2. EXPLANATORY NOTES

Shipboard Scientific Party¹ With Additional Contributions From Norman Hamilton, University of Southampton, United Kingdom,

and

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DATA PRESENTATION AND AUTHORSHIP

Except for the report on Paleomagnetism, the routine contributions to the site chapters (Chapters 3 to 8, 15 to 20) were written by members of the Shipboard Scientific Party as follows. Background and Objectives was written by R. B. Whitmarsh, except for Sites 225, 226, and 227 which was by D. A. Ross; Operations was written by R. B. Whitmarsh with O. E. Weser (Sites 219 to 224) or with D. A. Ross (Sites 225 to 230); Lithology was written by S. Ali (Sites 225, 230), D. Jipa (Site 222), R. B. Kidd (Site 221), T. K. Mallik (Site 220), A. Matter (Sites 223, 228), H. M. Siddiquie (Site 219), P. Stoffers (Sites 224, 226, 227), and P. R. Supko (Site 229), with Igneous Petrology by R. G. Coleman. R. L. Fleisher wrote the Foraminifera and Sedimentation Rate reports, J. E. Boudreaux the Nannofossil report, and C. Nigrini the Radiolaria report with the Biostratigraphic Summary being written by one of these paleontologists. Geochemistry was written by S. Ali and P. Stoffers (Sites 219 to 224) or by F. T. Manheim (Sites 225 to 230); Physical Properties by R. B. Kidd (Sites 219 to 224) or by R. W. Girdler (Sites 225 to 230); Correlation of Reflection Profiles and Lithologies by R. B. Whitmarsh; Paleomagnetism by N. Hamilton (shore-based study on samples from Sites 219 to 224); and Heat Flow by R. W. Girdler (Sites 225, 227, 228, 229). The Discussion and

Conclusions sections are based on the ideas and contributions of the whole Shipboard Party and was written by R. B. Whitmarsh (Sites 219, 223, 224, 228, 229, 230); O. E. Weser (Sites 220, 221, 222); and D. A. Ross (Sites 225, 226, 227). The authorship of extra studies by shorebased workers is indicated in the text with the writer's full name appearing in the author list at the beginning of the chapter.

The first page of each site chapter contains a site location chart, summary statistics, and an abstract of results. In addition, it also shows a graphical summary of the stratigraphic column. The immediately succeeding pages contain the operational and scientific text. Following the text is the Hole Summary, at a scale of 250 meters per page, which summarizes the paleontological, lithological, and physical properties data on pairs of facing pages. Finally, there are the Core Summaries (paleontology, lithology, physical properties, and core photographs).

Following the site chapters are the more interpretative chapters drawing together the results of two or more sites. These chapters have been written by members of the Shipboard Scientific Party and by shore-based workers.

A geophysical Appendix is located at the end of the report and contains the airgun profiles obtained by *Glomar Challenger* during Leg 23. These and other underway geophysical data (track, bathymetry, and magnetic anomalies) are obtainable as a data report directly from the Deep Sea Drilling Project. Science Editors for this report were O. E. Weser (Leg 23A, Arabian Sea) and P. R. Supko (Leg 23B, Red Sea).

UNDERWAY OBSERVATIONS AND ON-SITE OPERATIONS

All scientific observations onboard *Glomar Challenger* were recorded according to the time at the meridian of Greenwich (GMT). However, since the ship's crew and the drilling crew operated on local time, the times recorded in the Operations section of the site chapters are in local time (LT).

Navigation was based almost entirely on the satellite navigation system. In the southern Red Sea relative navigation was carried out by means of frequent radar or visual fixes on landmarks. However, in absolute terms these fixes showed discrepancies of up to one mile with respect to the satellite fixes. The position of every site has been determined from the average of between 3 and 8 satellite fixes. In the Arabian Sea graphically determined mean

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surface current vectors were useful in predicting the ship's position when combined with a dead-reckoned course, but in the Red Sea the strong and variable surface currents usually gave imprecise results.

Underway depths were continuously recorded on a Gifft precision graphic recorder (PGR). The depths were read on the basis of an assumed 800 fathoms/second sounding velocity. The sea depth read from the PGR 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, 10 meters were added to the resultant depth to give the depth beneath the drill floor as a guide to the drillers when they were lowering pipe.

The total magnetic field was measured underway every 6 sec by a Varian proton precision magnetometer and recorded on a 1000-gamma-wide stripchart.

The seismic profiling system consisted of two Bolt airguns, a Scripps-designed hydrophone array, Bolt amplifiers, two bandpass filters, and two Edo recorders. By the nature of the equipment the recorders had to display different sweep times, but usually the master Edo triggered the guns every 5 or 6 sec. Up to Site 225 a 40 (or 30) cubic inch and a 5 cubic inch gun were used. For most of the remainder of the Red Sea track a 10 and a 5 cubic inch gun were used since penetration could be traded off against resolution in this region. Six disposable sonobuoys were used in conjunction with an airgun in an attempt to measure sediment thickness when "basement" was not visible on the vertical reflection profiles. Two buoys gave records with subbottom reflections between Sites 222 and 223, but these records were of insufficient quality for sediment thicknesses to be calculated.

No precruise survey was available for any of the sites and so a short presite survey was always carried out. This was usually supplemented by a track directly over the sea-bed acoustic beacon on departure. The system for automatically positioning Glomar Challenger over the sea-bed beacon was inoperative for Sites 220 to 224 due to a computer hardware fault. However, the master and officers of the ship were able to successfully keep on station at each of these sites by manually controlling the ship's propulsion. This procedure would have been impracticable in the much shallower Red Sea, and, consequently, a technician was brought onboard at Djibouti to effect repairs before the first Red Sea site was reached. At all holes, 3- or 4-cone roller bits with tungsten carbide inserts were used. The standard core length was chosen to be 9.0 meters but, since this length is not exactly equal to one joint of drill pipe, during continuous coring about every sixth core had to be cut short.

Often the driller was able to "feel" the sea bed as the bit reached the sediment, and the length of pipe out at this point may be regarded as a measure of the depth of the sea. However, since there were also occasions when the bottom was not felt for 10 or more meters below the PGR depth, it is possible that these "depths" are in error and correspond to the first firm sediment below the sea bed. Therefore, the quoted sea depths at each site are from the PGR. This procedure makes it possible to relate the site depth to the contoured bathymetry around a site. Lastly, it should be stressed that it became common practice during Leg 23 to drill ahead with the inner core barrel in place. This procedure arose from the time saved if the empty barrel were dropped down the pipe immediately after the retrieved barrel had been brought on deck. In this way a joint had to be opened only once per core. Although during drilling it is unlikely that sediment will enter the open core barrel due to the flushing action of the water jets around the bit, this may have occasionally occurred so that part of the recovered sediment is not representative of the specified cored interval. In practice, the possibility of this being a serious problem increases as the sediments become more indurated and the length of the drilled interval increases.

NUMBERING AND DOWNHOLE DEPTH OF CORES

Cores were cut into sections 1.5 meters long measured from the base of the recovered material. To reference a sample in the text, a shorthand numbering system was devised. Briefly, a sample designated as 23-219A-11-3, 24-25 cm (or abbreviated to 219A-11-3, 24-25 cm) came from between 24 and 25 cm below the top of Section 3 of Core 11 from the A hole at Site 219 which was drilled during Leg 23. A core-catcher sample is denoted by CC, e.g., 219A-11-3, CC, and a sample from the sidewall corer by SW-1 where 1 is the number of the sidewall core obtained at a site, e.g., 224-SW-1. Basalt pieces in a core were marked with an arrow pointing to the top of the core and sequentially numbered.

By convention, and for the lack of any definitive criterion, when the core barrel is only partly full the top of the uppermost section containing core material is assumed to have come from the top of the cored interval and the core-catcher sample is assumed to have been continuous with the base of the bottom section when in situ.

Since the plastic liner of the inner core barrel is 9.28 meters long at times more than 9 meters of sediment was recovered. In these cases the short extra core was designated Section 0 and when the above convention is followed, overlapping cores unavoidably appear on the hole summary.

HANDLING OF CORES

The cores were labeled and cut into sections as described in Volume 2, Appendix II of the Initial Report of the Deep Sea Drilling Project. When gas was present in the core, a gas sample was taken through the plastic liner before the core was split. In the core laboratory the following routine procedures were usually carried out.

1) Weighing of full sections to obtain a mean section density,

2) Continuous density/porosity determination along cores by the GRAPE,

3) Thermal conductivity measurements on selected sections,

4) Geochemical sampling (Red Sea only),

5) Electrical resistivity measurements (Red Sea only).

The liners were then cut lengthways and normally the cores were split, except when the cores were degassing vigorously or when evaporites or basalt had been cored. The archive half of each core was cleaned and photographed. The working half was described by the sedimentologists and sampled in the manner described in Volume 2, Appendix II. Paleomagnetic samples (Arabian Sea only) and sonic velocity measurements were taken at this stage. The working half of each section was then passed to the paleontologists for further sampling. Finally, both archive and working halves were stored in core vans onboard Glomar Challenger at a temperature of 4°C until the end of August 1972 when they were shipped from Durban to the United States. The cores are now stored at the West Coast Core Repository at Scripps Institution of Oceanography. Requests for samples should be sent to the Curator of cores at this institution.

DRILLERS TERMINOLOGY

For the sake of brevity, drilling jargon has sometimes been used in this report. To help those unfamiliar with the drilling operations to understand the phraseology sometimes used in the Operations section of a site chapter and elsewhere, a brief glossary of terms is appended here.

Bit weight – the drill bit is decoupled from the bottom of the drill string by normally four telescoping pipe sections (bumper subs) separated by heavy pipe. Thus the weight of heavy pipe acting on the bit can be increased by lowering the drill string so as to close up more and more of the telescopic sections, and vice versa.

Breaking circulation – seawater pumped down the drill pipe is used as the circulating fluid in the open circulation system used by *Glomar Challenger*. During coring, circulation is avoided as far as possible since the water emerging from the jets between the roller cones tends to wash away, or at least break up, the softer sediments. However, sometimes after several meters of a core have been cut, it becomes necessary to initiate circulation, perhaps only momentarily, to clear away sediment cuttings from the bit. This is called breaking circulation.

Punch core – a punch core is obtained simply by lowering the pipe into the sea bed without rotating it. Usually a special reduced diameter inner core barrel (known as an extended barrel) is used which protrudes about a foot beyond the bit so as to protect the sediment from the water jets.

Sandline – this is a winch cable which passes down the inside of the drill pipe and is used for retrieving the inner core barrel or for raising and lowering the heat flow instrument.

Spotting mud – the seawater circulation system is not always able to flush dense rock chippings out of the hole onto the sea bed. After cutting through formations such as chert, limestone, or basalt, cuttings may accumulate at the bottom of the hole so that the rotating roller cones on the bit are in danger of becoming jammed up. Under such conditions a "plug" of denser bentonite mud is pumped or "spotted" through the hole to flush out these cuttings.

Torque up - the drill string is said to have torqued up whenever the string gets stuck in some part of the hole and cannot be rotated, or can only be rotated with difficulty.

Washing down - a procedure whereby penetration is accomplished solely by means of using the water jets to wash away the sediment without rotating the pipe.

DRILLING DISTURBANCES

The types and causes of drilling disturbances have been extensively discussed in previous volumes of the Initial Reports (e.g., Volumes 5, 7, and 12). Since these earlier remarks can be applied to the Leg 23 cores, drilling disturbances do not warrant further discussion here. A drilling disturbance code was developed onboard ship, however, which was based on photographs of some "typical" disturbances. These photos were used as references by the sedimentologists when filling in the Visual Core Description form for each section of core and have been used on the core summaries presented in this report. For purposes of "calibration" these reference sections and their symbolic representation are presented here (Figure 1).

SEDIMENTOLOGICAL AND STRATIGRAPHIC CONVENTIONS

Sediment Classification and Nomenclature Rules

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

CLASSIFICATION AND NOMENCLATURE RULES

I. Rules for class limits and sequential listing of constituents in a sediment name

- A. Major Constituents
 - Sediment assumes the name of those constituents present in major amounts (major defined as >25%). See example in rule IA3.
 - Where more than one major constituent is present, the one in greatest abundance is listed farthest to the right. In order of decreasing abundance, the remaining major constituents are listed progressively farther to the left.
 - Class limits, when two or more major constituents are present in a sediment, are based on 25% intervals, thus: 0-25, 25-50, 50-75, 75-100.

Example illustrating rules 1 to 3 and the resulting sediment names:

% Zeolites	% Nannos		
0-25	75-100	=	Nanno ooze
25-50	50-75	=	Zeolitic nanno ooze
50-75	25-50	=	Nanno zeolitite
75-100	0-25	=	Zeolitite

B. Minor Constituents

- Constituents present in amounts 10-25% prefixed to the sediment name by using the term rich.² Example: 50% nannofossils, 30% radiolarians, 20% zeolites is called a zeolite-rich rad nanno ooze.
- Constituents present in amounts 2-10% prefixed to the sediment name by using the term bearing.²
- Example: 50% nannofossils, 40% radiolarians, 10% zeolites is called a zeolite-bearing rad nanno ooze.
- C. Trace Constituents.

Constituents present in amounts <2% may follow the sedi-

 $^{^{2}}$ Normally, the trace constituents never appear in the sediment name. As regards minor constituents, the BEARING and sometimes even the RICH constituents may be omitted from the sediment name when deposits are complexly constituted.



Figure 1. Symbolic representation of types of core disturbance. These symbols have been used in the Core Summary forms.

ment name but will be accompanied by the word trace. This procedure is optional.²

- II. Specific rules for biogenous constituents
 - A. Nannofossil is applied only to the calcareous tests of coccolithophorids, discoasters, etc.
 - B. Abbreviations and contractions as nanno for nannofossil, foram for foraminifera, rad for radiolarian, and spicule for sponge spicule may be used in the sediment name.
 - C. The term ooze follows a microfossil taxonomic group whenever one of these groups is the dominant sediment constituent.
 - D. Usage of the terms marl and chalk to designate amounts of microfossils, 30-60% and >60%, respectively, as used by Olausson and others, is dropped. The term chalk is retained to designate a consolidated calcareous ooze.
 - E. Consolidated diatom and rad oozes are termed diatomite or radiolarite, respectively.
- III. Specific rule for volcanic constituents

Pyroclastics are given textural designations which are already established in the literature. Thus, volcanic breccia \geq 32 mm, volcanic lapilli \leq 32 mm, >4 mm, volcanic ash \leq 4 mm. It is at times useful to further refine the textural designations by using such modifiers as coarse or fine.

- IV. Specific rules for authigenic constituents
 - A. Authigenic minerals enter the sediment name in a fashion similar to that outlined under rules IA and B.
 - B. The terms ooze and chalk also apply to carbonate minerals of any type using the same rules that apply to biogenous constituents.
 - C. Ferruginous is the term applied to the microscopic translucent subspherical iron-oxide minerals.
- V. Specific rules for clastic sediments
 - A. Clastic constituents, whether detrital, volcanic, biogenous, or authigenic, are given a textural designation. When detrital³ grains are the sole clastic constituent of a sediment, a simple textural term suffices for its name. The appropriate term is derived from Shepard's triangle diagram (see Figure 2).
 - B. When the tests of a fossil biocoenosis or authigenic minerals and detrital grains occur together, the fossil or authigenic material is not given a textural designation. Note, however, that the detrital material is classified texturally by recalculating its size components to 100%. With the presence of other constituents in the sediment, the detrital fraction now requires a compositional term. For this purpose, the term detrital is employed, which enters the sediment name as per rules IA and B.
 - C. Clastic fossil tests
 - 1. Redeposited fossil tests become a clastic constituent and are given a textural designation, in the manner of detrital grains. Now, however, the textural term is preceded by the appropriate terms identifying the fossil constituents as per rules IA and B.
 - 2. To warrant a textural term the clastic nature of the fossil remains must be obvious and significant, a test easily met by most near-shore fossils. However, for practical purposes redeposited pelagic fossils seldom pass this test and, therefore, are rarely suffixed by a textural term.
 - 3. At times other clastics, usually detrital in nature, accompany redeposited fossils tests. Again, the term detrital is employed to embrace the detrital fraction. Note (comparing rule VB with VC3) that the sediment name does not distinguish between "in place" and redeposited fossils. This distinction remains to be made on an informal basis.
 - 4. In shallow water, the skeletal debris of a clastic sediment commonly contains various taxonomic groups. Rather than specifying each group individually in the sediment name, it may be preferable to employ the term shelly.



TEXTURAL TRIANGLE

Figure 2. Sediment textural diagram (from Shepard, 1954).

D. Clastic volcanics

Redeposited pyroclastics also become a clastic constituent. As before, they are recognized by the term volcanic, but now receive a textural term such as gravel, sand, silt, etc. Classification as clastic again requires evidence of obvious and significant current transport.

E. Clastic authigenic constituents Where authigenic minerals are recognized as being a redeposited constituent, they are given a textural designation in addition to their species name in the manner set forth for biogenous clastics (rule VC).

VI. Color

- A. Color is not formally part of the sediment name. However, its employment for sediment description is important particularly as it provides one of the criteria used to distinguish pelagic and terrigenous sediment. The color designation always precedes the sediment name.
- B. Common usage dictates that it is no longer expedient to employ the term red as an all-inclusive color term for pelagic sediments which range through various shades of red, yellow, and brown. The proper color designation should be used.
- VII. General comments
 - A. Sediments are not formally divided into the two groups, pelagic and terrigenous, by the sediment classification. This distinction is left to be made on an informal basis.
 - B. There exists at present, fine-grained carbonate particles, which by virtue of their unknown origin, cannot be classified as either biogenous, clastic, or authigenic. Such particles are prefixed by the term micarb. Because they also do not exhibit evidence of obvious and significant current transport, they are not given a textural designation consequently, the terms ooze and chalk are applied to them where appropriate. Those which do give evidence of obvious and significant current transport are no longer of unknown origin. These are termed calcareous particles.
 - C. The suffix stone is added to the textural term of consolidated clastic sediments.
 - D. For cemented sediments the adjectives calcareous and siliceous are used as appropriate.

Stratigraphic Terminology

On Leg 23 a diversity of lithologic types was encountered. With proper study, a hierarchy of formal lithostratigraphic units could probably be derived from these

 $^{^{3}}$ Detrital = all clastic grains derived from the erosion of preexisting rocks except for those of biogenous, authigenic, or volcanic origin.

lithologies. However, such a hierarchy would have a better foundation if it were integrated with the results of the other DSDP Indian Ocean legs; therefore, for now, the lithologies have only been informally recognized as units and subunits. For each site these designations are outlined in the Table in the Lithology section and also on the Hole Summary form. The boundaries between units and subunits in cored intervals were sharp or transitional. When a boundary occurred between cores, it was placed in the middle of a drilled interval. These boundaries were based on such sediment attributes as composition, color, and lithification.

Graphical Representation of Lithologies

Lithologic symbols have been devised which are now standard for every leg (again with minor modification), since Leg 18. These symbols are shown in Figure 3.

It will be noted that these symbols encompass both compositional and textural aspects of the sediments. To represent both of these aspects simultaneously in a lithologic column is difficult. Consequently, the convention on Leg 23 has been that when a sediment is of clastic origin, a textural symbol is used and when of nonclastic origin a compositional symbol is used. There were a few instances where it was not obvious as to whether a sediment was of clastic origin or not. In such cases the sediment was represented by a compositional symbol. A good example is provided by the nanno oozes in the turbidite sequence at Site 221 (see Chapter 5).

The sediments on Leg 23, particularly those in the Arabian Sea, were lithologically complex. It was not uncommon for them to contain four or more constituents. Obviously there would be difficulties in representing all these constituents simultaneously by a system of overprinting lithologic symbols. Consequently, the technique of vertical stripping was used. With this technique each sediment component is depicted by a vertical bar where width is dependent on the prevalence of the component it represents. Basically, this technique can accommodate all the major and the "rich" portions of the minor constituents. The bar widths for a two-component sediment are shown on Figure 4. Note that the class limits of the vertical bars coincide with those of the sediment classification.

For constituents present in amounts of 2 to 10 percent, a procedure of overprinting a letter or symbol on the lithologic column was used. The appropriate designations are shown below:

- F = Foraminifera
- N = Nannofossils
- D = Diatoms
- R = Radiolarians
- A = Ash
- Z = Zeolite
- G = Glauconite
- AR = Aragonite
- S = Sponge Spicules
- SI = Silicoflagellates
- DE = Detrital
- M = Micarb
- GY = Gypsum
- AN = Anhydrite

- SA = Salt
- \blacktriangle = Chert

Mn = Manganese Nodule

Pyrite

The above system of graphical representation has become fairly well standardized for most recent DSDP legs. It is anticipated that it will be used on all Indian Ocean legs, which thereby makes this the first ocean where this lithologically unifying aspect is present.

Site Summary Forms

Boundaries of geochronologic units are shown to the left of the graphic lithology column. They are based on nannofossil, foraminiferal, and radiolarian fossil zonations. Where encountered in cored interval, these boundaries are shown by solid lines. A dashed line represents an interpolated boundary. Their position was determined either by noting where the sedimentation rate curve intersects an epoch boundary or by making a best estimate from the paleontological data. For those rare instances where the paleontologists differed completely as to where a boundary should be placed, a dotted line was drawn. Unconformities are shown by wavy lines. Again, a solid wavy line represents a cored unconformity, whereas a dashed wavy line represents an interpolated one. A shortened wavy line was drawn for those unconformities which do not serve as an epochal boundary or do not divide an epoch into Late, Middle, or Early.

Absolute ages are shown for all cored geochronological boundaries. The approximate maximum sediment age at total depth is also indicated. These ages were based on Berggren (1972a) as described elsewhere in this chapter.

The graphic lithology column presents a gross generalization of the lithologies encountered in cored intervals. Lithologies are also shown for drilled intervals where lithologies were sufficiently uniform to warrant interpolating between cores.

Core Forms

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 to agree with the shore laboratory result. Entries in the column headed "Litho Sample" indicate where control on lithologies exists. Where adjacent control points indicated a lithologic change, this change was made midway between these points. 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." Numerical color designations and names follow the Munsell system as employed by the GSA. Instead of entering them in their appropriate location next to the lithology column, they were replaced by a simple color code whose relation to the Munsell designation is shown in a color legend on each core form. It was felt that this approach made it easier to visualize color changes,



Figure 3. Leg 23 lithologic symbols.



Figure 4. Class limits of vertical bars used on Hole Summaries and Core Forms.

particularly for those cores where many changes took place. At a few sites a subcolumn headed "Sed. Struc." was utilized to indicate the presence of graded bedding. Upward-pointing arrows display where this feature occurs.

Written descriptions always begin with the name of the dominant lithology. This is followed by pertinent remarks concerning various aspects of the sediments. It was the philosophy on Leg 23 to refrain from incorporating genetic or other interpretive aspects, relegating such information to the written text in the site chapters. Next is a smear-slide description of the dominant lithology, followed by similar descriptions of important minor lithologies. The reader should be aware that smear-slides are not point-counted, and therefore percentage values initially so derived are usually not too precise. In this sense the numerical values serve more as an approximation of relative constituent amounts rather than as an accurate quantitative guide. Although perhaps a letter-type scale of abundance would serve almost as well, such an approach which has limited classes loses much of the ability to discern trends of increase or decrease of various constituents. 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 (as shown by F. J. Paulus, 1972); however, this error was eliminated by using the shore-based carbon carbonate data which has a high degree of precision.

The lower half of the Lithologic Description column contains the results of shore-based laboratory studies on grain-size, X-ray, and carbon carbonate, most of which were carried out at Scripps and Riverside. Results from other laboratories are also shown and are appropriately noted. Of the X-ray data, only the results from bulk analyses are shown. Grain-size analyses were entered only for sediments mostly or entirely of clastic origin, while those for nonclastic sediments were left out. The reason for making this distinction was that one of the prime uses of textural parameters is to help interpret the current flow regime at the depositional site.

X-RAY MINERALOGY

Methods

Semiquantitative determinations of the mineral composition of bulk samples, 2-20 μ , and $<2\mu$ fractions were performed according to the methods described in the Initial Reports of the Deep Sea Drilling Project Volumes 1 and 2 and in Appendix III of Volume 4. The mineral analyses of the 2-20 μ and $<2\mu$ fractions were performed on CaCO₃-free residues.

The X-ray mineralogy results of this study are summarized in Tables 1 through 11 of Appendix II. The mineralogy data are presented in Tables 12 through 23 of this appendix. Sediment ages, lithologic units, and nomenclature of the sediment types in Tables 1 through 11 (see Appendix II) are from the DSDP Leg 23 Shipboard Hole Summaries and from a subsequent update supplied by O. E. Weser, DSDP. The stratigraphic position of samples submitted for X-ray diffraction analysis from Leg 23 are listed in Tables 1 through 11 (see Appendix). The sample depth (in meters) below the sea floor in Tables 1 through 11 (see Appendix) identifies the samples as they are reported in Tables 12 through 23 (see Appendix).

No samples were submitted for X-ray diffraction analyses from Site 226. At the request of Leg 23 scientists, some bulk samples from calcareous sediments at Site 223 were not analyzed in order to allow for more analyses of the decalcified fractions.

Several unidentified minerals were detected in Leg 23 samples. Their abundances were determined on a semiqualitative basis using a hypothetical mineral concentration factor of 3.0. Unidentified minerals are reported on a ranked, semiqualitative scale as outlined below:

Trace: (<5%); diffraction pattern was weak and identification was made on the basis of two major diagnostic peaks.

Present: (5-25%); a number of peaks of the mineral are visible in the diffraction pattern.

Abundant: (25-65%); diffraction peaks of the mineral are prominent in the total diffraction pattern but the peaks of other minerals are of an equivalent intensity.

Major: (>65%); the diffraction peaks of the mineral dominate the diffraction pattern. Although a certain quantity of the unidentified minerals is implied, their concentration is not included in the concentrations of the identified minerals, which are summed to 100 percent.

Drilling Mud Usage

Drilling mud, containing montmorillonite and barite, was used on Leg 23 as follows:

Hole 219, between Cores 23 and 24; Hole 219A, before Core 1 and between Cores 13 and 14, 20 and 21; Hole 220, between Cores 20 and 21; Hole 222, between Cores 18 and 19, 21 and 22, 25 and 26, 27 and 28, 28 and 29, 30 and 31, 31 and 32, 33 and 34, 34 and 35; Hole 223, between Cores 24 and 25, 32 and 33, 35 and 36; Hole 224, between Cores 4 and 5, 10 and 11; Hole 227, between Cores 36 and 37; Hole 228, between Cores 17 and 18; Hole 229A, between Cores 3 and 4 and during Cores 10, 11, 12.

Most samples submitted for diffraction analyses do not occur close to intervals in which drilling mud was used. In the cases of samples from Hole 222, Core 28, Hole 224, Core 5 and Core 11, and Hole 228, Core 18, drilling mud was used prior to coring. In all of these cases, however, the montmorillonite content is normal and barite is absent indicating that contamination by drilling mud is unlikely.

Mineral Notes

Dolomite was frequently detected in Leg 23 bulk samples but much less frequently in the 2-20 μ fractions. This apparent reduction in the occurrence of dolomite is the result of partial dissolution of fine-grained dolomite during the decalcification procedure.

Magnesian calcite (MgCa) was detected at Sites 225, 228, 229, and 230 in the upper sedimentary units in the Red Sea. The presence of magnesian calcite is manifested as a distinct peak or a bulge to the lower d-spacing side of the pure calcite (211) peak position. The content of magnesian calcite in the sample was estimated by deconvoluting the peaks of magnesian and pure calcite. In cases where the peaks were well resolved, a peak position of 2.996Å was measured for magnesian calcite which corresponds to a MgCO₃ content of approximately 14 percent (Goldsmith et al., 1961).

BIOSTRATIGRAPHIC FRAMEWORK

Basis for Age Determination

Planktonic Foraminifera

Numerous zonations for the Cenozoic have been developed for planktonic foraminifera, none of which is entirely satisfactory for use at the Arabian Sea sites. Following Brönnimann and Resig (1971) and Berggren (1972b), the zonation employed here is the letter-number series developed by Blow (1969) for the late Middle Eocene to Holocene, and by Bolli (1966), as modified by Berggren (1971), for the remainder of the Paleogene. This zonation system is discussed further by Berggren (1972a).

The Blow-Berggren system is somewhat unsatisfactory for a number of reasons. Brönnimann and Resig have discussed the difficulties in subdividing the Pliocene according to Blow's criteria; this subdivision proved difficult in the Arabian Sea, even where good Pliocene faunas were recovered. More important, serious problems were encountered in attempting to apply the Bolli-Berggren zones to the Early Eocene intervals recovered at several sites. In general, the taxa used to differentiate these zones are rare or absent, and the ranges of potentially useful subsidiary taxa have not yet been firmly established. In spite of these problems, it has not seemed wise, on the basis of the limited information available, to erect a separate zonation system for the Arabian Sea.

Several modifications of the zones recognized by Berggren (1972a) have been accepted for the purpose of determining consensus ages for the studied samples; these have been made to accommodate differences between the nannofossil and foraminiferal zonations employed, because of the consistent presence of nannofossils and the common absence of diagnostic foraminifera and radiolarians. They are:

1) The base of N.18, rather than N.19, is used as the Miocene/Pliocene boundary. This horizon, where observed,

correlated closely with the top of the Discoaster quinquitannis Zone.

2) The Oligocene has been subdivided into three, rather than two, sections. Zones P.22 and P.21 constitute the Late Oligocene; P.20 and part of P.19 the Middle Oligocene; and P.18 and the remainder of P.19 the Early Oligocene. The boundaries are at 30 m.y.B.P. and 34 m.y.B.P., respectively.

3) The base of the Middle Eocene is the base of P.9, rather than P.10.

Benthic Foraminifera

In discussing paleobathymetry determinations and indications of downslope transport of benthic foraminifera, it has occasionally been necessary to refer to a classification of benthic marine environments. There is no consensus on the approximate depths of the boundaries between these ecological regions; the zonation system used here is essentially that of Bandy (1960). The depth environments are as follows (depths are approximate):

- 1) Inner neritic: 0 to 50 meters
- 2) Central and outer neritic: 50 to 150 meters
- 3) Upper bathyal: 150 to 600 meters
- 4) Middle bathyal: 600 to 2500 meters
- 5) Lower bathyal: 2500 to 4000 meters
- 6) Abyssal: below 4000 meters

In general, benthic foraminifera were not identified as to species in samples from this leg. Depth determinations were made on the basis of the principles discussed by Bandy (1960).

Calcareous Nannofossils

The calcareous nannofossil zones in this report follow mainly the "standard calcareous nannoplankton zonation" schemes proposed by Hay et al. (1967), Martini (1970), Martini and Worsley (1970), Gartner (1969), Bramlette and Wilcoxon (1967), and Berggren (1972a). The modification made includes the use of the *Discoaster dilatus* Zone in the Middle Miocene.

Radiolaria

The radiolarian zonation used herein is basically that of Riedel and Sanfilippo (1971) with some modifications, as explained in the text, by Nigrini. In the individual site reports taxonomic revisions by Petrushevskaya and Koslova (1972) have not been included. They are, however, discussed in the special chapter concerning Radiolaria (Nigrini, this volume).

Sedimentation Rates

The shipboard paleontologists have, in most cases, reached a consensus age determination for each sample recovered at the sites visited during Leg 23. Sedimentation rate curves have been constructed, and rates calculated, for each appropriate site. Rates of sedimentation are expressed in meters per million years and are indicated in italics for each line segment.

Absolute Ages of Zone Boundaries

The radiometrically based time scale used to provide the basis for these rates is essentially that of Berggren (1972a), with the following modifications:

1) The Oligocene has been subdivided into Early, Middle, and Late, rather than simply Early and Late. The ages of the Early/Middle and Middle/Late Oligocene boundaries are 34 m.y. and 30 m.y., respectively.

2) The Early/Middle Eocene boundary has been recognized at the base of the *Discoaster sublodoensis* Zone (essentially equivalent to the base of Foraminiferal Zone P.9), with an age of 50 m.y.

Red Sea age determinations were based wholly on the recognition of Late Miocene to Holocene nannofossil zones. It has thus been necessary to use the age determinations for Late Neogene events recognized by Gartner (1972; in press) from the Caribbean and the Equatorial Pacific. The use of these dates is based, of necessity, on the assumption of synchroneity of the nannofossil events in widely separated geographic regions, an assumption particularly dubious in light of the extreme environmental conditions prevailing in the Red Sea. There is little indication, however, that the nannofossil succession is significantly different in the Red and Arabian seas from that in other tropical oceanic areas. The following ages have been used for Late Neogene nannofossil zones:

1) *Emiliania huxleyi* datum: 0.18 m.y. for the initial appearance of this species. This event was observed only at Site 229.

2) Late Pleistocene: Gephyrocapsa oceanica Zone, G. caribbeanica Zone, and Coccolithus doronicoides Zone. No dates are available for the boundaries between these zones, nor for the boundary with the overlying E. huxleyi Zone (highest occurrence of G. protohuxleyi). Conservatively, the top of this interval has been arbitrarily placed at the present; the base, defined by the highest occurrence of Pseudoemiliania lacunosa, is dated (Gartner, 1972) at 0.35 m.y. All Late Pleistocene zones are assigned this time interval on the sedimentation rate charts.

3) Early Pleistocene: *Pseudoemiliania lacunosa* Zone. 0.35 to 1.8 m.y.

4) Late Pliocene: Discoaster brouweri Zone and D. pentaradiatus Zone. Gartner (in press) was unable to determine a date for the extinction of D. pentaradiatus, and hence for the boundary between these zones. The base of this interval is marked by the highest occurrence of D. surculus, an event dated at 2.1 m.y. It was felt that the maximum reasonable range should be allowed to the zones, particularly where the ages are not well established. The D. brouweri and D. pentaradiatus Zones are thus arbitrarily assigned the overlapping age ranges of 1.8 to 2.0 m.y. and 1.9 to 2.1 m.y.

5) Late Pliocene: Discoaster surculus Zone and Sphenolithus abies Zone. The base of this interval is marked by the extinction of Reticulofenestra pseudoumbilica (2.4 m.y.). No date is available for the boundary between these two zones; they are arbitrarily assigned the ages 2.1 to 2.3 m.y. and 2.2 to 2.4 m.y., respectively.

6) Early Pliocene: Reticulofenestra pseudoumbilica Zone and Discoaster asymmetricus Zone. Again, the boundary between these zones has not been dated in the sense that they are used here. At Site 227, however, the top of the D. asymmetricus Zone is located a short distance (15 m) below the extinction of Ceratolithus tricorniculatus, an event to which Gartner (in press) assigned the age of about 3.6 m.y. On this basis, age ranges of 2.4 to 4.0 m.y. and 3.6 to 5.0 m.y. have been arbitrarily assigned to the *R*. *pseudoumbilica* and *D. asymmetricus* zones, respectively.

7) Late Miocene: *Discoaster quinqueramus* Zone. 5.0 to 6.0 m.y.

Sedimentation Rate Plots

Where no agreement was reached concerning the age of a particular interval of recovered sediment, two lines are shown on the sedimentation rate curve to express the alternative explanations. In all such cases, the discrepancies are between foraminiferal and nannofossil ages; the appropriate line segments are therefore labeled "F" and "N," respectively. Similarly, any unconformities indicated by one interpretation and not the other are also so labeled. Site reports for the individual fossil groups should be examined in these cases.

Where a drilled interval is bounded above and below by cores containing fossils referred to different zones, it is represented by a stippled pattern on the sedimentation rate curves. Only when ages on either side of an interval are compatible with a single sedimentation rate is a line projected through it. No attempt is made to postulate either unconformities or rate changes within uncored intervals. Where sediments above and below the drilled interval are of the same age, the interval is not represented by stippling.

In several instances where coring is essentially continuous and where no fossil zones are missing (cf. sedimentation rate curve, Site 227, 60 to 100 m), the slopes of the curves suggest either unconformities or abrupt short-term changes in sedimentation rate. When conclusive evidence for either of these interpretations is absent, no choice between these alternatives is made. Occurrences of this situation are indicated on the curves by a question mark.

In continuously cored sequences where one or more fossil zones are missing, an unconformity is presumed to be present and is indicated on the sedimentation rate curves by a heavy dashed line labeled "U."

It can be seen from the discussion above that the sedimentation rate curves represent only those interpretations which are firmly controlled by fossil evidence. Interpretations not indicated in site sedimentation rate summaries may, in some cases, be made by various authors in other site reports.

SHIPBOARD GEOCHEMICAL METHODS

The standard DSDP procedures for interstitial water and allied studies are described in the shipboard manual (Waterman, 1970), and encompass pore fluid extraction, pH, salinity measurements, and special packaging of water for shore laboratories. On the Red Sea portion of Leg 23, several additional techniques were employed. These and brief summaries of modified standard techniques are described in this section.

Selection of Samples

In order not to delay sampling of pore fluids until cores had been split (which would normally require waiting until the time-consuming GRAPE measurements had been completed), 10-cm-long samples were normally sawed off the ends of core sections, capped, and immediately taken to the chemical laboratory. At times, 20-cm samples were taken where recovery permitted and sampling would not result in loss of important features or horizons. The interiors of the sediment samples were taken for squeezing, with the samples being placed in the squeezer with minimum delay to avoid evaporation and other chemical changes.

In the shallow cores some unavoidable drilling distortion and disturbance of sediment were encountered, as shown in Figures 5a and 5b. Pore-water extraction and analysis and examination of depth-compositional relationships suggest that some of the deformation has not resulted in the significant addition of seawater into the samples rather, the restricted diameter of the core barrel results in sediment flowage without serious fluid dilution (Figure 5b). Where sediments of differing competency are penetrated, sediment fragments retaining an undisturbed character will be found "floating" in a drilling slurry. Here again, the slurry may not necessarily be greatly contaminated with surface seawater. Some water may actually be "squeezed out" of the core in much the same fashion as is done in our laboratory apparatus. At other times the outer, or more fluid portions of the core are clearly contaminated with fluids. Successful pore fluid analysis depends on careful and discriminating sampling to choose the least contaminated samples possible and make appropriate tests of reliability (i.e., several squeezings in a given core section). Diffusion in the course of geologic time should cause conservative



Figure 5. Results of sediment disturbance during the coring process. (a) "Islands" of more consolidated materials float in matrix of drilling slurry. (b) Plastic deformation of sediment.

interstitial constituents to be relatively constant within meter-long core intervals, whereas where seawater contamination has occurred, erratic variations should occur in closely spaced samples.

Although a disturbed sediment sample in some relatively unconsolidated sections may retain "authentic" pore fluids, the porosity and water content may be hopelessly altered. Special care was taken to obtain the best possible water content samples from available sections. To this end the fixed interval sampling program of Leg 23A was modified on Leg 23B to sample only intervals of apparently good preservation. For example, in Figure 5a the coherent fragments would have been chosen. Where the syringes could no longer penetrate the sediment, small portions were removed by knife or spatula. According to shipboard technicians on previous legs, syringes were used to collect samples well beyond the point where they could be relied on to get valid samples. In many sections the central, harder portions (presumably more representative of in situ materials) may have been by-passed in favor of sampling the outer softer slurry nearest the liner walls. Needless to say, this type of sampling will not reflect the true distribution of sediment physical properties.

Pore Fluid Extraction

Stainless steel squeezers modified from Manheim (1966) were employed for extracting pore fluids from the sediments. The squeezers incorporate lower and upper rubber pressure seal discs. When placed under pressure, through action of a piston in a cylinder, the pore fluid is forced from the sediment through filter paper into a channel leading to a disposable syringe inserted into the base of the squeezer (Figure 6). When extraction is completed, a 2 to 30 minute process, depending on the sediment permeability and water content, the syringe is capped with a micropore filter attachment and aliquots are taken for immediate analysis and packaging for shore laboratories. Volumes typically obtained may be seen in the interstitial water tables provided in the Geochemical section of the site chapters. They vary from upwards of 20 ml in soft sediments to 1/2 ml in highly consolidated sediments.

For unconsolidated or moderately consolidated sediments the large squeezer (see foreground of Figure 6), having a 7-cm-diameter filter (38.4 cm area), is employed. For more consolidated sediments requiring higher pressure the smaller squeezer is used in the hydraulic press (Figure 6). It has a standard filter diameter of 4.25 cm (14.2 cm² area). The size of the syringe emplaced in the base is chosen to correspond to the anticipated fluid yield. In Figure 6, a very dense shale is being squeezed, and consequently the smallest syringe (1 ml) is used as a receiver. In both the large and small squeezers as the pressure is increased, the rubber gaskets are pressed more tightly against the cylinder wall, eliminating fluid leakage from the system. Only in highly liquid samples does some occasional mud leakage occur around the lower gasket system before enough pressure can be applied to expand the gaskets.

Beneath the filter papers, a stainless steel screen disc with a ring of silicone rubber (bathtub caulk) applied on the outside rim permits flow of fluid through the filters

Figure 6. Small (4.25 cm) filter size squeezer emplaced in hydraulic press with 1-ml syringe inserted as fluid receiver (very dense sediment). In center foreground: large (7-cm filter size) squeezer with teflon wiper disc.

into the central drainage hole, without fluid escaping around the filters.

The applied load varied from a few thousand pounds to 24,000 lb (Table 1), the capacity of the laboratory press. At these pressures a hard pellet is molded within the squeezer, and extrusion devices were constructed to extract the piston and pellet (Figures 7 and 8). After removing the base, the cylinder with contained sediment pellet and gasket elements is replaced in the laboratory press and the piston pushed down. The filter base, screen, cylinder, piston, and gaskets are then rinsed with water followed by

			TABLE	1		
Load	to Pres	sure Co	nversions	for	Hydraulic	Squeezers

	Small Squeezer		Large Squeezer	
Load (1b)	Psi	kg/cm ²	Psi	kg/cm ²
1,000	455	32.8	167	12.0
3,000	1,360	98	500	36
5,000	2,270	163	835	60
10,000	4,550	328	1,670	120
20,000	9,010	650	3,320	239
24,000	10,900	788	4,010	288

Note: Small squeezer has internal diameter (piston) of 4.25 cm, larger squeezer has 7 cm diameter.

acetone (to dry them quickly). The unit is then ready for another extraction.

During Leg 15, special low-temperature squeezings were performed in addition to those at room temperature (Sayles et al., in press). This procedure provided information on the temperature-of-squeezing effects that have been shown to influence the concentrations of certain cations in pore fluids by changing ion-exchange coefficients of the sediments. In the Red Sea, bottom-water temperatures are rather close to laboratory temperatures (23°C to 26°C); however, with increasing depth below the sea bed, the temperatures rise above laboratory conditions. Thus, in order to extract sediments at temperatures corresponding to in situ conditions, still higher temperatures must be applied to the squeezers. This was done as shown in Figure 9 by means of a heating tape connected to a rheostat. Aluminum-backed adhesive tape and asbestos cloth was placed over the heating tape. A thermistor was placed in the upper part of the cylinder to monitor temperature, and the thermistor output was read on a voltmeter (Figure 10). Through these procedures temperatures ranging from 35°C to 65°C were applied to the sediments in order to simulate in situ conditions. One problem was anticipated and found; unlike conditions on Leg 15 (in the Carribbean), where maximum (laboratory - in situ) temperature differences occurred near the sediment-water interface, in the Red Sea this difference increased with depth. Because of the increase in consolidation with depth, very little water could be obtained from the hottest (bottommost) samples, hindering subsequent analysis. Also, any effects of sample inhomogeneity, evaporation-condensation, etc. would be more noticeable on the samples having small pore fluid vields than where abundant fluid was obtained. For example, contamination is likely to be serious for wellconsolidated sediments if some coring disturbance has taken place. This is because the more disturbed zones contain and yield more water than the better-consolidated undisturbed remnants. Such effects can, however, be recognized relatively easily by duplicate squeezings and analyses of the pore fluid for chloride or total salt.

Spectrochemical Analysis

An ARL spectrograph and comparator were placed aboard in Colombo, Sri Lanka, to permit immediate semiquantitative analysis of sediments, rocks, and waters recovered onboard (Figure 11). Some analyses were performed on Arabian Sea samples, but the major effort took place in the Red Sea. Samples were dried in an oven at 80°C for about 1 hour and then ground to a fine powder with an agate pestle and mortar. The instrument is capable of analyzing over 30 elements down to trace quantities by means of a DC arc technique. Samples (10 mg) were mixed with 20 mg of SP-1 grade graphite powder and packed into 1/4-inch graphite electrode cups, then arced at 10 amps for 2 minutes. The resulting spectra (from about 2300Å to 4800Å) were recorded on 35 mm Spectrum Analysis No. 1 film (Kodak) and compared visually with arcings of a series of oxide standards, made up in simulated rock matrices and shot under the same conditions. Results were reported in the usual U.S. Geological Survey increments which are approximately multiples of the inverse of the cube root of

Figure 7. Extraction apparatus to remove sediment pellet and gasket assembly from squeezer (designed and constructed by James Pine and John Anthony). Large cylinder can be placed directly in cylinder support (left) by pulling apart halves of circular frame. The entire assembly with piston is then placed in hydraulic press and piston is depressed, extruding retainer base, sediment pellet, and rubber and teflon discs. For the small squeezer the adapter rings are first placed around the groove in the cylinder as shown (center), then the unit is placed in the cylinder support (Figure 8).

10, e.g., 10, 30, 50, 70, 100 ppm, etc. Detection limits are shown (Table 1, Manheim, this volume, Chapter 29). Several hundred samples, encompassing a total of more than 5000 elemental determinations, were processed. In addition, some supplementary analyses, with special reference to low zinc concentrations, potassium, and rubidium, were performed on the spectrochemical samples, by the shipboard operator, David Sims, at the U.S. Geological Survey in Denver, Colorado.

Field Arsenic Method (Gutzeit)

Arsenic to 10 ppm was determined by a wet chemical technique. Samples were fused with KOH and reduced, leading to release of arsine gas (AsH₃). This was passed through a specially impregnated paper disc, and the resulting color spots were compared with standard papers.

Special Archiving and Packaging for Shore Analysis

Special fluid and gas samples were selected and packaged in heat-sealed polyethylene pipe (with a propane torch and large forceps), glass ampules or Vacutainers (evacuated glass tubes sealed with rubber membranes). Samples for alkalinity determination were prepared with additions of precise volumes of standard HC1 solutions to prevent precipitation of CaCO₃ (Gieskes, in press) and loss of CO₂ on storage. The alkalinity may then be determined in the laboratory by back-titrating with standard base. A variety of sediment samples, both heat-sealed in heavy polyethylene bags to conserve natural humidity or as squeezed pellets, were also archived for distribution to shore-based laboratories. The data from these laboratories which relate to major and trace element studies, uranium, lead, sulfur,

Figure 8. Cylinder-piston assembly in cylinder support, ready for depression of piston to extrude sediment pellet and gasket assemblies.

oxygen, and carbon isotopes; K-Ar dating techniques; and special mineralogical studies are largely reported in the section on Geochemistry.

Interstitial Water Analysis

Specific Gravity by Micropycnometer

For routine water sampling, pipetting is much faster and more convenient than weighing. However, for abnormally salty interstitial waters such as those in the Red Sea, one cannot assume that the specific gravity of the pore fluids is essentially that of seawater. We found brines having Sp. G. up to 1.20; i.e., pipetting yields an aliquot about 17 percent heavier than a similar volume of seawater, and such measurements, if uncorrected, result in error, if they are assumed to represent g/kg, ppm, or other usual oceanographic weight/weight measurements.

A micropycnometer used by mineralogists in the U.S. Geological Survey proved to be helpful, not only for brine, but also mineral grain analysis. It is depicted in a sketch (Figure 12). In use, the pycnometer is tared out to nil weight (with ball) on the Cahn Electrobalance. This is done by hanging wire of proper weight on the right side of the balance. Our pycnometer actually weighed about 580 mg.

To use, the pycnometer is filled with a syringe needle to brim full. The ball is emplaced, and excess fluid blotted off with a lab tissue twisted to a hard string. After weighing, the operation is repeated with distilled water. Brine weight divided by water weight is specific gravity.

The pycnometer is made by heating the end of a glass tube and flattening it after it is scaled over. A ball is made by melting a thin capillary tube of glass in a propane torch flame, allowing the molten-viscous ball to gather glass until proper size is reached. A small "handle" helps pickup the ball with tweezers. Capacity of our model was about 58 mg (0.058 ml of water).

The chief problem was achieving reproducibility in filling (one could blot off too much water). With weight range at 100 mg, good weighing reproducibility could be achieved (0.05 mg, or 0.1% of weighed quantity). Therefore, a properly ground-in stopper should improve results achieved. However, the results are adequate to correct alkalinity values to weight-weight units.

Alkalinity

Because of past poor results with alkalinity determinations (especially for high values) on stored samples, it

Figure 9. Heated squeezer emplaced in hydraulic press. Stainless steel squeezer is wrapped with heating tape, aluminum-backed tape, and asbestos cloth. Wires lead from thermistor taped to upper cylinder wall (inside) to ohmmeter.

THERMISTOR CALIBRATION

Figure 10. Diagram showing construction of squeezer heater with thermistor calibration curve.

was held desirable to measure alkalinities onboard. Because of an inadvertent failure to bring along proper colored endpoint indicators for the alkalinity titration, and slowness of pH electrode response, the measurements were carried out in small vials by direct titration with 0.01N HC1, using "pHydrion" pH papers as an indicator (a bit of paper was torn off and placed in the bottom of the vial). The colored solution, rather than the paper itself, was examined and the end point taken at pH 4.5. Liberated CO₂ was removed by a stream of tank nitrogen. For very low values (e.g., those in brines) titration was preceded by addition of 1 ml 0.001N K2CO3 solution. This amount was later subtracted from the total alkalinity determined. Although the method lacks the precision of the backtitration technique employed in the shore laboratories, it yielded satisfactory reproducibility (±0.1 meg/kg, corrected for Sp. G.) for the present purposes.

pH

Flow-through pH measurements were discontinued because results from Leg 15 and subsequent Legs have indicated that an undesirable amount of equilibration with ambient air occurs, probably due to the small sample size and relatively large contact area with glass (and air). pH was measured on about 1/2 ml fluid using test tube and mini combination electrode. In general pH measurements are handicapped by slow equilibration of electrodes, and much faster ones are needed. Punch-in pH measurements on the sediments were limited by dense sediments and time limitations.

Eh

Although Eh values may be useful to individual investigators, several authors have reported that usual methods of determining them (Werner Stumm, M. Whitfield and others) do not produce thermodynamically valid numbers in the presence of oxygen. Discussion with the shipboard technicians has revealed that these measurements yield capricious and rather subjective results even at best. As a result, these measurements were not made and are not recommended for future studies. *Meior nulli quamque mala*.

Salinity - Refractive Index

Salinity was determined on interstitial water samples by placing a few drops of micropore-filtered fluid on a Goldberg temperature-compensated refractometer. With care, refractive index may be read to an accuracy corresponding to 0.2 or even 0.1 ppm in salinity, calibrated to a seawater relationship (difference between measured index and that of seawater is ΔN ; S(ppm) = $\Delta N \times 0.550$). Two problems occur ar very high salinities. The instrument is capable of reading only to $\Delta N = 400$ or 220 ppm, and sharpness of the light-dark interface is reduced at very high values. Second, the salinity-refractive index relationship that holds well for diluted or evaporated seawater breaks down for solutions varying from seawater composition.

For the first problem weight dilutions performed with the onboard Cahn electrobalance brought solutions into readable ranges (note that volume dilutions are not appropriate because of the difference in the specific gravity of the solutions). For the second problem, salinities determined by index of refraction provide useful measures of relative change in salinity with depth, since compositional changes rarely occur suddenly, owing to the influence of diffusion. The net error for nearly saturated (NaC1) brines found at depth in the Red Sea sediments does not exceed approximately 10 g/kg for a salinity of about 250 g/kg. True salinities may be obtained later from the shore-based analyses by summing all the major constituents in the brines. One should also point out that salinity chloride ratios applicable to seawater are likewise altered in the interstitial brines of the Red Sea.

Gases

Since the *Glomar Challenger* cannot set well casing, activate blowout preventers or other oilfield safeguards normally used while working in areas having potential high pressure hydrocarbon accumulations, the JOIDES Advisory Panel on Pollution Prevention and Safety requires that such accumulations be avoided. However, hydrocarbon gases are not restricted to accumulations of matured petroleum hydrocarbons. Methane, as well as traces of ethane and higher hydrocarbons, are produced by fermentative-bacterial processes in virtually all anerobic sedimentary strata that contain more than about 0.5 percent organic matter. This includes vast areas beneath the sea floor. Where sulfate is

Figure 11. An Applied Research Laboratories Spectrographic Analyzer, recording up to 20 or more spectra on 35 mm film. On top of spectrograph is a torsion balance used for weighing small sediment and rock powder samples for loading into graphite electrodes.

totally absent from the sediment and its pore fluid, large quantities of methane are frequently synthesized from H and CO₂, produced by fermentation of organic matter (Wolfe, 1971). Avoiding or aborting sites where such gas is found would severely limit the scope of the DSDP. In order to distinguish between dispersed gas of fermentative origin and gas associated with matured petroleum hydrocarbons that form through thermal cracking and other transformations in sediments at depth and at higher temperatures (which may migrate upward into traps), gas chromatographic equipment has been mandated onboard the Glomar Challenger. The equipment is intended to detect and distinguish methane from ethane and higher hydrocarbons. The presence of the latter two gases in significant amounts is regarded as an indication of the possible presence of petroleum-type accumulations, and hence is grounds for terminating a site.

The onboard instrument is a small Carle "Basic" gas chromatograph of the thermal conductivity type, with a detection limit on the order of 20 ppm. It employs helium carrier gas at the rate of about 20 ml/min. Although gas samples have been taken from gassy cores and supplied to collaborators in the Inorganic Geochemistry program on a regular basis, use of the onboard chromatograph for scientific, as contrasted with safety, purposes, has been infrequent. A typical chromatogram from a very gassy core from Site 229 is attached (Figure 13). This site was later abandoned owing to excess gas.

The gas samples are withdrawn from gas pockets in cores by drilling and punching a sharp penetrating device through the core liner. The hollow point is connected through a petcock to a syringe. After penetration the syringe needle is inserted into the rubber membrane of an evacuated glass tube (Vacutainer) and the petcock opened. From this tube standard volumes (e.g., 200 μ l) of gas may be injected into the entry membrane of the gas chromatograph. This gas will be contaminated to a greater or lesser extent by air from the rig floor or laboratory, but an approximate correction

Figure 12. Relationship between salinity as determined by index of refraction (see text) and specific gravity of brines. Note that index of refraction generally gives values of salinity that are too low for the concentrated brines. The lines show the specific gravity/salinity relationships for pure NaCl and MgCl₂ solutions at room temperature. The scatter of points is probably mainly due to analytical error, and the values should not be regarded as more than field determinations. They are chiefly useful for correcting and converting volumetric (pipette) measurements to weight units for shipboard determinations. ID of micropycnometer 2 mm.

for this air may be made from the area (height) of the air peak, assuming that the true pore gas does not contain appreciable nitrogen.

It goes without saying that the gas chromatograph measurements measure only the distribution of gases remaining in the pockets or separations found in the cores. During raising of the core from ocean floor depths to the surface, much of the original gas has an opportunity to dissipate. Since the solubility of gases increases with pressure, most of the separated gas phases are lost.

Diffusimetry-Resistivity Measurements on Cores

One of the important but poorly known parameters of sedimentary rocks is their diffusion coefficient, or how readily they permit the diffusion of dissolved species through their interconnected pore spaces. One can take advantage of a parallel between the way interconnected pore spaces conduct electricity and the way they permit ions to move through by diffusion to obtain net diffusion constants for sediments (Manheim, 1970). In both cases the solid particles are nonreactive for practical purposes (i.e., are nonconductors and impermeable). This is not strictly correct, for at high solid/fluid ratios, and especially for relatively fresh waters, clays can conduct an appreciable amount of the electrical current passed by a rock. Interactions between ion species and the rocks are also possible for certain ions, and ion interactions play a role where more precise determinations of diffusion coefficients are desired. However, considering the variability of the sediment intervals and the question of possible physical disturbance of cores removed to a lower-pressure environment, it is

believed that the method yields results that are useful as a first approximation to in situ properties.

The basic relationship sought is the "formation factor" (F), or ratio of rock resistivity to the resistivity of pore fluid within the given rock. This parameter is inversely proportional to the diffusion coefficient of a given rock type for major nonreactive ion species such as chloride. As porosity and permeability of a rock increase, F approaches 1. For 100 percent porosity there is no difference between "rock" and pore water resistivity, and the diffusion coefficient becomes that for the free solution. It is tortuosity or geometry of the microchannels in the rock pore spaces instead of porosity that governs the formation factor. Typically, shales have higher formation factors than sandstones or limestones of comparable porosity because of the way pores are effectively plugged by clay platelets in much the same way as leaves tend to clog storm sewers.

Procedure

The basic data are generated by determining apparent sediment resistivity on the interior, undisturbed parts of cores, using a 4-electrode system (Figure 14) and a Schlumberger resistivity bridge (Mud Tester). At the same time, a reference fluid (surface seawater from the Indian Ocean) is measured, using the same sample cup geometry. Then, using a special mini cell, the true resistivity of both reference fluid and the pore water from the sediment (extracted using the regular interstitial water techniques) are determined. With these data and the ambient temperatures in hand, cell constants, true sediment resistivity, and the formation Factor F can be calculated as follows:

Given

 R_s (app) at t° C: Apparent resistivity of sediment in sample cup

 R_w (app) at t° C: Apparent resistivity of reference water in sample cup.

Figure 13. Gas chromatogram for gas sample from Site 229. Units refer to reduction in sensitivity of readout. Negative peaks at 2.1 and 3.6 minutes are of unknown origin.

Figure 14. Resistivity probe inserted in sediment sample in liner cap. Calibration of cell constant is made by filling identical receptacle with standard (surface) seawater. Wood and plastic spacers adjust electrode penetration.

R_{pw} at t° C:	True resistivity of pore water in mini
D	cell or from salinity
R_W at $I \subset :$	True resistivity of reference water
	from mini cell
C = cell cons	$tant = R_W/R_W (app)$
$R_s = R_s (app)$	1×C
and the second se	

 $F = R_s / R_{DW}$

1) Correct R_W values to temperatures for R_W (app) and determine C. Multiply R_s (app) by C to get R_s .

2) Correct R_{pw} to temperatures corresponding to those for R_s (app). Divide R_s by R_{pw} to get F.

To convert F to diffusion constants one may substitute the free solution diffusion coefficient of a dominant salt (NaC1) for k in the expression D = k/F. An adjustment may be made for in situ temperatures by substituting the k_{NaC1} for the appropriate temperatures in the equation.

Pore fluid resistivities are determined directly using an approximately 1-ml cell or are taken from a plot of resistivity against salinity determined by refractive index (Figure 15). The latter method is useful for the more consolidated materials such as shales and intervening anhydrites, from which it may be possible to extract only very small quantities of fluid. Where resistivity measurements were made on sediments from which no direct pore fluids measurements were available, salinities (and corresponding resistivities) were interpolated from a depth/salinity curve for the site in question. This appeared to be justifiable because of the smooth variation of salinity with depth that characterizes Red Sea (and most marine sediments) strata.

Where sediments were too hard to permit entry of the electrode points without fracturing or distorting the sediments, holes were drilled with an electric drill through a plastic template (Figure 16). If sediments were very dry the electrodes were moistened with pore fluid to establish good electrical contact. W. Deuser (oral communication, 1972) has suggested that where highly resistive sediments are involved, such that even surface moisture could influence

Figure 15. Resistivity (ohmmeters) plotted against salinity (refractive index) for samples from Sites 225 to 228.

results, mercury could be used as the electrical contact medium.

Bottom Water Sampler

A Kuster bottom hole water sampler was employed for the first time on *Glomar Challenger* drillings. It consisted of a tube capable of capturing bottom fluid at ambient pressure by means of a clock-operated valve system. In principle, it should be capable of permitting analysis of

Figure 16. Preliminary borings made through template into harder sediments and rocks prior to insertion of 4-point electrode system. Sample in question is rock salt.

both fluid and entrained gases from the bottom fluid. The samplings taken at Site 225 indicated that, as expected, the bottom-hole fluid consisted of from 80 to 100 percent surface seawater. Nevertheless, in the event of artesian or other unusual formation pressures, it is possible that such samplers could obtain authentic formation fluids that discharged into the borehole. Moreover, it also seems probable that bottom fluid samples might reveal a more accurate picture of entrained hydrocarbon or other gas concentrations than cores which were allowed to degas while being transported to the surface without any tight seal preventing gas escape.

The present, rather inadequate method of recovering gas and fluid from the Kuster tool is depicted in Figure 17. The method incorporates the following steps, after removal of the tool from the borehole.

1) Screw nipple coupling to vacuum hose

2) Ready sample bottles and syringe

3) Pump down Erlenmeyer flask with tubing clamp closed

4) Open tubing clamp near fittings and pump out jacket

5) Shut off clamp on line from vacuum pump

6) Puncture metal membrane

7) Bleed in gases slowly, using valve

8) Insert syringe needle into vacuum hose and take gas sample

9) Insert gas into gas chromatograph

10) Allow remainder of gas and fluid to enter Erlenmeyer until sufficiently full. Decouple bomb and release all pressure

11) Open bomb and remove remaining fluid

Ideally, one should permit minimum waste volume in gas recovery system and also calibrate the volume of the system and take pressure measurements before releasing fluid. Little

Figure 17. Diagram of hookup to bottom fluid tester.

Key to numbers:

- 1. Nipple coupling for vacuum hose
- 2. Pressure valve
- 3. Exit port, female screw fitting
- Exit manifold to isolate (O-rings) metal membrane on bomb from external atmosphere.(a) pin assembly and drive
- 5. Positioning pin to adjust connection
- 6. Sampler bomb with (a) metal membrane to be punctured by pin 4a)

gas was obtained at Site 225, the only site where a test was made.

PHYSICAL PROPERTIES

Shipboard Measurements

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

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

 $W = \frac{-\text{weight of wet sediment}}{\text{weight of wet sediment plus salts}}$

No corrections were made for the salts, but the values are thought to be accurate to within $\pm 3\%$. The values are shown on core and hole diagrams by the symbol Δ .

(2) Sediment Porosity (ϕ) : The porosity 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/cm³ and a water density of 1.024 g/cm³.

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

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

The densities of the seawater saturated cores were measured in three ways: (1) by weighing each 1.5-meter core section giving a mean density for the whole section. These values are plotted on the core summaries at the midpoint for each section (symbol \Box); (2) from the water content W (syringe samples). These values are plotted on the site summaries (symbol *); (3) by continuous measurement along the length of the core section with the GRAPE using as standards, water (1.024 g/cm³) and aluminium (2.6 g/cm³). The GRAPE technique is described by Evans and Cotterell (1970) and Whitmarsh (1972). The values are plotted on core and site summaries: 150 data points per 1.5 meters on the core summaries and 60 data points per 1.5 meters on the site summaries (giving continuous plots). It is noted that 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 (Vp): The sonic velocity (V) 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, see description by Boyce in Initial Report, Volume 15).

Measurements were made at laboratory temperature and pressure, a time delay of about 4 hours being allowed for the cores to reach equilibrium. The accuracy is about $\pm 2\%$. The values (Km/s) are plotted on the site summaries (symbol \rightarrow , the value being at the center of the symbol).

(5) Specific Acoustic Impedance (Zp): This is defined as density (g/cm^3) multiplied by compressional wave velocity (km/s) and has units 106 Ns/m³. The parameter is of value in the interpretation of seismic reflection profiles and is plotted on the site summaries (symbol \bigcirc).

(6) Thermal conductivity (k): The thermal conductivity may be 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.

Measurements on the soft sediments were made using the needle-probe technique described by von Herzen and Maxwell (1959). The needle was inserted through a small hole drilled in the plastic core liner, and the temperature was recorded for about 5 minutes. Conductivity measurements on samples of anhydrite and rock salt (see Wheildon et al., this volume) were made using the divided bar technique (e.g., Jessop, 1969). Values are plotted on the site summaries (symbol X).

Preliminary Paleomagnetic Measurements

Sample Preparation

The majority of the samples taken for paleomagnetic measurement were vertically oriented cylindrical specimens 2.54 cm in diameter and approximately 2.54 cm in length. These were obtained by drilling centrally perpendicular to the cutface of the hemicylindrical samples, of average volume 30 cm³, provided from the shipboard sampling of the cores. Thus, individual samples are oriented only with respect to the vertical, there is no absolute azimuthal orientation. This procedure of sample preparation was adopted for all semiconsolidated and consolidated sediments and for the basalts.

The unconsolidated laminated silts and fine sands of Pleistocene age in Hole 221 were sampled at sea by carefully pushing thin-walled glass cylinders (2.25 cm in diameter and 2.00 cm in length) into the cut sediment face. A piston arrangement was utilized to ensure perpendicular penetration. The ends of the glass cylinders were capped with tight-fitting plastic lids marked with an orientation arrow.

Measurement

All measurements of magnetic remanence of the samples were made on a Digico computerized slow-speed spinner magnetometer operating at 7 Hz (Molyneux, 1971). Such a system combines the advantages of rapidity of measurement with increased accuracy. The latter is achieved by the use of Fourier analysis to delineate angular information, combined with linear as opposed to exponential integration, and automatic correction for the magnetization of the rotational parts of the system.

Individual spins for the majority of the sediment samples were completed using a signal integrated over 128 revolutions. For more weakly magnetized sediments, particularly those from Hole 219A, integration continued over 512 revolutions, while for the strongly magnetized basalts, 32 revolutions were found to be sufficient. A complete set of measurements consisted of a total of six spins about three orthogonal axes after which the digital computer output gave the direction and intensity of the remanent vector. Use of a subroutine within the magnetometer program facilitates rotation of the measured remanent vector about known axes so that directional data can easily be corrected to its in situ, in hole attitude. For these samples, however, the results give only relative declination, with respect to an arbitrary zero, but true inclinations assuming an original vertical penetration by the drill string.

After initial measurement of the NRM all samples were subjected to alternating field (Af) demagnetization and remeasured. A peak field of 50 oersted was used for the sediments and 100 oersted for the basalts. The apparatus used is similar to that described by Creer (1959). Four basalts and 11 sediment samples were stepwise demagnetized to peak alternating fields of 600 oersted and 200 oersted, respectively. Plots of the relative intensity (J/Jo) versus demagnetizing field for these samples are given in the appropriate site chapters.

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