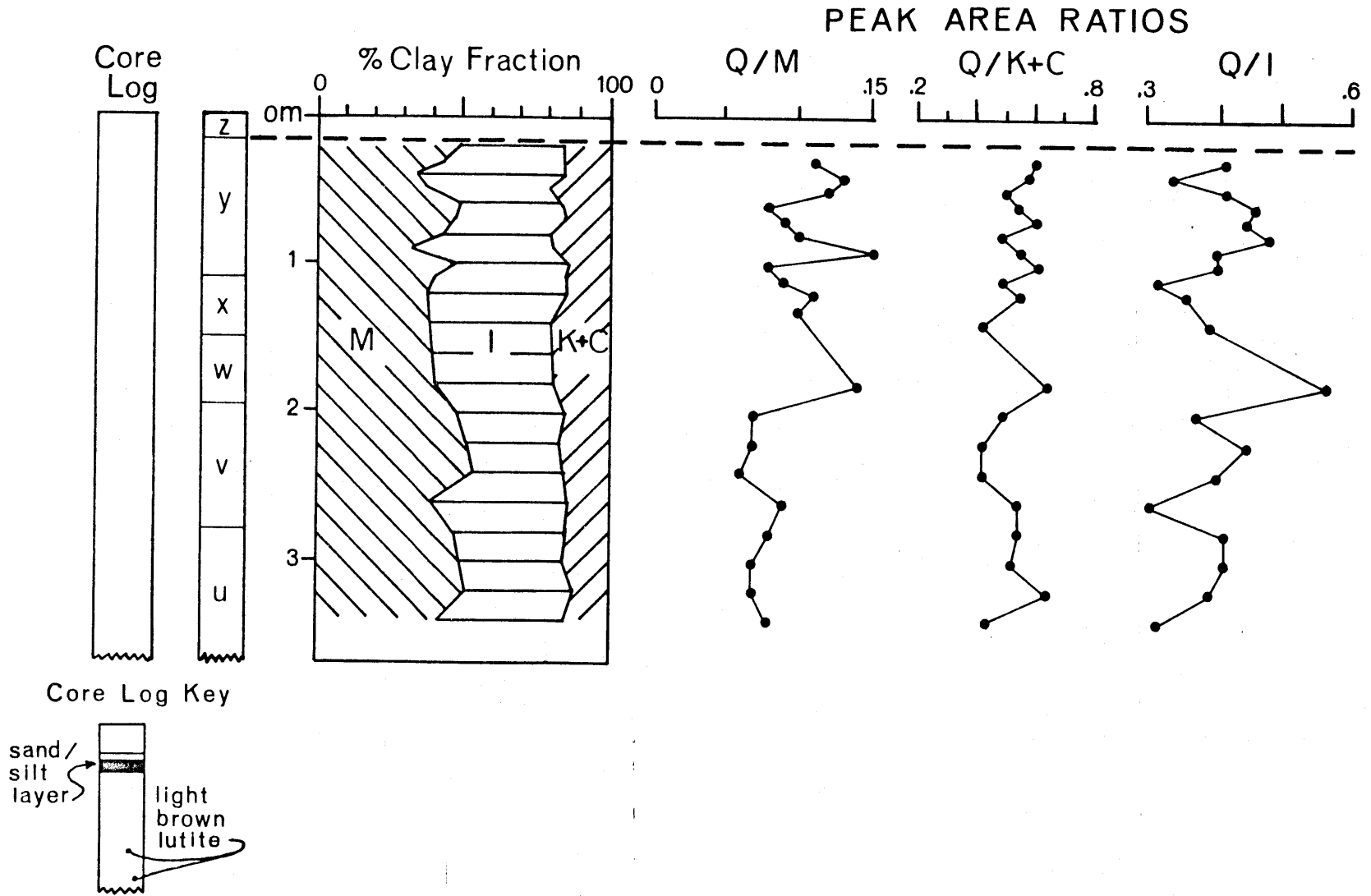


● Leptodinium
△ Spiniferites

Fig. 1

A180-39 CLAY MINERALOGY

FIG. 5



CH-96 G1 CLAY MINERALOGY

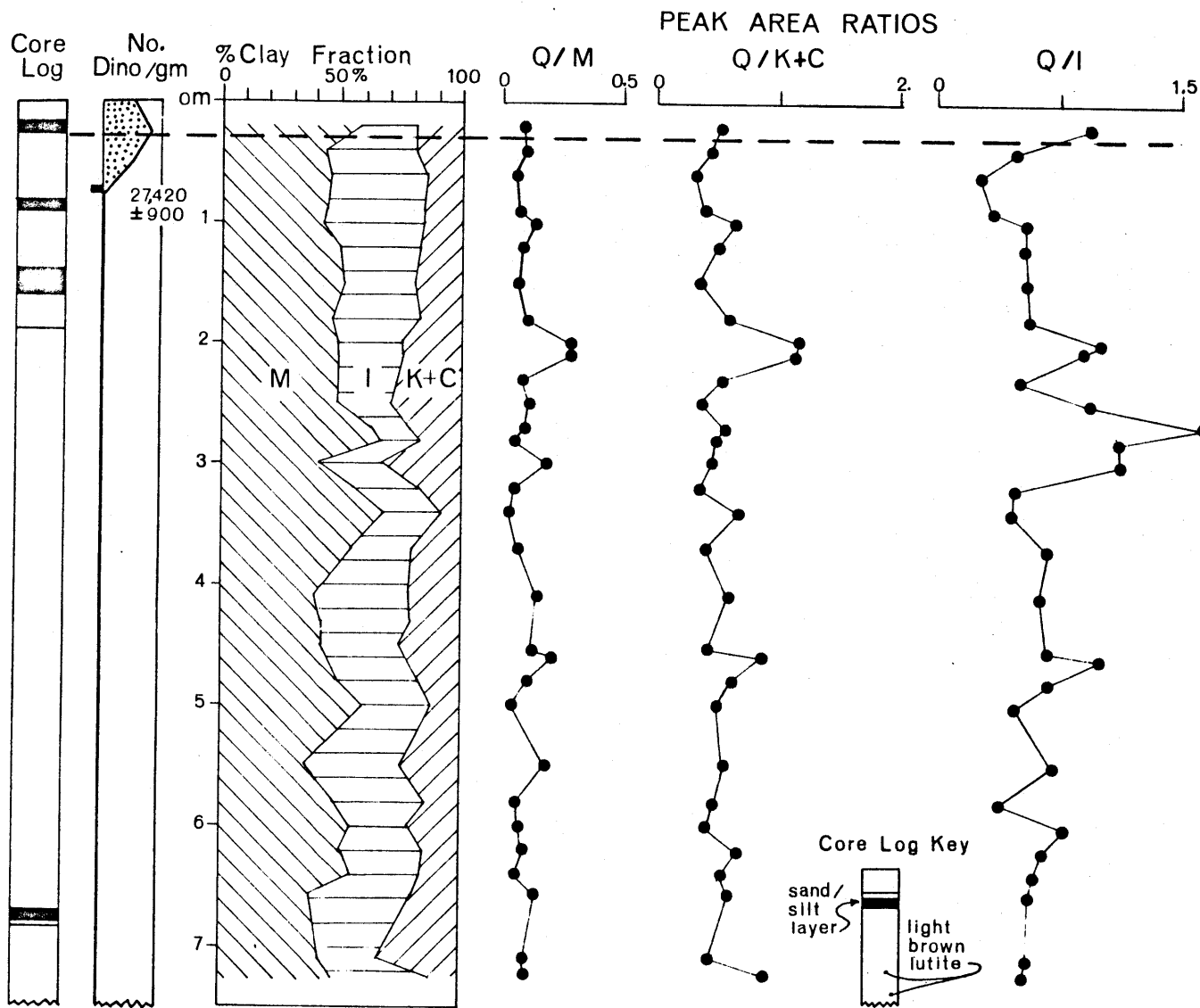
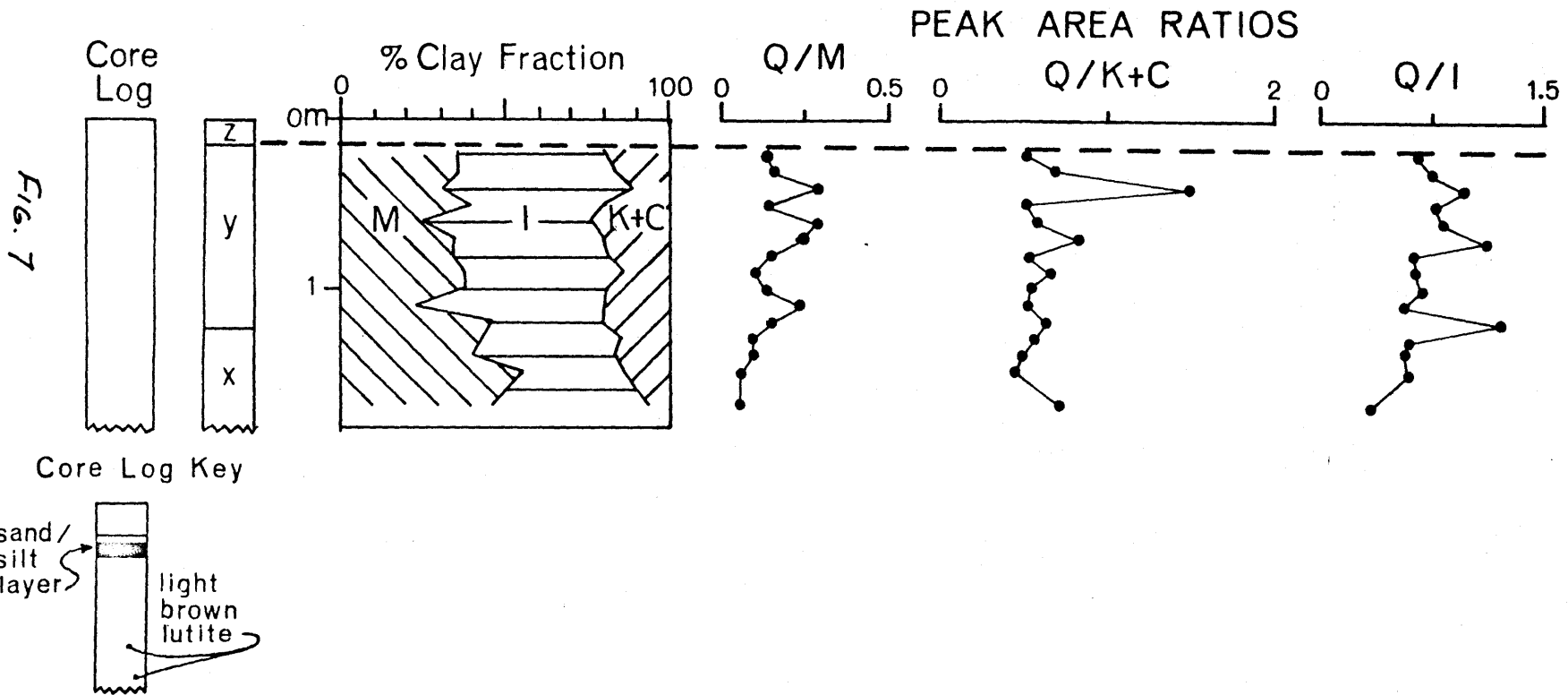


Fig. 6

SP8-4 CLAY MINERALOGY



CH96 G-10 CLAY MINERALOGY

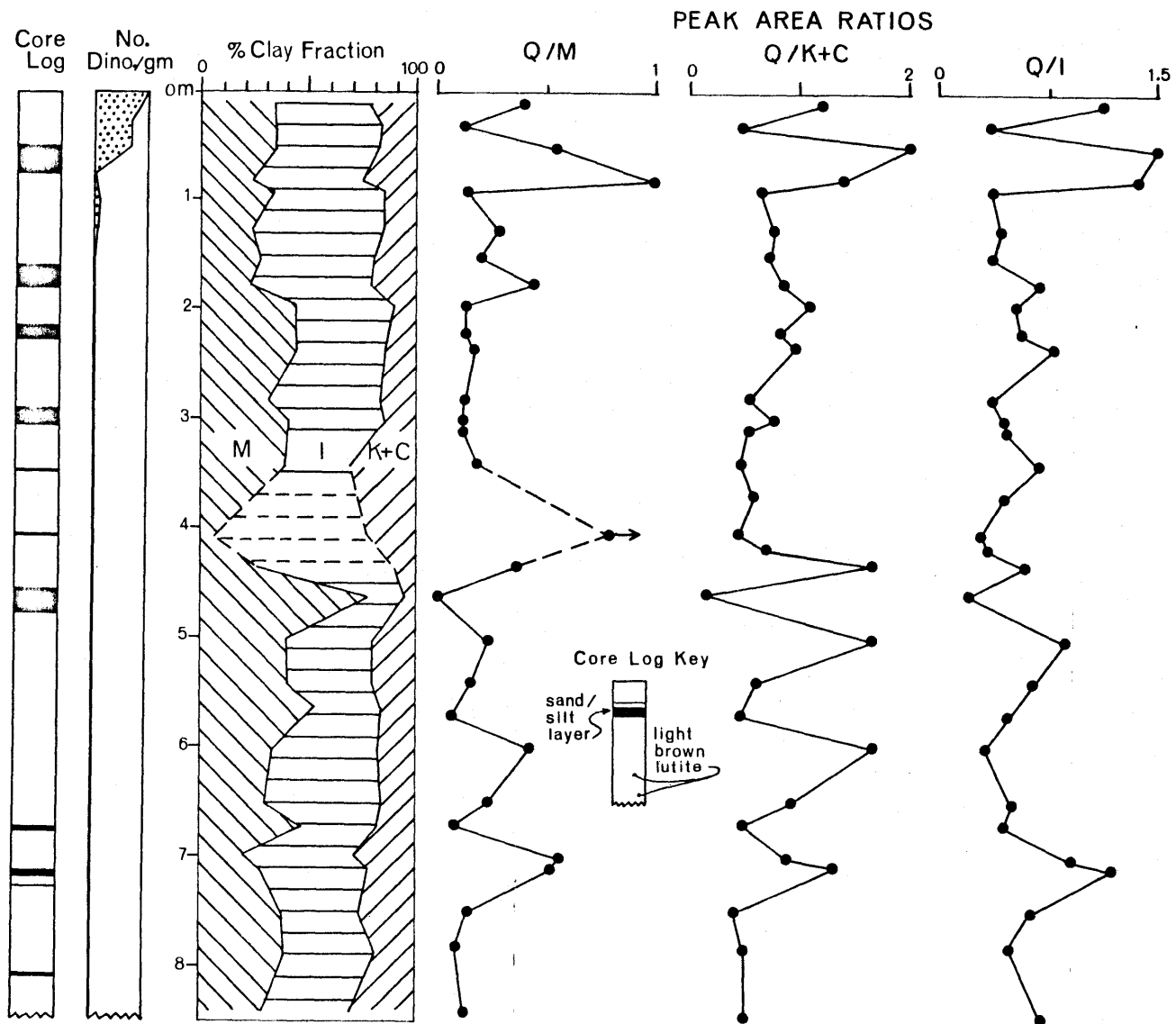


FIG. 8

FIG. 9

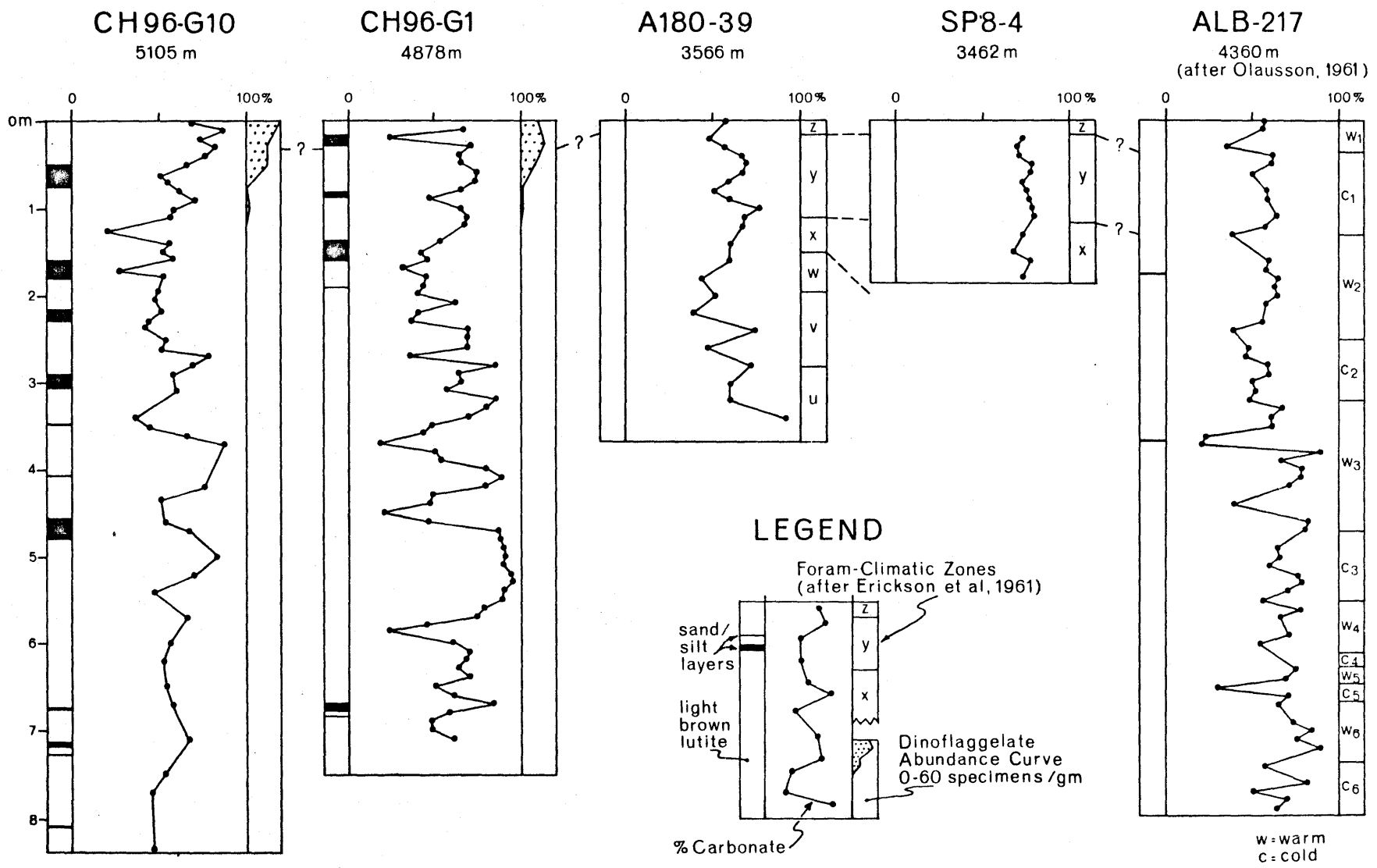


Fig. 10

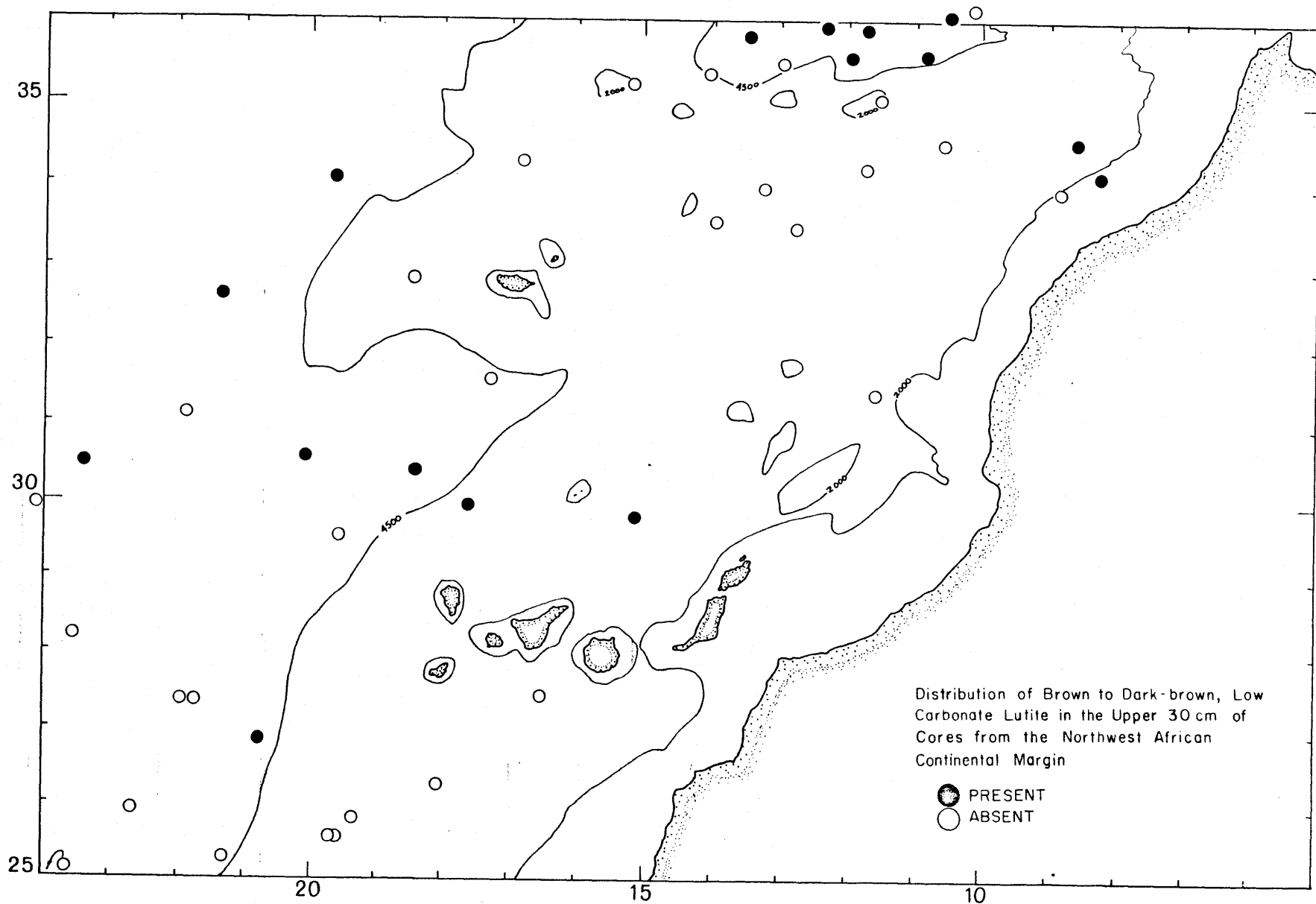
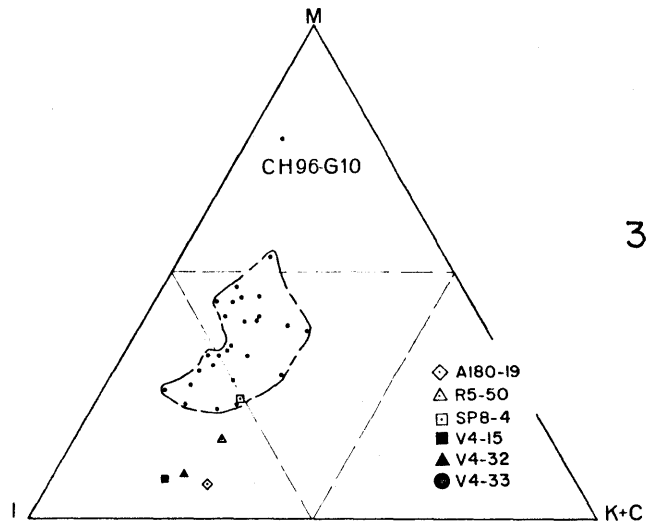
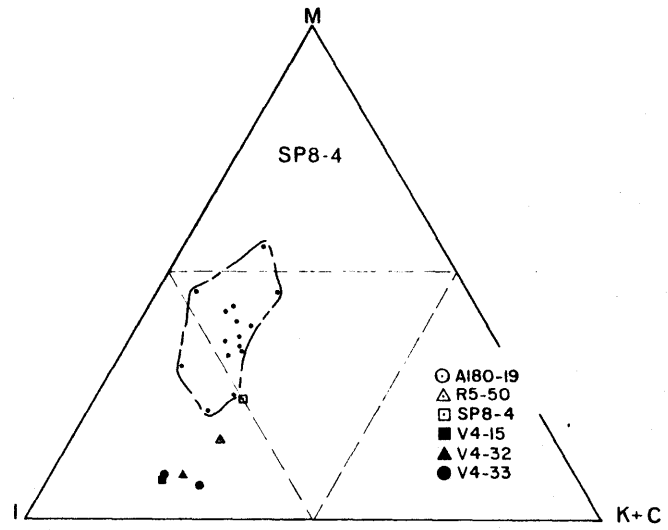


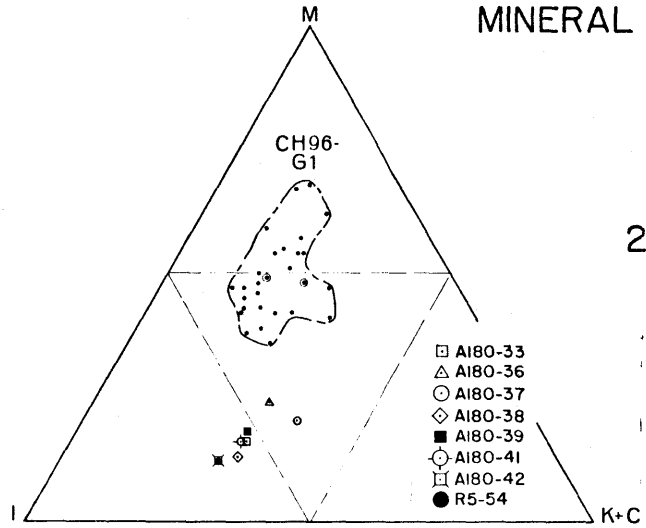
Fig. 11



33° N



RANGE OF CLAY
MINERAL ABUNDANCE



26° N

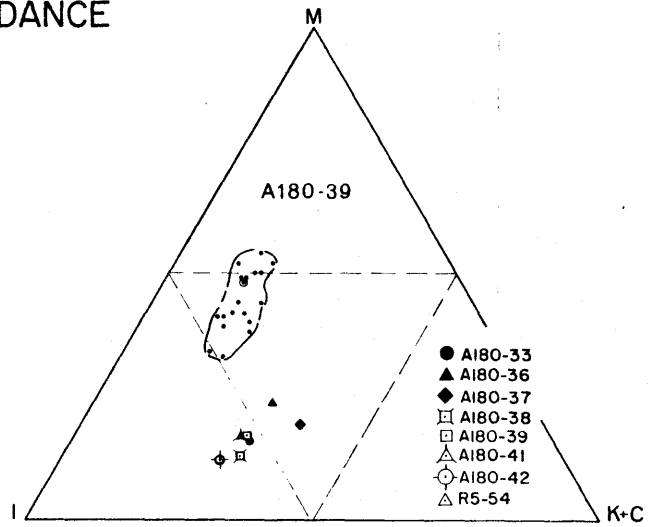
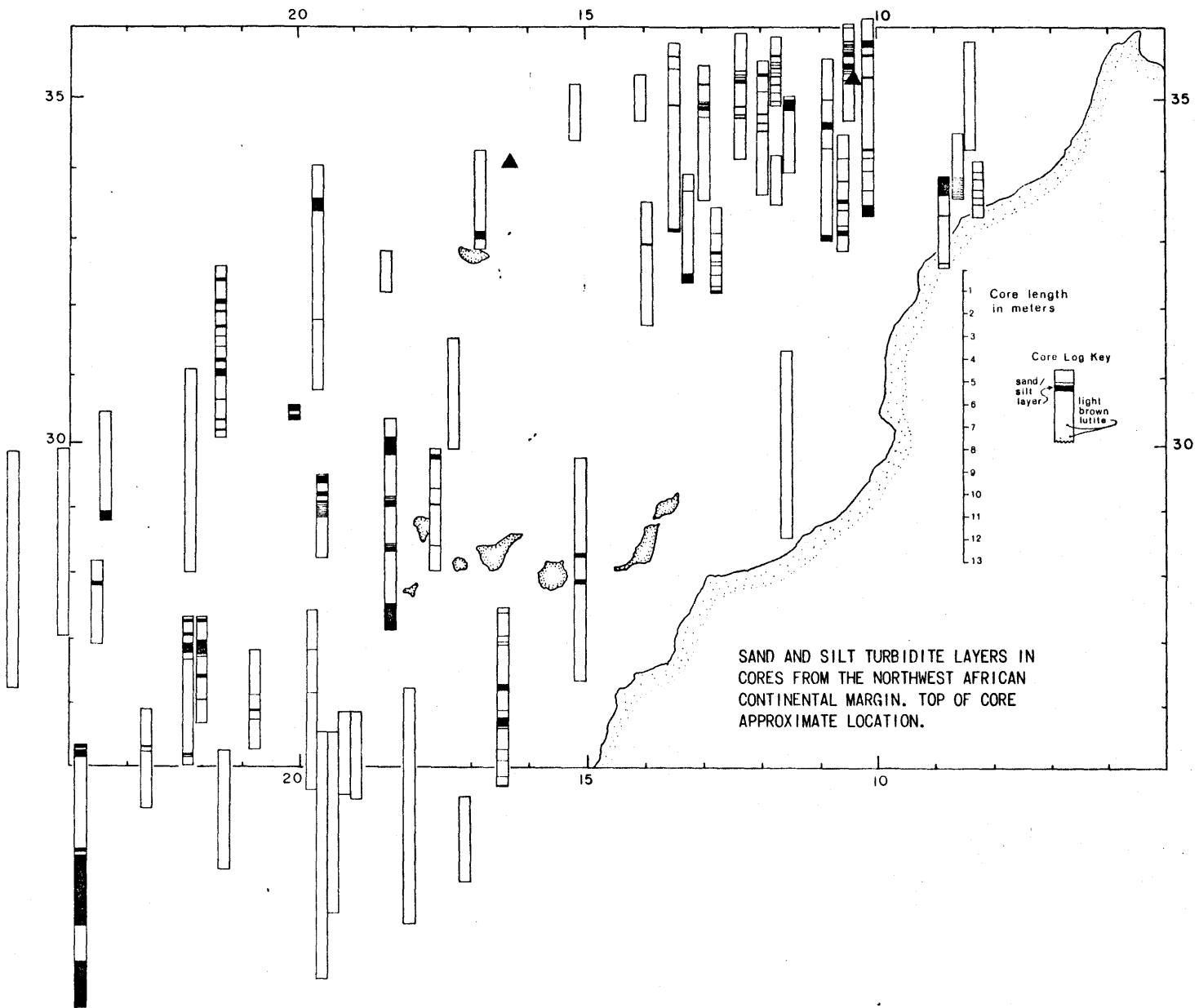


FIG. 12



APPENDIX 1

Laboratory Techniques: All samples were first separated by size. Sediments were soaked overnight in a 2% sodium metaphosphate deflocculating solution and wet sieved at 64 microns. The washings were carefully collected and the silts and clays were separated by centrifugation. All size fractions were dried at 60-70 C and weighed.

Clay Mineral Analysis by X-Ray Diffraction: oriented aggregates of clay minerals were prepared by passing very dilute suspensions of the clay size fraction in deflocculating solution through silver (Millipore) filters (nominal pore diameter 0.45 microns) under vacuum. Fine grained carbonate was removed by spraying the prepared filter with dilute acetic acid while still under vacuum after all suspensate had passed through. Two preparations of four samples with and without acid treatment were run to test for effects of this treatment on the X-ray diffraction patterns. No significant differences were noted in the replicate runs.

Some samples from core A180-39 were noticeably iron stained from storage in core pipes. Two splits of three samples were prepared and the amorphous iron was dissolved from one split by treating the sediment with a warm, bicarbonate buffered, sodium dithionate-citrate solution which removes the free iron as a soluble complex and leaves the iron

silicate clays virtually unchanged (Mehra and Jackson, 1960). No special treatment was given the other split. Both splits were then deposited on filters and X-rayed under the same conditions. No significant difference was noted between the diffraction patterns of the treated and untreated samples. It is assumed that in spite of the obvious staining the total amorphous iron in the sediments is negligible with respect to the X-ray procedure.

Montmorillonite, illite, and kaolinite were the main clay mineral groups identified in the marine sediments of the northwest African margin. Chlorite was also identified in the sediments but its concentration was very low. Attempts to differentiate the kaolinite (002) and chlorite (004) peaks by a slow scan ($\frac{1}{2}$ degree 2θ /min) of the $24-26^\circ 2\theta$ region as suggested by Biscaye (1964b) were unsuccessful. Therefore, abundance of kaolinite and chlorite are presented as the sum of the two groups with the understanding that the abundance of chlorite is probably much less than 10%.

Since some of the (00 λ) X-ray reflections of the various clay minerals coincide and thus interfere, it was necessary to apply various treatments to the clays which change their basal spacings to avoid misidentifications. After being run untreated, each filter was placed on a thin film of ethylene glycol, for at least 45 min. The glycol invades the crystal

lattice of the montmorillonite causing them to expand to a 17 Å d-spacing from a spacing of approximately 14-15 Å. No other minerals are affected by this treatment. After the glycolated filters were run they were placed in an oven and heated to 550° C for at least 30 min. This treatment preferentially destroyed the 7Å kaolinite plus chlorite peak, collapsed the montmorillonites to about 10Å, left the 10Å illite peak unchanged, and slightly enhanced the 14Å chlorite peak.

X-ray conditions were kept the same for all runs. Samples were run from 2° to 40° 2θ at 2°/min, 40 ma, 40 kV, using Ni filtered CuK radiation on a Phillips diffractometer.

The semi-quantitative method of Biscaye (1964a, 1965) was used to determine the absolute amount of each clay mineral present. Peak areas were measured by counting the number of 0.1 inch squares between the diffraction trace and a visually estimated background baseline, and, on glycolated diffractograms, the 17Å (001) peak-area ascribed to the montmorillonite group was added to four times the 10Å (001) illite peak-area plus two times the 7Å kaolinite (001) plus chlorite (002) peak-area. Absolute abundance was computed by dividing the multiples of each characteristic peak area by the sum of the peak areas.

Biscaye points out that besides the difficulty in accurately measuring peak areas above the normal X-ray background noise and because of uncertainties in sample preparation, differences in mineral crystallinity, physical properties, and chemistry between

samples, and the obviously invalid assumption that clay minerals constitute 100% of the less than 2 micron fraction, the resulting absolute values can only be viewed as very rough estimates of the amounts actually present. In such closed systems, real variations in one component can cause artificial variations in the other components. However, Pierce and Siegal (1969) have shown that of five commonly used methods for estimating clay mineral abundance, including those similar to Biscaye's, all were able to consistently show true trends in the relative amounts of the clay minerals. Changes in the absolute percent reported here should only be viewed as rough estimates of the true amounts present. In addition, variations of less than 20% should be viewed critically since the sum of all possible errors is nearly 20%. Sample data is tabulated in Appendix 2.

A second, more qualitative, approach to the measurement of mineral abundance is the ratio of peak-areas characteristic of any two minerals. In this study the quartz peak at 4.36 A was compared to the characteristic clay mineral peaks cited above. Interpretation of changes in quartz/clay mineral peak area ratios was made by comparing the peak-area ratio curve with the corresponding depth interval in the absolute abundance curve of the clay mineral. If the absolute abundance of the clay mineral was relatively constant through the interval ($\pm 10\%$), the change in peak area ratio was probably caused by change in quartz abundance. Otherwise, no significance was attached to changes in peak area ratios.

Analysis of the Silt Fraction: grain mounts of the 20-64 micron carbonate-free fraction were studied for their composition under the petrographic microscope. At least 200 grains were counted for each sample and the resulting mineral abundances presented as percent of total grains counted. Data is summarized in Appendix 3.

Percent Carbonate Determinations: percent carbonate was determined by two methods. The method of Hülsemann (1966) finds the percent total carbonate from the manometrically determined volume of CO₂ gas evolved during HCl treatment; the acid leaching method assumes the percent carbonate is equal to weight lost in the sample after treatment with dilute acid. According to Hülsemann the accuracy of the manometric method is $\pm 0.1\%$. To determine the accuracy of the acid leaching method splits of 15 samples from core CH96 G1 were analysed by both methods. By considering the values derived from the Hülsemann method as true values, the acid leaching method attained an accuracy of $\pm 5\%$. Sample data is compiled in Appendix 4.

Preparation of Dinoflagellates: ten to 15 gram samples from the cores were first leached in dilute HCl for 3 days with occasional stirring to remove carbonates and then washed to neutrallity in distilled water. Concentrated HF was then added to the residue to remove silicates and warmed to 68° C in a water bath. After treating for 3 days with HF the organic

residue was washed to neutrality with distilled water and sieved at 20 microns to remove extraneous matter. The remaining suspension was diluted to exactly one liter and well mixed. A 100 ml aliquot of the freshly agitated suspension was extracted by decantation, centrifuged, and poured off to reduce the volume of the supernatant. Small drops of the concentrated 100 ml aliquot were placed individually on a microscope slide and all specimens therein identified and counted until the entire aliquot had been examined. After the preceding treatments the only organisms remaining were the dinoflagellates.

As a measure of dinoflagellate abundance total number of specimens per gram was determined by multiplying the number of specimens per 100 ml aliquot by the proper factor to equal the total number in one liter. This number was divided by the dry weight of the sample before treatment to determine the number per gram of sediment. A minimum of 300 individuals is normally required to be able to draw meaningful statistical inferences on the true population. In the 26 samples studied total number of individuals in any 10-15 gram sample exceeded 200 in only one case. Therefore, no attempt is made to treat the results on a statistical basis and only the number of dinoflagellates per gram dry sediment is reported as a measure of absolute abundance. A species list and summary of species counts appears in Appendix 5.

APPENDIX 2

Absolute abundance of the montmorillonite (17A), illite (10A), and kaolinite + chlorite (7A) clay mineral groups expressed as percent of weighted peak areas, and quartz (4.36A)/clay mineral peak-area ratios.

| Core No. | Depth (cm) | 17A M | 10A I | 7A K+C | 4.36/10A Q/I | 4.36/17A Q/M | 4.36/7A Q/K+C |
|----------|------------|-------|-------|--------|--------------|--------------|---------------|
| CH96 G1 | 20 | 57 | 23 | 20 | .93 | .09 | .52 |
| " " | 40 | 43 | 37 | 20 | .48 | .102 | .44 |
| | 60 | 45 | 39 | 16 | .26 | .06 | .31 |
| | 90 | 43 | 40 | 17 | .35 | .08 | .40 |
| | 100 | 42 | 41 | 17 | .55 | .14 | .65 |
| | 120 | 49 | 33 | 18 | .54 | .09 | .50 |
| | 150 | 51 | 28 | 21 | .55 | .08 | .35 |
| | 180 | 46 | 36 | 18 | .57 | .11 | .60 |
| | 199 | 48 | 27 | 25 | 1.0 | .29 | 1.18 |
| | 210 | 48 | 27 | 25 | 2.06 | .2 | 1.14 |
| | 230 | 48 | 35 | 18 | .51 | .09 | .53 |
| | 249 | 47 | 23 | 30 | .94 | .12 | .37 |
| | 270 | 62 | 16 | 22 | 1.59 | .10 | .57 |
| | 280 | 66 | 16 | 18 | 1.13 | .07 | .49 |
| | 299 | 41 | 26 | 33 | 1.14 | .19 | .46 |
| | 320 | 55 | 27 | 18 | .48 | .06 | .36 |
| | 340 | 67 | 24 | 9 | .47 | .04 | .68 |
| | 370 | 54 | 25 | 21 | .69 | .08 | .42 |
| | 409 | 39 | 39 | 22 | .64 | .16 | .60 |
| | 430 | 42 | 37 | 21 | 1.02 | .22 | .88 |
| | 454 | 42 | 32 | 26 | .70 | .14 | .44 |

| Core No. | Depth (cm) | 17A M | 10A I | 7A K+C | 4.36/10A Q/I | 4.36/17A Q/M | 4.36/7A Q/K+C |
|-----------------|------------|-------|-------|--------|--------------|--------------|---------------|
| CH96 G1 " " | 480 | 49 | 33 | 18 | .70 | .12 | .65 |
| | 500 | 59 | 28 | 13 | .50 | .06 | .52 |
| | 549 | 36 | 39 | 25 | .73 | .20 | .59 |
| | 580 | 47 | 38 | 15 | .41 | .08 | .50 |
| | 600 | 54 | 24 | 22 | .80 | .09 | .43 |
| | 620 | 50 | 34 | 16 | .67 | .11 | .69 |
| | 640 | 54 | 29 | 17 | .62 | .08 | .56 |
| | 657 | 38 | 42 | 20 | .59 | .16 | .62 |
| | 710 | 42 | 35 | 23 | .58 | .12 | .46 |
| | 724 | 47 | 40 | 13 | .56 | .12 | .91 |
| CH96 G10 " " | 10 | 33 | 45 | 22 | 1.13 | .39 | 1.2 |
| | 30 | 35 | 47 | 17 | .35 | .12 | .48 |
| | 50 | 34 | 48 | 18 | 1.5 | .54 | 2.0 |
| | 80 | 23 | 52 | 25 | 1.4 | .99 | 1.4 |
| | 90 | 33 | 52 | 15 | .36 | .14 | .65 |
| | 125 | 23 | 61 | 16 | .42 | .28 | .77 |
| | 150 | 27 | 58 | 15 | .36 | .20 | .72 |
| | 175 | 22 | 56 | 22 | .68 | .44 | .85 |
| | 195 | 44 | 45 | 11 | .52 | .13 | 1.09 |
| | 220 | 44 | 42 | 14 | .56 | .13 | .82 |
| | 234 | 45 | 40 | 15 | .78 | .17 | .96 |
| | 280 | 31 | 52 | 17 | .36 | .13 | .55 |

| Core No. | Depth (cm) | 17A M | 10A I | 7A K+C | 68 | | | |
|----------|------------|-------|-------|--------|--------------|--------------|---------------|------|
| | | | | | 4.36/10A Q/I | 4.36/17A Q/M | 4.36/7A Q/K+C | |
| CH96 | G10 | 300 | 41 | 45 | 14 | .44 | .12 | .76 |
| " | " | 310 | 40 | 42 | 18 | .46 | .12 | .53 |
| | | 340 | 38 | 32 | 30 | .68 | .18 | .46 |
| | | 370* | | | | .44 | | .58 |
| | | 405** | 5 | 73 | 22 | .27 | | .44 |
| | | 418* | | | | .33 | | .69 |
| | | 433 | 26 | 63 | 11 | .58 | .36 | 1.65 |
| | | 460 | 77 | 17 | 6 | .19 | .01 | .14 |
| | | 501** | 40 | 40 | 20 | .86 | .23** | 1.64 |
| | | 540 | 41 | 39 | 20 | .64 | .15 | .60 |
| | | 570 | 53 | 31 | 16 | .46 | .07 | .45 |
| | | 600 | 33 | 50 | 17 | .31 | .42 | 1.7 |
| | | 650 | 30 | 55 | 15 | .49 | .23 | .92 |
| | | 670 | 47 | 40 | 17 | .43 | .08 | .48 |
| | | 700 | 21 | 53 | 26 | .87 | .56 | .90 |
| | | 710 | 28 | 50 | 22 | 1.17 | .52 | 1.31 |
| | | 750 | 39 | 35 | 26 | .62 | .14 | .40 |
| | | 785 | 45 | 37 | 18 | .45 | .09 | .46 |
| | | 839 | 29 | 41 | 30 | .62 | .22 | .42 |

* - Very poorly crystallized material. No abundance estimate made.

** - Poorly crystallized material. Visual estimate of abundance.

| <u>Core No.</u> | <u>Depth (cm)</u> | <u>17A M</u> | <u>10A I</u> | <u>7A K+C</u> | <u>4.36/10A Q/I</u> | <u>4.36/17A Q/M</u> | <u>4.36/7A Q/K+C</u> |
|-----------------|-------------------|--------------|--------------|---------------|---------------------|---------------------|----------------------|
| SP8-4 " " | 20 | 35 | 45 | 20 | .44 | .14 | .52 |
| | 30 | 36 | 47 | 17 | .51 | .16 | .70 |
| | 40 | 31 | 57 | 12 | .64 | .29 | 1.5 |
| | 50 | 39 | 41 | 20 | .52 | .14 | .53 |
| | 60 | 25 | 51 | 24 | .56 | .29 | .58 |
| | 70 | 34 | 45 | 21 | .75 | .23 | .83 |
| | 80 | 33 | 48 | 19 | .42 | .15 | .54 |
| | 90 | 42 | 44 | 14 | .43 | .11 | .65 |
| | 100 | 37 | 44 | 19 | .46 | .14 | .55 |
| | 110 | 22 | 57 | 21 | .38 | .24 | .53 |
| | 120 | 46 | 33 | 21 | .81 | .15 | .64 |
| | 130 | 43 | 42 | 15 | .40 | .10 | .56 |
| | 140 | 40 | 43 | 17 | .38 | .10 | .50 |
| | 150 | 55 | 31 | 14 | .39 | .06 | .45 |
| 170 | 46 | 47 | 7 | .23 | .06 | .72 | |
| A180-39 " " | 20 | 50 | 35 | 15 | | | |
| | 30 | 44 | 41 | 15 | .42 | .11 | .61 |
| | 40 | 34 | 51 | 15 | .35 | .13 | .58 |
| | 49 | 38 | 42 | 20 | .42 | .12 | .46 |
| | 60 | 50 | 34 | 16 | .46 | .08 | .50 |
| | 70 | 48 | 38 | 14 | .45 | .09 | .61 |
| | 80 | 44 | 37 | 19 | .48 | .10 | .49 |
| | 90 | 33 | 49 | 18 | .41 | .15 | .56 |
| | 100 | 49 | 38 | 13 | .41 | .08 | .62 |

70

| <u>Core No.</u> | <u>Depth (cm)</u> | <u>17A M</u> | <u>10A I</u> | <u>7A K+C</u> | <u>4.36/10A Q/I</u> | <u>4.36/17A Q/M</u> | <u>4.36/7A Q/K+C</u> |
|-----------------|-------------------|--------------|--------------|---------------|---------------------|---------------------|----------------------|
| A180-39 | 110 | 41 | 45 | 14 | .33 | .09 | .50 |
| " " | 120 | 39 | 46 | 14 | .37 | .11 | .56 |
| | 140 | 40 | 41 | 19 | .40 | .10 | .43 |
| | 180 | 42 | 41 | 17 | .56 | .14 | .65 |
| | 200 | 49 | 37 | 14 | .38 | .07 | .50 |
| | 220 | 52 | 31 | 16 | .45 | .07 | .44 |
| | 240 | 54 | 32 | 14 | .41 | .06 | .44 |
| | 260 | 41 | 46 | 13 | .32 | .09 | .55 |
| | 280 | 48 | 38 | 14 | .42 | .08 | .55 |
| | 300 | 50 | 35 | 15 | .42 | .08 | .55 |
| | 320 | 52 | 37 | 11 | .40 | .07 | .65 |
| | 340 | 42 | 43 | 14 | .33 | .08 | .45 |

APPENDIX 3

Results of grain counts of the 20-64 μ insoluble residue. Identifications made on the petrographic microscope. Values expressed as percent of total number of grains counted. Micaceous were mostly biotite; feldspars were mostly plagioclase. The category Other includes in order of decreasing abundance: volcanic glass, opaque minerals (mainly magnetite), olivine, sphene, zeolite (sanadine ?), and radiolarian tests. Except for quartz and small amounts of feldspar, none of the above minerals were identified in the clay size fraction X-ray diffraction patterns.

| Core No. | Depth (cm) | Quartz | Fspar | Mica | Pyroxene + Horneblnd | Hvy Min | Wthrd Frags | Other |
|-----------|------------|--------|-------|------|-------------------------|---------|-------------|-------|
| CH96 G1 | 20 | 45 | 8 | 8 | 8 | 1 | 22 | 6 |
| | 60 | 52 | 4 | 2 | 13 | 3 | 11 | 10 |
| | 90 | 30 | 7 | 9 | 9 | 8 | 9 | 12 |
| | 150 | 51 | 4 | 8 | 7 | 8 | 10 | 12 |
| | 230 | 50 | 4 | 7 | 4 | 2 | 24 | 12 |
| | 270 | 47 | 2 | 5 | 4 | 5 | 15 | 22 |
| | 340 | 47 | 3 | 10 | 7 | 8 | 12 | 8 |
| | 430 | 49 | 1 | 9 | 7 | 5 | 15 | 14 |
| | 500 | 56 | 2 | 6 | 8 | 1 | 9 | 18 |
| | 580 | 37 | 1 | 15 | 3 | 7 | 8 | 29 |
| CH96 G10* | 10 | 45 | 5 | 4 | 7 | | 8 | 30 |

* Heavy minerals included in Other in core CH96 G10, SP8-4, and A180-39.

| <u>Core No.</u> | <u>Depth (cm)</u> | <u>Quartz</u> | <u>Fspar</u> | <u>Mica</u> | <u>Pyroxene + Horneblnd</u> | <u>Hvy Min</u> | <u>Wthrd Frgs</u> | <u>Other</u> |
|-----------------|-------------------|---------------|--------------|-------------|---------------------------------|--------------------|-----------------------|--------------|
| CH96 G10 " " | 50 | 51 | 4 | 3 | 8 | | 8 | 22 |
| | 80 | 55 | 5 | 3 | 9 | | 7 | 21 |
| | 150 | 50 | 4 | 3 | 8 | | 5 | 30 |
| | 234 | 52 | 4 | 4 | 8 | | 6 | 25 |
| | 300 | 48 | 3 | 2 | 8 | | 8 | 30 |
| | 340 | 45 | 4 | 4 | 11 | | 10 | 26 |
| | 433 | 50 | 5 | 3 | 12 | | 8 | 20 |
| | 540 | 46 | 5 | 3 | 10 | | 8 | 26 |
| | 600 | 53 | 4 | 1 | 6 | | 8 | 25 |
| | 670 | 50 | 6 | 3 | 8 | | 11 | 19 |
| | 750 | 49 | 3 | 2 | 10 | | 11 | 24 |
| | 819 | 45 | 1 | 4 | 6 | | 10 | 30 |
| SP8-4 " " | 30 | 45 | 4 | 4 | 26 | | 17 | 4 |
| | 50 | 46 | 5 | 3 | 20 | | 20 | 6 |
| | 80 | 51 | 6 | 1 | 22 | | 12 | 7 |
| | 120 | 46 | 6 | 2 | 33 | | 11 | 12 |
| A180-39 " " | 20 | 67 | 8 | 4 | 2 | | 7 | 12 |
| | 49 | 63 | 9 | 5 | 3 | | 8 | 12 |
| | 80 | 60 | 7 | 3 | 1 | | 5 | 14 |
| | 120 | 60 | 5 | 3 | 2 | | 7 | 13 |
| | 180 | 65 | 7 | 4 | 3 | | 6 | 15 |
| | 220 | 66 | 8 | 5 | 3 | | 5 | 13 |
| | 280 | 68 | 9 | 3 | 1 | | 6 | 13 |

APPENDIX 4

Total carbonate as determined by the acid leaching (weight loss) method, A, and the method of Hülsemann (1966), H.

| Core No. | Depth (cm) | Percent Carbonate | | Core No. | Depth (cm) | Percent Carbonate | |
|-------------|---------------|----------------------|----|-------------|---------------|----------------------|----|
| | | H | A | | | H | A |
| CH96 G1 | 10 | 60.76 | | CH96 G1 | 220 | 46.41 | |
| | 20 | 24.05 | 23 | | 230 | 37.38 | 38 |
| | 30 | 71.06 | | | 240 | 69.49 | |
| | 40 | 63.55 | 64 | | 250 | 68.62 | |
| | 50 | 64.87 | | | 260 | 69.25 | |
| | 60 | 73.63 | 73 | | 270 | 35.83 | 33 |
| | 70 | 73.46 | | | 280 | 84.85 | 85 |
| | 80 | 64.87 | | | 290 | 78.18 | |
| | 90 | 47.09 | 40 | | 300 | 65.89 | |
| | 100 | 65.43 | 66 | | 310 | 56.72 | |
| | 110 | 68.10 | | | 320 | 85.72 | 70 |
| | 120 | 66.67 | | | 330 | 80.19 | |
| | 140 | 52.99 | | | 340 | 69.95 | 68 |
| | 150 | 41.69 | 43 | | 350 | 49.39 | |
| | 160 | 46.16 | | | 360 | 44.22 | |
| | 170 | 32.52 | | | 370 | 17.82 | 24 |
| | 180 | 45.41 | 46 | | 380 | 50.72 | |
| | 190 | 44.22 | | | 390 | 53.14 | |
| | 200 | 40.23 | | | 400 | 80.25 | |
| | 210 | 62.26 | 54 | | 410 | 88.38 | |

| Core No. | Depth (cm) | Percent Carbonate | | Core No. | Depth (cm) | Percent Carbonate | |
|----------|------------|-------------------|----|----------|------------|-------------------|----|
| | | H | A | | | H | A |
| CH96 G1 | 420 | 78.62 | | CH96 G1 | 650 | 54.39 | |
| | 430 | 48.79 | 37 | | 660 | 61.74 | |
| | 440 | 47.46 | | | 670 | 84.20 | |
| | 454 | 20.60 | 25 | | 680 | 57.90 | |
| | 460 | 37.73 | | | 692 | 48.38 | |
| | 470 | 87.40 | | | 694.5 | 84.82 | |
| | 480 | 87.95 | 90 | | 700 | 48.84 | |
| | 490 | 90.36 | | | 710 | 61.89 | 60 |
| | 500 | 90.59 | 90 | | 734 | | 83 |
| | 510 | 89.60 | | CH96 G10 | 0 | | 66 |
| | 520 | 93.58 | | | 10 | | 87 |
| | 530 | 94.55 | | | 20 | | 72 |
| | 540 | 90.47 | | | 30 | | 81 |
| | 550 | 88.54 | | | 40 | | 76 |
| | 560 | 77.92 | | | 60 | | 49 |
| | 570 | 74.73 | | | 70 | | 56 |
| | 580 | 44.52 | 51 | | 80 | | 62 |
| | 586 | 23.56 | | | 90 | | 71 |
| | 600 | 61.38 | 59 | | 100 | | 58 |
| | 610 | 71.25 | | | 110 | | 58 |
| | 620 | 67.91 | 68 | | 125 | | 20 |
| | 630 | 63.57 | | | 140 | | 57 |
| | 640 | 71.48 | 75 | | 150 | | 52 |

| Core No. | Depth (cm) | Percent Carbonate | | Core No. | Depth (cm) | Percent Carbonate | |
|----------|------------|-------------------|----|----------|------------|-------------------|----|
| | | H | A | | | A | |
| CH96 G10 | 160 | | 59 | CH96 G10 | 650 | | 55 |
| | 175 | | 26 | | 670 | | 60 |
| | 180 | | 54 | | 710 | | 67 |
| | 195 | | 50 | | 750 | | 53 |
| | 205 | | 48 | | 785 | | 49 |
| | 234 | | 42 | | 839 | | 52 |
| | 250 | | 55 | SP8-4 | 20 | | 73 |
| | 260 | | 52 | | 30 | | 70 |
| | 270 | | 79 | | 40 | | 70 |
| | 280 | | 70 | | 50 | | 79 |
| | 310 | | 60 | | 60 | | 78 |
| | 340 | | 36 | | 70 | | 73 |
| | 350 | | 45 | | 80 | | 75 |
| | 370 | | 88 | | 90 | | 76 |
| | 418 | | 75 | | 100 | | 78 |
| | 433 | | 51 | | 110 | | 80 |
| | 460 | | 53 | | 130 | | 73 |
| | 501 | | 84 | | 140 | | 68 |
| | 540 | | 47 | | 150 | | 78 |
| | 570 | | 67 | | 170 | | 73 |
| | 600 | | 56 | A180-39 | 0* | | 57 |
| | 620 | | 55 | | 20 | | 49 |

*Data from Ericson et al (1961)

| <u>Core No.</u> | <u>Depth (cm)</u> | <u>Percent Carbonate A</u> |
|---------------------|-----------------------|------------------------------------|
| A180-39 | 30 | 57 |
| | 40 | 67 |
| | 49 | 70 |
| | 60 | 67 |
| | 70 | 59 |
| | 80 | 51 |
| | 90 | 60 |
| | 100 | 77 |
| | 110 | 68 |
| | 120 | 67 |
| | 140 | 60 |
| | 160 | 60 |
| | 180 | 44 |
| | 200 | 52 |
| | 220 | 39 |
| | 240 | 74 |
| | 260 | 47 |
| | 280 | 72 |
| | 300 | 60 |
| | 320 | 60 |
| | 340 | 92 |

APPENDIX 5

The following dinoflagellate species were identified in cores CH96 G1 and G10: Leptodinium aculeatum Wall, L. patalum Wall, L. paradoxum Wall, L. striatum Wall, L. sphaericum Wall, Spiniferites furcata (Ehr.) Wetz., S. bulloidea Cooks. and Eis., S. mirabilis Ross., Operculodinium centrocarpum (Defl. and Cooks.) Wall, O. israelianum (Ross.) Wall, Nematosphaeropsis balcombiana Defl. and Cooks., Hemicystodinium zoharyi (Ross.) Wall, Lingulodinium machaerophorum (Defl. and Cooks.) Wall (CH96 G10 only), Tectatodinium vancampoae (Ross.) Wall, and various Peridinium cysts.

The following table is a summary of the number of cysts per dinoflagellate group per gram dry sediment: (on following page)

Core No./
Depth (in
cm)

TOTAL NO. DINOFLAGELLATES

OPERCULODINIUM

LEPTODINIUM

HEMICYSTODINIUM

SPINIFERITES

TECTATODINIUM

PERIDINIUM

LINGULODINIUM

TUBERCULODINIUM

ALL POLLEN

CH96 G10/

| | | | | | | | | | | |
|-----|------|-----|------|----|-----|----|-----|-----|-----|------|
| 0 | 58.0 | .9 | 42.4 | .6 | 1.5 | - | 1.2 | 3.8 | .9 | 22.0 |
| 25 | 33.0 | .3 | 28.0 | - | 1.4 | .3 | .3 | - | - | 3.0 |
| 50 | 32.0 | 3.6 | 18.0 | - | 2.5 | - | .3 | 3.6 | 1.1 | 7.5 |
| 75 | .5 | - | - | - | - | - | - | - | - | 1.8 |
| 100 | 6. | .3 | 5.9 | - | .2 | - | - | - | - | 1.4 |
| 125 | 3. | - | 2.6 | - | - | - | - | - | - | 1.8 |
| 150 | - | - | - | - | - | - | - | - | - | .2 |
| 300 | - | - | - | - | - | - | - | - | - | - |
| 350 | - | - | - | - | - | - | - | - | - | .5 |
| 400 | .05 | - | .05 | - | - | - | - | - | - | .5 |
| 450 | - | - | - | - | - | - | - | - | - | - |
| 520 | - | - | - | - | - | - | - | - | - | - |

Core No./
Depth (in
cm)

CH96 G10 (continued)

TOTAL NO. DINOFLAGELLATES
OPERCULODINIUM

LEPTODINIUM

HEMICYSTODINIUM

SPINIFERITES

TECTATODINIUM

PERIDINIUM

LINGULODINIUM

TUBERCULODINIUM

ALL POLLEN

| | | | | | | | | | | |
|-----|-----|---|---|---|---|-----|---|---|---|----|
| 600 | - | - | - | - | - | - | - | - | - | - |
| 650 | - | - | - | - | - | - | - | - | - | - |
| 675 | - | - | - | - | - | - | - | - | - | - |
| 700 | - | - | - | - | - | - | - | - | - | - |
| 750 | - | - | - | - | - | - | - | - | - | - |
| 800 | .05 | - | - | - | - | .05 | - | - | - | .2 |

Core No./
Depth
(in cm)

TOTAL DINOFLAGELLATES

OPERCULODINIUM

LEP.TODINIUM

HEMICYSTODINIUM

SPINIFERITES

TECTA TODINIUM

PERIDINIUM

NEMATOSPHAEROPSIS

TUBERCULODINIUM

ALL POLLEN

CH96 G1/

| | | | | | | | | | | |
|-----|------|-----|------|-----|------|----|----|----|----|-----|
| 0 | 28.0 | 5.0 | 11.8 | 1.9 | 5.1 | .3 | .6 | - | .3 | - |
| 25 | 41.0 | 3.4 | 7.4 | .1 | 25.0 | - | .4 | .7 | - | 3.3 |
| 50 | 24.0 | .1 | 23.0 | .2 | .3 | - | .2 | .2 | - | 1.3 |
| 75 | 0.1 | - | .1 | - | - | - | - | - | - | .4 |
| 100 | .3 | - | - | - | .1 | - | .1 | - | - | .5 |
| 140 | - | - | - | - | - | - | - | - | - | .1 |
| 200 | .5 | - | .5 | - | - | - | - | - | - | .1 |
| 305 | .5 | - | - | - | .5 | - | - | - | - | .5 |
| 400 | - | - | - | - | - | - | - | - | - | .2 |
| 450 | - | - | - | - | - | - | - | - | - | - |
| 500 | - | - | - | - | - | - | - | - | - | .2 |
| 600 | - | - | - | - | - | - | - | - | - | .3 |
| 650 | - | - | - | - | - | - | - | - | - | .01 |

Core No./
Depth (in
cm)

CH96 G1 (continued)

TOTAL NO DINOFLAGELLATES
OPERCULODINIUM
LEPTODINIUM
HEMICYSTODINIUM
SPINIFERITES
TECTATODINIUM
PERIDINIUM
NEMATOSPHAEROPSIS
TUBERCULODINIUM
ALL POLLEN

| | | | | | | | | | | | |
|-----|---|---|---|---|---|---|---|---|---|---|----|
| 700 | - | - | - | - | - | - | - | - | - | - | .3 |
| 720 | - | - | - | - | - | - | - | - | - | - | - |